Hong Kong Branch of National Precious Metals
Material Engineering Research Center

香港城市大學
City University of Hong Kong

眾志五載　其利斷金

Many Hands Make Precious Work

NPMM 5th ANNIVERSARY
國家貴金屬材料工程技術研究中心香港分中心五周年

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1

Faith Moves Mountains
精誠所至 金石為開

Message from Director
主任的話

Five years ago, following rigorous evaluations by the Innovation and Technology Commission (ITC) of the Government of the Hong Kong Special Administrative Region (HKSAR Government) and the Ministry of Science and Technology (MOST) of the People's Republic of China, the Hong Kong Branch of National Precious Metals Material Engineering Research Center (NPMM) was initiated to address the challenges relating to the development of new precious metal technologies and to advance the key roles they play in the economy and society. Today, the situation is even more critical than it was five years ago. Due to the country's limited recourses and relatively low levels of technological development, the precious metals industries in China are heavily reliant on imports. However, in recent years, the intense trade disputes between countries have enhanced the need to transform the industrial supply chain. Accordingly, there is an urgent need for fundamental and applied research on new metallic materials and the corresponding manufacturing technologies to satisfy the developmental requirements of the national economy and vital industrial sectors, and to compete in the international high tech field.

Precious metals are essential to people's livelihoods and the national and international economy. At the regional level, Hong Kong occupies a leading position in the jewelry industry in Asia. However, the traditional chemical electro-plating method used in jewelry is harmful to the environment and is prohibited in many developed countries. To address this issue, our group collaborated with Chow Tai Fook Jewellery Group Ltd in applying surface mechanical attrition techniques (SMAT) to gold and other precious metal jewelry, such as platinum and palladium jewelry, to improve the surface hardness. The patented technology not only enhances the mechanical properties of the precious metals but is also environmentally friendly.

Hong Kong plays an active role in the Greater Bay Area (GBA). The technologies developed by the NPMM can also be applied in the production of high-end electronic products such as mobile phones, which is an important sector in the GBA. Our group developed a flexible transparent conductive metal film using sputtering-based fabrication of a silver mesh that exhibits high electrical conductivity, mechanical flexibility, and robustness. As these types of film are used in the fundamental components of electronic devices and functional materials, our optimized technology will significantly enhance such products.

五年前，國家貴金屬材料工程技術研究中心香港分中心（貴金屬分中心）經過香港特別行政區政府創新科技署和中華人民共和國科學技術部（科技部）嚴格評估後正式成立，以期解決發展新貴金屬技術時遇到的挑戰，並提升有關技術在經濟和社會層面的重要性。由於中國貴金屬資源有限，技術發展相對上較為落後，貴金屬行業重度依賴進口，鑒於近年來國家之間的貿易糾紛日益加劇，現時發展貴金屬的迫切性比起五年前有過之而無不及，中國急需改革行業供應鏈，並進行有關新金屬材料及相應製造技術的應用研究，以滿足國家經濟及重點工業的發展需要，提升高科技領域的國際競爭力。

貴金屬對國民生計以至國內外經濟都不可或缺。就區域層面而言，香港是亞洲珠寶業的龍頭，但傳統上用於珠寶的化學電鍍方法對環境有害，被很多已發展國家禁用。有見及此，我們的團隊與周大福珠寶集團合作，把表面機械研磨處理技術應用到金、鉑、鈀等貴金屬珠寶，以增加表面硬度。這項技術已獲得中國發明專利，既改善貴金屬的機械性能，並更加環保。

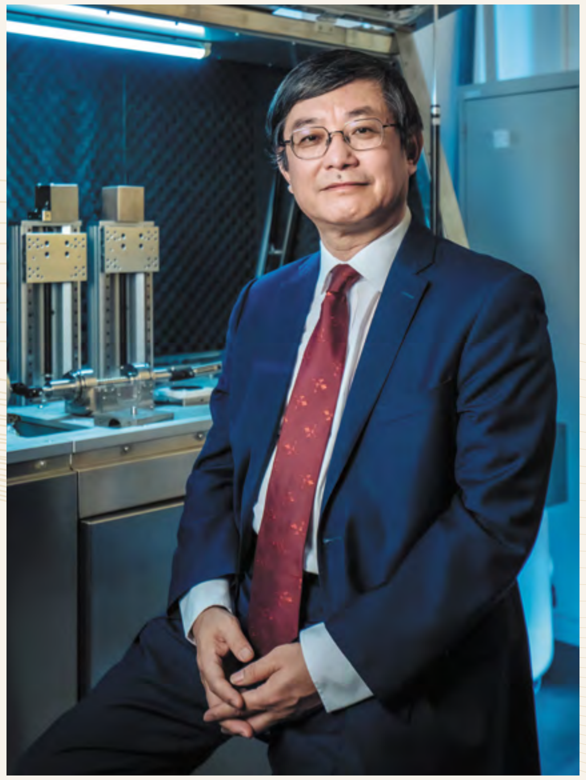
香港在大灣區的角色相當活躍，貴金屬分中心研發的技術可用於手提智能電話等高端電子產品，為大灣區這門主要產業出一分力。我們的團隊以濺射技術為基礎鑲嵌銀網，發明出一種柔性透明導電金屬薄膜。薄膜導電性能良好，具有很好的結構變形能力，而且表現穩健。採用這款薄膜用作電子裝置和功能性材料的基本組件，能夠大幅提升有關產品的品質。

At the national and international levels, in 2020, a new guiding document was unveiled on the nation's efforts to achieve its peak carbon emission and carbon neutrality goals under the new development philosophy and to emphasize the urgent need to improve energy efficiency. Future prospects for the contributions of the precious metal catalyst industry to the development of the chemical, petroleum refining, petrochemical, pharmaceutical, environmental protection, and new energy industries are very promising. For instance, the dealloying method developed by our group has enabled the optimization of nanoporous gold and platinum and their alloys over large specific surface areas with good mechanical performance, high purity, and low density characteristics. These nanoporous alloys can be used in light-quality, durable catalysis and energy storage devices. The pioneering breakthroughs of NPMM members in precious metals catalysis based on phase engineering nanomaterials (PEN) and nanocrystal/amorphous dual phase materials will boost the development of the technologies needed to transform national energy consumption.

High mobility is one of the main characteristics of modern life, and safe transport is a significant concern. Recent developments in energetic chips based on microelectromechanical systems (MEMS) and nanomaterials have very promising applications in automobile airbags, aeronautics and astronautics, mining, oil extraction, and pyrotechnics. Precious metal structural and functional materials are also widely used in equipment manufacturing and thus play a key role in people's daily lives and the key sectors in the national economy.

就國家和國際層面而言，中國於 2020 年公布最新指導文件，全國會致力根據最新發展原則達成碳達峰和碳中和（雙碳）目標，可見中國對提升能源效益的迫切性。貴金屬催化劑產業有望未來為化學、煉油、化工、藥劑、環保和新能源行業大派用場，舉例來說，我們研發的脱合金法優化特定大範圍的納米多孔金、鉑及其合金，能打造機械性能良好、純度高、密度低的金屬表面。這些納米多孔合金可用於製造耐用的光催化劑和電力儲存裝置。貴金屬分中心成員以納米材料相工程和雙相納米晶體 / 非晶態材料為基礎，在貴金屬催化方面取得重大突破，能够配合國家進行能源消耗轉型。

高流動性是現代生活的一大特色，交通安全自然非常重要。以微機電系統為基礎的能量芯片和納米材料發展迅速，未來極有望應用於汽車氣囊、航空及航天學、採礦、石油萃取和煙火技術。貴金屬的結構性和功能性材料能被廣泛用於製造儀器，對日常生活以至中國經濟至關重要。



Professor Jian LU, director of the Hong Kong Branch of National Precious Metals Material Engineering Research Center (NPMM).
國家貴金屬材料工程技術研究中心香港分中心（貴金屬分中心）主任呂堅教授。

Gold wire is one of the most commonly used bonding wires in the electronics industry, and is an optimal choice for future high-density electrical devices. The NPMM conducted an in-depth study of an Au wire bonding process to develop Au wire for large-scale applications in the microelectronics packaging industry in areas such as microelectronics, sensing, supercapacitors, energy storage, and catalysis. These efforts will greatly advance the industrial use of precious metal based components with high commercial value.

These applications would not have been possible without our solid fundamental research. The number of publications in prestigious international journals attributable to NPMM members jumped from 105 in 2017 to 188 in 2021. This 79% increase confirms the leading position of the NPMM in the fields of advanced metallic materials and nanomechanics. In the past five years, our members have published a total of 772 papers in the world's leading journals, including two papers published in *Nature*, one of which was the cover story, and five published in *Science*. During the last five years, 52 invention patents, including 36 US patents and 11 China patents, were granted to NPMM members, while 51 other patent applications were filed with NPMM members as key inventors. To translate these inventions to the market, two start-up companies have obtained HK$1 million in angel fund support from the HK Tech 300 initiative, respectively.

We are grateful for the guidance we have received from MOST and the support provided by the ITC. This strong support has enabled the NPMM to strengthen its research infrastructure and capacity to facilitate advanced research. We are grateful for the guidance we have received from MOST and the support provided by the ITC. This strong support has enabled the NPMM to strengthen its research infrastructure and capacity to facilitate advanced research. Our members have acquired approximately HK$200million in funding as Principal Investigator or Project Coordinator in a wide range of research projects, including the Research Grants Council (RGC) of HKSAR through the Areas of Excellence (AoE) Scheme, Collaborative Research Fund (CRF), and Theme-based Research Scheme (TBRS), the National Key Research and Development Program of MOST, and the Major Program of the National Natural Science Foundation of China (NSFC). In addition, our team developed the ultrasensitive Surface enhanced Raman spectroscopy (SERS) precious metal sensors for the InnoHK project's Hong Kong Center for Cerebro-cardiovascular Health Engineering (COCHE), funded by grants from the Innovative Technology Fund (ITF) under ITC. In 2021, the NPMM started to recruit associate members from other local universities to establish a robust platform for research on precious metals. We now have three associate members from the Chinese University of Hong Kong (CUHK), the Hong Kong Polytechnic University (PolyU), and the Hong Kong University of Science and Technology (HKUST). We would also like to take this opportunity to acknowledge the valuable contributions of former team members, Professor Kowksum CHAN and Dr. Xinrui NIU, to the development of the NPMM.

金線是電子工業中最常用的接合聯線，是未來高密度電子元器件的最佳選擇。貴金屬分中心深入研究了金電線接合過程，以在微電子封裝工業大規模應用金線，例如微電子、傳感器、能量儲存、催化等領域，大大推進具高商業價值貴金屬零件的工業用途。

實際應用離不開堅實的基礎研究。貴金屬分中心成員在知名國際期刊表現活躍，發布的文章由 2017 年的 105 份躍升至 2021 年的 188 份，升幅高達 79%，確立我們在先進金屬材料和納米力學的領導地位。過去五年來，成員在世界級頂尖期刊發表了合共 772 篇論文，其中兩篇文章在《*自然*》上發表，一篇更成為封面故事，另有五篇文章在《*科學*》刊登。成員在這段期間也獲批 52 項發明專利，包括 36 項美國專利和 11 項中國專利，作為主要發明者，成員尚有 51 項專利正在申請中。為了把這些發明產業化，我們中心成員成立了兩間初創企業，各得到 HK Tech 300 計劃的 100 萬港元天使資金。

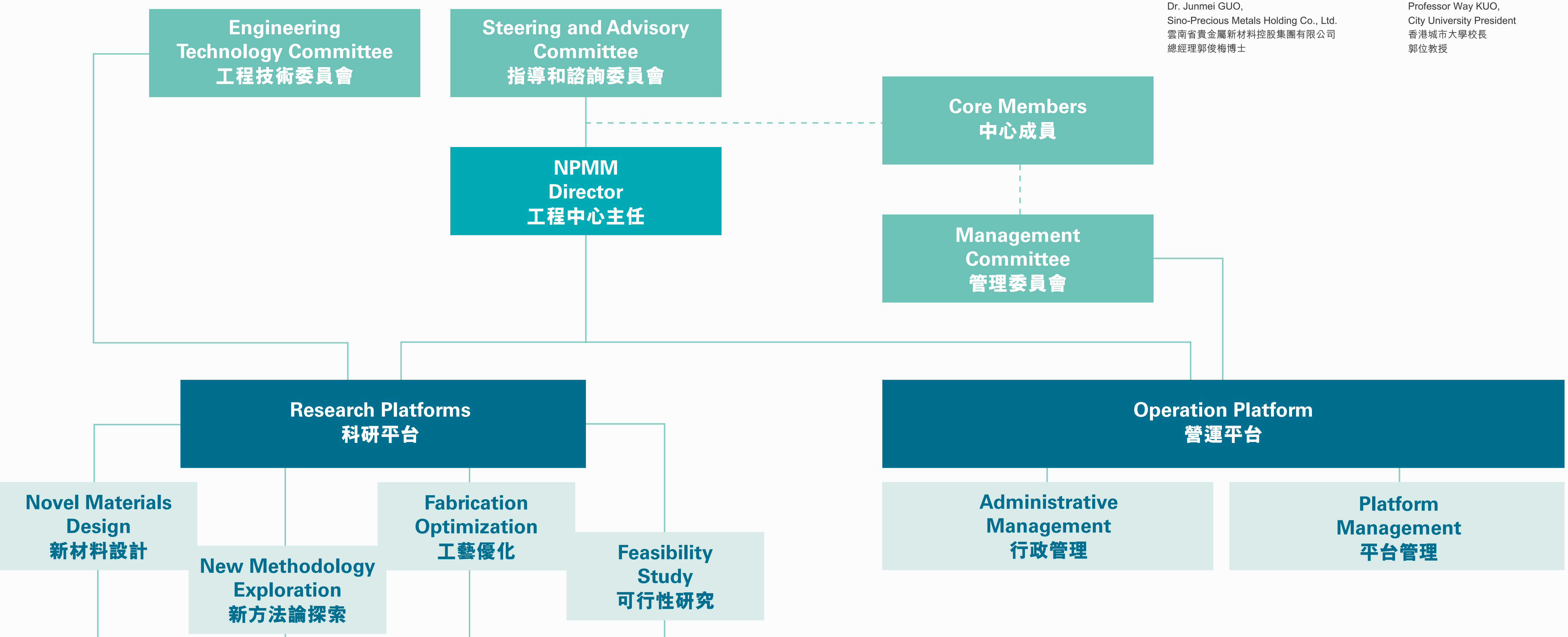
我們對科技部的指導以及創新科技署的支持心懷感激。兩者的強大支援提升了貴金屬分中心的研究設備和科研能力。成員在多個資助研究項目擔任首席研究員或項目統籌人，取得資助經費約 2 億港元，資助機構包括香港研究資助局的卓越學科領域計劃、協作研究金和主題研究計劃；科技部的國家重點研發計劃；以及國家自然科學基金重大項目等等。另外團隊成員在創新科技署資助的創新香港 (InnoHK) 研發平台旗下香港心腦血管健康工程研究中心研發超靈敏表面增強拉曼光譜貴金屬傳感器及其他創新科技署項目。2021 年，貴金屬分中心開始吸納其他本地大學學者作為中心成員，為貴金屬研究建立強大平台，現時我們有三名分別來自香港中文大學（中大）、香港理工大學（理大）和香港科技大學（科大）的合作成員。我們亦想藉此機會感謝團隊前成員：香港城市大學（城大）物理學系陳國森教授和機械工程學系副教授牛鑫瑞博士為貴金屬分中心成立作出寶貴貢獻。

In view of the increasing demand for precious metal based components, the NPMM will continue to conduct fundamental and applied research on the development and integration of new materials, develop comprehensive and systematic insights on new materials and prototypes of related technologies, promote the translation of research into products, and achieve real engineering applications based on our research. In the coming five years, the NPMM aims to leverage its advantages in Hong Kong to become a focal point for research on precious metals and nanomaterials and to connect to mainland China and the world.

以貴金屬為基礎的元器件需求與日俱增，貴金屬分中心會繼續進行研發及結合新材料相關的基礎和應用研究；就新材料及其原型的相關技術提出全面而有系統的見解；推動研究成果產業化；以及以基礎研究為起點，尋求應用方法。貴金屬分中心致力活用香港的優勢，爭取在未來五年成為貴金屬及納米材料研究的樞紐，立足香港、心繫家國、放眼世界。

Professor Jian LU (left), Director of NPMM, and Professor Chain Tsuan LIU (right), Deputy Director of NPMM.
貴金屬分中心主任呂堅教授（左），以及副主任劉錦川教授（右）。

Hierarchical Structure
中心架構

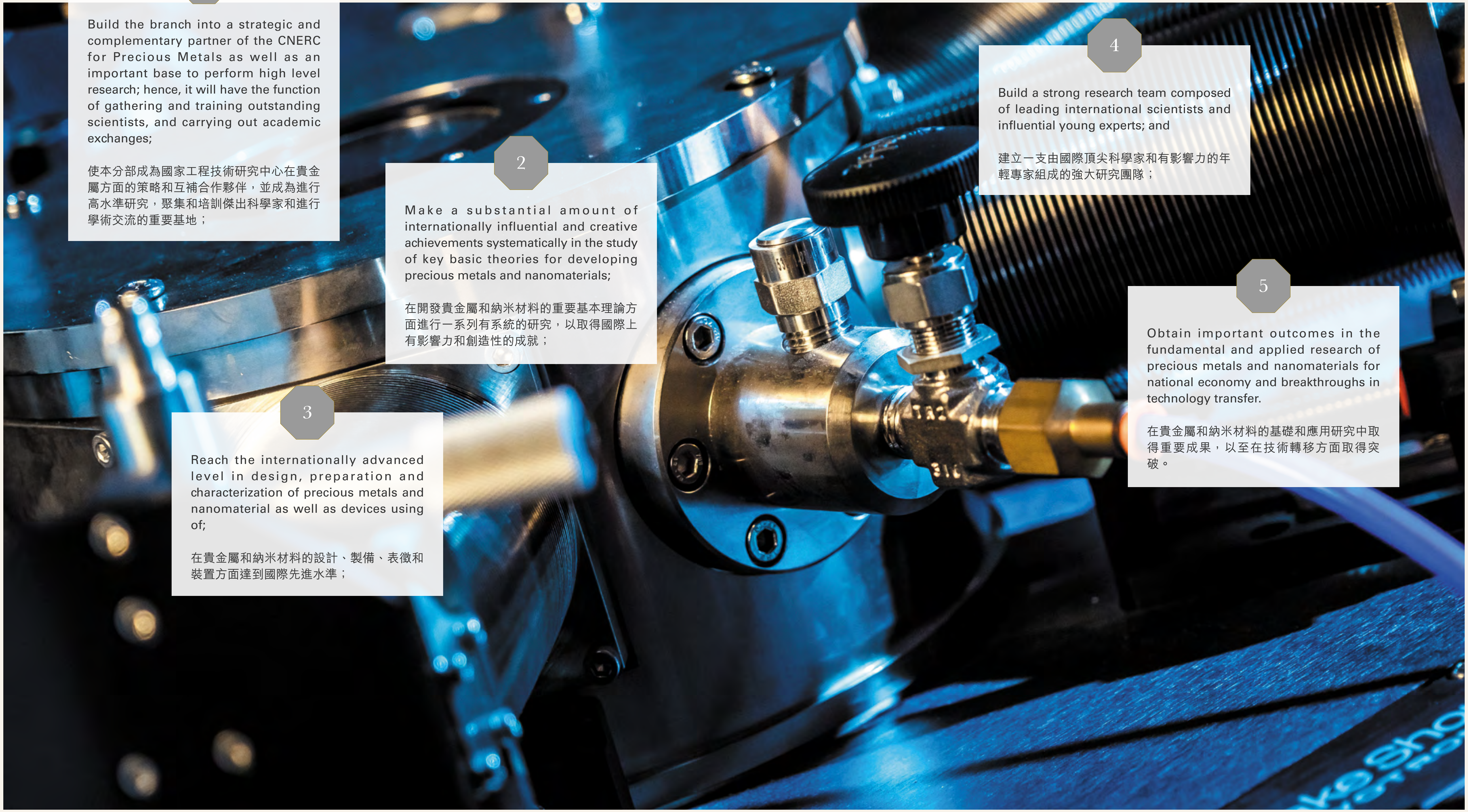


Dr. Junmei GUO,
Sino-Precious Metals Holding Co., Ltd.
雲南省貴金屬新材料控股集團有限公司
總經理郭俊梅博士

Professor Way KUO,
City University President
香港城市大學校長
郭位教授

An Advisory Steering Committee Meeting is held annually with the management of the Sino-Precious Metals Holding Co., Ltd., to discuss collaboration plans and research directions.
貴金屬分中心每年會與雲南省貴金屬新材料控股集團有限公司（雲南貴金屬集團）的管理層進行高層學術交流討論會，討論合作計劃和研究方向。

Mission
使命



1

Build the branch into a strategic and complementary partner of the CNERC for Precious Metals as well as an important base to perform high level research; hence, it will have the function of gathering and training outstanding scientists, and carrying out academic exchanges;

使本分部成為國家工程技術研究中心在貴金屬方面的策略和互補合作夥伴，並成為進行高水準研究，聚集和培訓傑出科學家和進行學術交流的重要基地；

2

Make a substantial amount of internationally influential and creative achievements systematically in the study of key basic theories for developing precious metals and nanomaterials;

在開發貴金屬和納米材料的重要基本理論方面進行一系列有系統的研究，以取得國際上有影響力和創造性的成就；

3

Reach the internationally advanced level in design, preparation and characterization of precious metals and nanomaterial as well as devices using of;

在貴金屬和納米材料的設計、製備、表徵和裝置方面達到國際先進水準；

4

Build a strong research team composed of leading international scientists and influential young experts; and

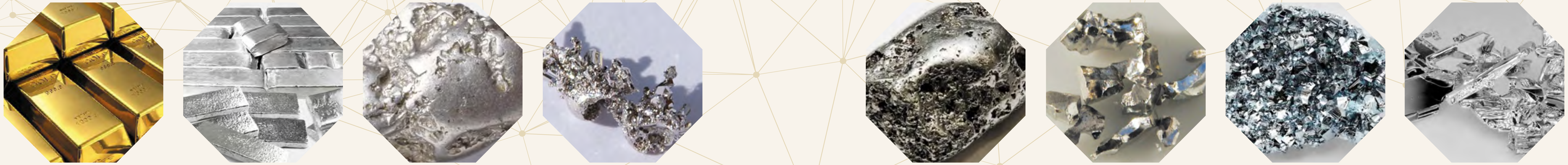
建立一支由國際頂尖科學家和有影響力的年輕專家組成的強大研究團隊；

5

Obtain important outcomes in the fundamental and applied research of precious metals and nanomaterials for national economy and breakthroughs in technology transfer.

在貴金屬和納米材料的基礎和應用研究中取得重要成果，以至在技術轉移方面取得突破。

Introduction to the Hong Kong Branch of National Precious Metals Material Engineering Research Center (NPMM)
國家貴金屬材料工程技術研究中心香港分中心（貴金屬分中心）簡介



Eight elements of precious metals include:
(From left to right): Gold, Silver, Platinum, Palladium, Rhodium, Iridium, Osmium and Ruthenium.
八種貴金屬包括：
(左至右) 金、銀、鉑、鈀、銠、銥、鋨、釕。

The elements of precious metals, which include gold, silver, platinum, palladium, rhodium, iridium, osmium and ruthenium, have specific atomic structures and physical and chemical characteristics, such as high-temperature anti-oxidation, resistance to corrosion, excellent electricity conductivity and high catalytic activity.

As research on precious metals is closely related to the electronics, information technology, catalyst, and jewelry industries, it plays an important role in Hong Kong's economy. For instance, gold, silver and platinum are well-known as materials for jewelry and watches; however, like other precious metals, they also have wide industrial applications. All mobile devices contain precious metals and all computer chips use gold. High-end computers have an even higher demand for extremely small amounts of interconnected gold metal. Precious metals are also excellent catalysts and are very efficient in the storage of energy. They can be used in alloy and aviation applications because of their anti-oxidation characteristics at high temperatures.

The Hong Kong Branch of the National Precious Metals Material Engineering Research Center (NPMM) at City University of Hong Kong (CityU) was established in December 2015 with approval from the Ministry of Science and Technology (MOST) of the People's Republic of China. It formed part of the second batch of Hong Kong branches of Chinese National Engineering Research Centers, nominated and sponsored by the Innovation and Technology Commission (ITC) of the Government of the Hong Kong Special Administrative Region (HKSAR Government). CityU is devoted to expanding its cooperation with mainland educational and scientific research institutions, especially in combination with Hong Kong and mainland research institutes, to develop high-technology industries that can make positive advances. Accordingly, the NPMM was jointly established by CityU and the National Research Centre for Precious Metal Materials and Engineering Technology at Kunming Institute of Precious Metals (KIPM).

貴金屬元素包括金、銀、鉑、鈀、銠、銥、鋨、釕。這些元素的原子結構特殊，物理化學性質優異，如具備高溫抗氧化和抗腐蝕性、優良的導電性、高催化活性等。

貴金屬研究與電子、資訊科技、催化劑及首飾產業息息相關，在香港及珠三角經濟的地位舉足輕重。舉例而言，金、銀、鉑作為首飾及鐘錶材料，廣為人識；但它們其實與其他貴金屬一樣，在工業上用途極廣。每一部流動電子產品都含有貴金屬，每部電腦的芯片都含有黃金，而越高端的電腦，對黃金金屬超細聯線的納米結構的要求越高。貴金屬同時是優質催化劑、高功能能量儲存器件，更可用於在高溫環境下的應用合金設計及航空航天抗氧化領域。

香港城市大學（城大）獲中華人民共和國科學技術部（科技部）批准，於 2015 年 12 月成立國家貴金屬材料工程技術研究中心香港分中心（貴金屬分中心）。貴金屬分中心屬國家工程技術研究中心在香港成立的第二批分中心，由香港特別行政區創新科技署遴選及贊助。一直以來，城大致力加強與內地教育及科研機構合作，尤其是透過中港研究機構合併，發展高科技行業，貴金屬分中心就是由城大與昆明貴金屬研究所國家貴金屬材料工程技術研究中心（昆明貴金屬研究所）共同創立。

Known as the "cradle of platinum studies," KIPM is the backbone of expertise and technology innovation in precious metals in China. The Chinese National Engineering Research Center for Precious Metals (CNERC for Precious Metals) was founded in 2008 and involved KIPM supervised by the China Nonferrous Metals Industry Corporation and Yunnan Provincial Science and Technology Committee. With its strong basic research capacity and comprehensive abilities in applied technology development, KIPM is the main knowledge and technology innovation power in the country's precious metals industry, providing engineering verification and assessment for scientific research achievements.

With its expertise in the field, CityU is a leading institute in research on advanced structural materials. The Center for Advanced Structural Materials (CASM) was set up in 2011 with a team of experts in the field of precious metallic materials. The team is considered one of the best research groups in both Hong Kong and wider China in the field of nano-structured materials and nano-mechanics. Before the establishment of the NPMM, the team had already supervised 77 research projects related to precious metals and nanomaterials, with over HKD 160 million in national and local funding, such as from MOST and RGC. These achievements provided a firm foundation for the NPMM's progress in industrialization and knowledge transfer.

昆明貴金屬研究所有「鉑族搖籃」之稱，是中國貴金屬領域內知識及技術創新的主力。昆明貴金屬研究所有由中國有色礦業集團公司和雲南省科學技術院督導，並參與了 2008 年國家貴金屬材料工程技術研究中心的成立。昆明貴金屬研究所的具有堅實的研究基礎，並能全方位協助開發應用技術，是中國貴金屬行業的主要知識與創科龍頭，為科研成就提供工程認證和評估。

城大在先進結構材料方面的研究領域表現領先，擁有多項專門技術。先進結構材料研究中心於 2011 年成立，旗下擁有的貴金屬材料專家團隊是香港以至大中華地區當中，最佳的納米結構材料與納米力學研究團隊之一。貴金屬分中心成立前，團隊已指導了 77 個貴金屬與納米材料研究項目，並已取得海內外超過 1 億 6,000 萬港元資金，當中包括國家科技部和香港研究資助局等。這些成果為貴金屬分中心的工業化和知識轉移提供堅實基礎。

The award ceremony of NPMM is officated by government officials of the Ministry of Science and Technology (MOST) of the People's Republic of China and the Innovation and Technology Commission (ITC) of the Government of the Hong Kong Special Administrative Region (HKSAR Government).
中華人民共和國科學技術部及香港特別行政區創新科技署官員主持貴金屬分中心授牌儀式。

The development and application of advanced materials is an important indicator of social productivity. In modern history, research and development of advanced materials, manufacturing and processing technology, and the integration of the design of the end products has not only promoted the progress of human civilization and societal development but also reflects a country's comprehensive science and technology development strength. However, the study and development of new materials in China is still far behind that in industrially developed countries, which makes it difficult to fully meet the needs of the national economy and of high-technology industrial development. Hence, there is an urgent need in China to expand basic and applied research on new metallic materials and related manufacturing technologies.

The precious metals and nanomaterials developed in China have always lacked originality, having been built upon processes imported from abroad and adapted to suit local circumstances. In recent years, the development of precious metals and nanomaterials in the country has focused on industrialization. Limited resources of precious metal elements have hindered the development of precious metals research. Outside of KIPM and Sino-Precious Metals Holding Co., Ltd., there are few enterprises with an independent research capacity in precious metals, and most of the research in China has been conducted in universities or other research institutions. Because of a lack of collaboration between industry and research institutions, most scientific research institutions are biased toward theoretical research and basic science, resulting in practical technological research having a lower profile. Hence, scientific research and industrial production are imbalanced at present, with an increasing lack of professional expertise and technical training. More systematic research must be conducted to reach industrial-scale production in the foreseeable future.

The Chinese Central Government has been fully aware of the issue for some time. The "12th Five-Year Plan (2011-2015) for National Economic and Social Development" highlighted the importance of developing metallic materials with high strength, low weight and high performance. A fabrication process for new materials and their applications to new energy and medicine is one of the eight key scientific issues proposed by the outline of "The National Medium- and Long-Term Program for Science and Technology Development (2006-2020)." To meet this strategic need, the top priority is to develop a new generation of low-cost precious metallic materials with high performance. Given the current status of energy materials, the search for safe, stable and green energy has important national strategic significance and is closely related to China's overall sustainable development.

先進材料的開發和應用是社會生產力的指標。現代歷史中，先進材料的研發、製造及處理技術，以及成品設計結合不單推動人類文明和社會進步，更反映一個國家在科學和技術發展的全面實力。不過，中國對新材料的研發仍然遠遠落後於工業發達的國家，難以完全滿足國內經濟和高科技工業發展的需要。因此，中國有急切需要開拓新金屬材料及相關製造技術的基礎和應用研究。

中國發展出的貴金屬和納米材料欠缺原創元素，一直依賴海外引入的程序為基礎，再按本地條件調整。中國近年來的貴金屬和納米材料發展專注於工業化，貴金屬元素來源有限也限制了貴金屬研究的發展。除了昆明貴金屬研究所和雲南省貴金屬新材料控股集團有限公司（雲南貴金屬集團），很少公司有能力獨立進行貴金屬研究，所以大部分國內研究在大學或其他研究機構進行。由於行業與研究機構缺乏合作，大部分科技研究機構的重心傾向理論研究和基礎科學應用研究相對不受重視。現時科學研究和工業製造處於不平衡狀態，而專業知識和技術培訓也漸見匱乏。為了在可見未來達成工業規模生產，我們需要進行更多系統性研究。

中央政府早已意識到這個問題。《中華人民共和國國民經濟和社會發展第十二個五年規劃綱要》強調發展高強度、高效能的輕量金屬材料的重要。新材料的鑲嵌，以及其對新能源和藥物的應用是《國家中長期科學和技術發展規劃綱要》 (2006-2020) 提出的八大關鍵科學議題之一。為配合戰略需要，首要任務是開發新一代低成本、高效能的貴金屬材料。由於現時能源狀態緊張，找出安全、穩定、環保的能源有重要的國家戰略意義，並與中國整體可持續發展息息相關。

中华人民共和国国民经济和社会发展
第十二个五年规划纲要

人民出版社

To reduce the gap between Hong Kong/mainland China and developed countries in the application and industrialization of precious metals and nanomaterials, it is necessary to strengthen exchanges and cooperation between domestic and international researchers in related fields. Although mainland academic institutions have done tremendous work in this area, their focus is mainly on recipe design and reformation theory, which is some distance from industrialization and engineering applications. To address this pain point, the NPMM entered into a long-term collaboration agreement with Sino-Precious Metals Holding Co., Ltd., a leading enterprise in precious metal production and development, to conduct systematic research to improve manufacturing techniques for large-scale commercialization and industrialization. With a stable team led by the Chinese Academy of Engineering in scientific research and production, Sino-Precious Metals Holding Co., Ltd. provide sufficient space and capability to help promote the development of precious metals and their industrial application.

Through a six-year effort, the NPMM is now a strategic platform for the promotion of the research and application of precious metal elements and nanomaterial engineering technology, and a place where talents are cultivated and academic exchanges and collaborations are forged. As a research center of international standard, the NPMM contributes to the economy of Hong Kong and mainland China by driving forward industrialization and commercialization. In the future, the NPMM will continue to enhance the competitiveness of mainland China and Hong Kong by advancing technology and strengthening collaborative links, ultimately helping the country to achieve an internationally leading position in the field of precious metal elements and nanomaterial engineering technology.

為縮短香港 / 中國與已發展國家之間在貴金屬和納米材料應用及工業化的距離，我們有需要加強與海內外相關領域的研究人員的交流和合作。雖然中國學術機構已在這個領域完成大量工作，可是他們的重點在於步驟設計及革新理論，離工業化及工程應用有一段距離。為處理這個問題，貴金屬分中心與貴金屬製造及開發龍頭雲南貴金屬集團開展長期合作，共同進行系統性研究，以改善大規模產業化和工業化製造技術。在中國工程院領導的強大團隊協助下，雲南貴金屬集團能為雙方合作開發貴金屬及其工業應用提供足夠空間和支援。

經過六年努力，貴金屬分中心已成為推廣貴金屬及納米材料工程技術研究和應用的戰略平台，人才輩出，促進學術交流和合作。作為具有國際水平的研究中心，貴金屬分中心推動工業化和產業化，為中港經濟出一分力。貴金屬分中心未來會繼續改進技術和加強聯繫，提升兩地競爭力，最終幫助中國成為貴金屬及納米材料工程技術方面的國際領袖。

NPMM members take photo with government officials at the award ceremony of NPMM.
貴金屬分中心成員在授牌儀式上與政府官員合照。

2

Together, We Soar
同行五載 越戰越強

Milestones
大事記

2015

Establishment: In December, the Hong Kong Branch of the National Precious Metals Material Engineering Research Centre (NPMM) at City University of Hong Kong (CityU) was established, with approval from the Ministry and financial support ITC.

成立：香港城市大學（城大）獲科技部批准、香港創新科技署贊助，於 12 月成立國家貴金屬材料工程技術研究中心香港分中心（貴金屬分中心）。

2016

中華人民共和國香港特別行政區政府
創新科技署

Funding Support: In August, NPMM received its first ITC reimbursement.

資金贊助：貴金屬分中心於 8 月得到香港創新科技署首筆資助款項。

2017

云南省贵金属新材料控股集团有限公司
Sino-Precious Metals Holding Co., Ltd.

Industrial Collaboration: NPMM began a close collaboration with Sino-Precious Metals Holding Co., Ltd., on the industrialization of high-purity gold and silver production for electronic applications. Frequent meetings have been held between the company and NPMM to share state-of-the-art technologies.

工商界合作：貴金屬分中心與雲南省貴金屬新材料控股集團有限公司（貴金屬集團）緊密合作，實現電子行業用高端金基材料的產業化前期開發和應用、產品深度加工和品質控制平台建設。

2018

1

Industrial Collaboration: The collaboration between NPMM and Chow Tai Fook Jewellery Group Ltd. resulted in the granting of a Chinese technology patent. This technology not only dramatically reduces the cost of producing gold jewelry but also enables energy savings.

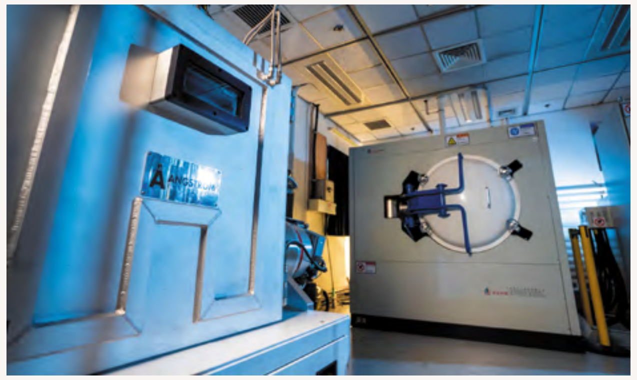
工商界合作：與周大福珠寶集團有限公司共同研發的“微合金化黃金”技術獲國家知識產權局授權專利，該技術既可以減低金飾製造成本，更可以節省能源。

周大福
CHOW TAI FOOK

2

Enhancing Research Facilities: In November, the renovation of the new NPMM laboratories at CityU was completed. These state-of-the-art laboratories include electrochemical workstations and additive manufacturing facilities; workstations for the performance testing of batteries, semiconductors, and other electronic applications; and workstations for thermodynamic analysis of the dynamic and static behavior of precious metals. These facilities complemented the existing Surface Mechanical Attrition Treatment (SMAT) section and the new magnetron sputtering system, and thus the NPMM began to take shape.

加強科研設備：新實驗室在 11 月竣工並投入服務，主要分為三大部分：一、電化學工作站和 3D 列印；二、電池、半導體性能以及光電性能的測試；三、材料動態和靜態熱力學分析工作站。加上本來的表面機械研磨處理技術中心和現放置磁控濺射系統的實驗室，貴金屬分中心初具規模。



3

Industrial Penetration: In November, NPMM participated in the two-day Discussion Forum on Precious Metals in China. Organized by Sino-Precious Metals Holding Co., Ltd., the forum is one of the most influential events in the precious metals industry.

工商界交流：貴金屬分中心參與為期兩天的中國貴金屬論壇，該論壇由貴研鉑業股份有限公司承辦，是中國貴金屬行業最具影響力和凝聚力的盛會之一。

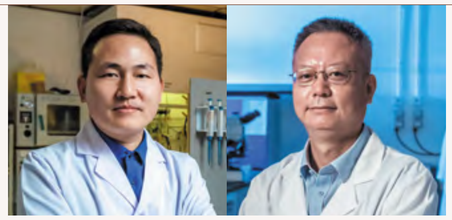
4

Promoting Academic Exchange: In June, NPMM held the 14th International Conference on Nanostructured Materials at CityU. This event attracted 600 participants from over 35 countries and regions.

促進學術交流：貴金屬分中心成功於 6 月份香港城市大學組織了第 14 屆國際納米結構材料會議 (NANO 2018)，並吸引了 600 位來自 35 個國家及區域的參加者。

NANO 2018

2019



1

Talent Recruitment: Professor Hua ZHANG, Herman Hu Chair Professor of Nanomaterials, Chair Professor of the Department of Chemistry (CHEM) and of the Department of Materials Science and Engineering (MSE), and Dr. Zhanxi FAN, Assistant Professor of Chemistry (CHEM), joined NPMM. Professor Zhang is a world expert in the two-dimensional structure of materials, especially precious metals, and has led his group to conduct research on (crystal-)phase engineering of novel noble metal nanomaterials and controlled epitaxial growth of noble metal heterostructures. The results of this research could have broad applications, such as in catalysis, clean energy, (opto-)electronic devices, and nano- and biosensors. Under Professor Zhang's supervision at Nanyang Technological University (Singapore), Dr. Fan's research projects mainly included the controlled synthesis of novel metal nanomaterials, the design and preparation of functional metal-based heteronanostructures, and the catalytic conversion of small molecules.

廣納人才：世界級二維貴金屬專家、化學系、材料科學及工程學系胡曉明講座教授（納米材料）張華教授、化學系助理教授范戰西博士加入貴金屬分中心。張教授帶領其團隊針對研發納米貴金屬晶相工程及控制貴金屬異質結構的外延生長，並廣泛應用於催化劑、清潔能源、光電組件、納米/生物感測器等。范博士師從張教授，致力於材料化學，納米科學，以及催化等交叉領域，從而設計合成新型金屬及金屬基納米材料，系統研究其基本物理與化學性質，並深入探索納米材料在電化學催化和能源轉化等領域的重要應用。

2

Industrial Penetration: In December, NPMM participated in the three-day Discussion Forum on Precious Metals in China for the second consecutive year.

工商界交流：貴金屬分中心連續兩年參與中國貴金屬論壇。

2020

1

Industrial Collaboration: With the signing of a memorandum of intent, NPMM started collaborating with Guangzhou KingMed Diagnostics Group Co., Ltd. to develop a rapid surface-enhanced Raman scattering detection-based screen for severe acute respiratory syndrome coronavirus 2.

工商界合作：貴金屬分中心與廣州金域醫學檢驗集團股份有限公司簽訂合作意向備忘錄，正式展開合作，研發基於SERS 檢測的新冠病毒快篩技術。

2

Research Collaboration: NPMM set up a Greater Bay joint Division with Shenyang National Laboratory for Materials Science to conduct research on precious metals and feasibility studies of their potential applications.

合作研究：貴金屬分中心跟瀋陽材料科學國家研究中心在大灣區建立了聯合研究部，進行貴金屬相關的基礎和應用研究。

3

Promoting Academic Exchange: To adapt to COVID-19 pandemic situation, NPMM's Annual Steering Management Meeting and the Academic Research Seminar were held online for the first time. Sixty-five participants joined the seminar.

促進學術交流：在新冠疫情下，貴金屬分中心首次在線上舉辦一年一度的管理指導會議和學術交流研討會，共計 65 人參與。

2021

1

Research Collaboration: NPMM joined the Hong Kong Centre for Cerebro-cardiovascular Health Engineering, which is supported financially by the ITC and was admitted to the Inno-Health cluster of the InnoHK Programme (a major research and development initiative of the HKSAR Government), to develop new treatments for cardiovascular disease using innovative technologies that enable early detection and intervention.

合作研究：貴金屬分中心加入香港心腦血管健康工程研究中心，該中心隸屬於由創新科技署資助的創新香港研發平台轄下的 Health@InnoHK 創新平台，研發如何及早預防和控制心血管疾病。

2

Promoting Academic Exchange: In November, NPMM held the Advanced Design and Manufacturing Conference in a hybrid mode at CityU, with support from the NSFC and the Beijing–Hong Kong Academic Exchange Centre (BHKAEC), to facilitate research and development in Hong Kong and Mainland China. Thirty-nine prominent scholars delivered speeches at the conference.

促進學術交流：為進一步促進內地、香港兩地高校的科研合作發展，為兩地科研人員提供研討和交流的平台，貴金屬分中心、國家自然科學基金委員會與京港學術交流中心於 2021 年 11 月在城大合辦先進結構設計與製造研討會，共有 39 位學者在研討會上發表學術成果。

3

Talent Recruitment: Dr. Tao YANG, Assistant Professor of MSE, became a Member of NPMM.

廣納人才：材料科學及工程學系助理教授楊濤博士加入貴金屬分中心。

2022

1

Talent Recruitment: NPMM further strengthened its team by appointing Associate Members from other local universities. Professor Minhua SHAO, Chair Professor of the Department of Chemical and Biological Engineering of HKUST; Professor Zijian ZHENG, Professor of the Department of Applied Biology and Chemical Technology (ABCT) of PolyU; and Dr. Ye CHEN, Assistant Professor of the Department of Chemistry of CUHK joined NPMM to enhance its academic exchange with other research groups and institutions.

廣納人才：貴金屬分中心進一步拓展人才隊伍，首次招募來自本港其他院校的教職員成為中心合作成員。香港科技大學化學及生物工程學系的邵敏華講座教授、香港理工大學應用生物及化學科技學系的鄭子劍教授、香港中文大學化學系助理教授陳也博士加入工程中心，以加強與不同研究小組和機構之間的學術交流。

2

Talent Recruitment: Professor Wenjun ZHANG, Chair Professor of MSE and CHEM, became a Member of NPMM.

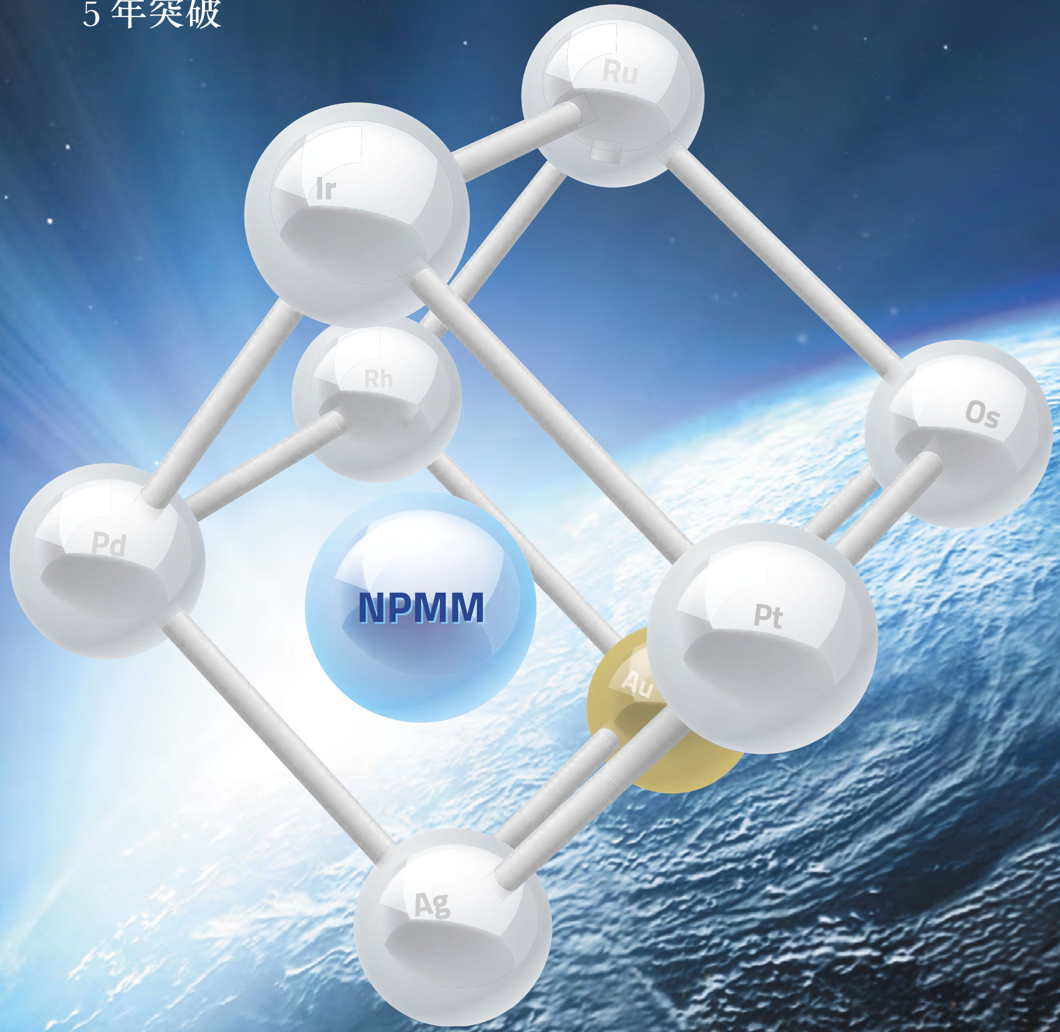
廣納人才：材料科學及工程學系及化學系講座教授張文軍教授加入貴金屬分中心。

3

Commercialization and Entrepreneurship: LUMAT-SERS Limited, the start-up founded by our group member, was established to leverage Surface-enhanced Raman spectroscopy (SERS) technology.

產業化與創業：貴金屬分中心組員成立初創公司路馬特有限公司，研發表面增強拉曼光譜技術。

Breakthrough with Numbers
5 年突破



After 5 years of effort,
we are proud to achieve…

經過五年的努力，
我們達成了……

291	Talents Nurtured (Including the number of research staff and PhD Students)	人才培育（包括研究人員及博士研究生）
772	SCI Papers Published	學術文章刊登
51	Invention Patents Filed	發明專利申請中
52	Invention Patents Granted	發明專利授權
93	Research Projects	資助研究項目
~$200 Million	Grants Received	資助經費
8	Top 2% scientists	首 2% 科學家

*Data Sources : Stanford University and Essential Science Indicators (ESI), Clarivate Analytics
* 數據來源：史丹福大學及科睿唯安基本科學指標

3

Leading the Way
人才輩出 各領風騷

NPMM Members
中心成員

Prof. Jian LU
呂堅教授

(Director, Academician (NATF), Chair Professor (MNE))
(中心主任，法國國家技術研究院院士，機械工程學系講座教授)

Members from CityU
城大成員

Prof. Chain Tsuan LIU
劉錦川教授

(Deputy Director, Fellow (NAE), Foreign Fellow (CAE), University Distinguished Professor (CENG))
(中心副主任，中國工程院外籍院士，工學院傑出教授)

Prof. Hua ZHANG
張華教授

(Foreign Fellow (EAS), Herman Hu Chair Professor of Nanomaterials)
（歐洲科學院外籍院士，胡曉明講座教授席（納米材料））

Prof. Xunli WANG
王循理教授

(Dept. Head (PHY), Chair Professor)
(物理學系系主任及講座教授)

Prof. Wenjun ZHANG
張文軍教授

(Chair Professor, MSE)
(材料科學及工程學系講座教授)

Prof. Xiaoqiao HE
何小橋教授

(Professor, ACE)
(建築學及土木工程學系教授)

Prof. Yang LU
陸洋教授

(Professor, MNE)
（機械工程學系教授）

Prof. Yong YANG
楊勇教授

(Professor, MNE)
(機械工程學系教授)

Prof. Kaili ZHANG
張開黎教授

(Professor, MNE)
(機械工程學系教授)

Dr. Yangyang LI
李揚揚博士

(Associate Professor, MSE)
(材料科學及工程學系副教授)

Dr. Zhanxi FAN
范戰西博士

(Assistant Professor, CHEM)
(化學系助理教授)

Dr. Tao YANG
楊濤博士

(Assistant Professor, MSE)
（材料科學及工程學系助理教授）

Postdocs and Researchers
博士後和研究員

Ph. D
博士研究生

Scientific Officers: 2
科學主任：2

Administrative Staff: 2
行政人員：2

Prof. Minhua SHAO
邵敏華教授

(Chair Professor, CBE, HKUST)
(香港科技大學化學及生物工程學系講座教授)

Prof. Zijian ZHENG
鄭子劍教授

(Professor, ABCT, PolyU)
（香港理工大學應用生物及化學科技學系教授）

Prof. Ye CHEN
陳也教授

(Assistant Professor, CHEM, CUHK)
（香港中文大學化學系助理教授）

Associate Members from other Universities
其他院校成員

Biology & Research Scope of NPMM Members
中心成員介紹

Professor Jian LU　呂堅教授

CityU
- Chair Professor of Mechanical Engineering (MNE)
- Senior Fellow of Hong Kong Institute for Advanced Study (HKIAS)
- Director of Hong Kong Branch of National Precious Metals Material Engineering Research Center (since December 2015)
- Director of Centre of Advanced Structural Materials (since August 2011)
- Vice-President (Research and Technology) and Dean of Graduate Studies (15 November 2013 - 30 November 2020)
- Dean of College of Science and Engineering (01 September 2010-14 November 2013)

香港城市大學
- 機械工程學講座教授
- 香港高等研究院資深院士
- 國家貴金屬材料工程技術研究中心香港分中心主任（2015 年 12 月 ~）
- 先進結構材料研究中心主任（2011 年 8 月 ~）
- 副校長 (研究及科技) 兼研究生院院長（2013 年 11 月 15 日 ~2020 年 11 月 30 日）
- 科學與工程學院院長（2010 年 9 月 1 日 ~2013 年 11 月 14 日）

His research interests are surface science and engineering, processing and mechanical properties of nanomaterials and advanced materials, experimental mechanics and residual stress. Professor Jian LU has published more than 460 journal papers including papers in *Nature (cover story), Science, Science Advances, Nature Materials, Nature Communications, Materials Today, Advanced Materials, Physical Review Letters, Acta Materialia, Journal of the Mechanics and Physics of Solids*. His publications have been cited more than 34,000 times. He is the inventor of more than 67 granted patents with international extension, including 38 in USA, 24 in China and 5 in Europe.

研究成果在 *Nature*, *Science, Nature Materials, Science Advances, Advanced Materials, Materials Today, Nature Communications, PRL, JMPS, Acta Materials, Angewandte Chemie International Edition, Material Science and Engineeering R: Report, Progress in Materials Science, Advanced Functional Materials, Advanced Science* 等一流雜誌上發表 460 餘篇，引用逾 3.4 萬次（Google Scholar）。共取得超過 67 項專利授權 (含拓展專利)，其中在美國取得 38 項，中國取得 24 項，歐洲取得 5 項。

He was awarded in 2006 the French Knight Order of National Merit (Chevalier de l'Ordre National du Mérite); and in 2017 the Knight of the National Order of the French Legion of Honour (Chevalier de la Legion D'honneur); In 2011, he was elected as an Academician of the National Academy of Technology of France. He was the recipient of the 12th Guanghua Engineering Science and Technology Award in 2018, which was regarded as "the most prestigious award for engineering and technology achievement in China".

呂教授于 2018 年獲中國工程院第十二屆光華工程科技獎；2011 年當選法國國家技術科學院院士，是該院 300 多位院士中首位華人院士；2017 年獲法國國家榮譽軍團騎士勳章；2006 年獲法國國家榮譽騎士勳章。

Research Scope

The research scopes and achievements of Professor Jian LU and his team in precious metals in recent years are listed below.

(1) Develop different surface mechanical attrition treatment (SMAT) methods for the physical preparation of superhard nanotwinned gold, which proposes a new pollution-free process and related alloy design methods for hard gold manufacturing.

(2) Innovation of ultrahigh sensitive nano-etched Surface Enhanced Raman Spectroscopy (SERS) sensors, which can be used for detection of chemical/pharmaceutical processes and food/cosmetic ingredients, rapid screening of COVID-19-positive patients, and early diagnosis of cardiovascular diseases, cancer, and Alzheimer's disease.

(3) Develop a novel wet chemical synthesis for the preparation of precious metal nanomaterials with unconventional crystal and amorphous phases, realized heterogeneous and amorphous/crystalline heterogeneous precious metal nanomaterials with different crystalline phase structures, and other unconventional crystalline phase metal and alloy with nanostructures by using unconventional phase precious metal nanomaterials as templates for the epitaxial growth. These new precious metal nanomaterials show unique physical and chemical properties and exhibit superior catalytic performance, allowing for highly efficient catalysts with less precious metal content and significantly lower costs, which have good prospects for application in key areas such as hydrogen production, solar hydrogen production, and water pollution treatment.

(4) Develop alloy design and experimental mechanical methods to support the transformation of the passiveness in the field of electronic precious metal linkage materials, where Chinese companies have an ultra-small market share, and to help develop transparent conductive films of precious metals for flexible smartphones.

(5) Development of key technologies in areas such as 3D/4D printing of precious metal jewelry and ceramic carriers for complex-shaped precious metal catalysts. These above-mentioned efforts have opened up new pathways for the development of high-performance precious metal nanomaterials.

研究範疇

呂堅教授及其團隊在貴金屬領域近年的研究方向及成果如下：

(1) 發展了不同的表面納米化技術（SMAT）用物理法製備納米孿晶超硬黃金，為硬金製造帶來了無污染的新工藝及相關合金設計方法；

(2) 發明創造了超高靈敏度表面納米刻飾表面增強拉曼光譜 （SERS）探針 , 可用於化工與製藥過程檢測，食品及化妝品成分檢測，新冠陽性病人快篩，心血管病，癌症及老年呆癡病的早期診斷；

(3) 發展了新穎濕化學合成製備具有非常規晶相以及無定形相的貴金屬納米材料，實現了具有不同晶相結構的異質相及無定形 / 晶相異質相貴金屬納米材料的製備，利用非常規相的貴金屬納米材料為範本外延生長實現了其它非常規晶相的金屬及合金納米結構的製備，這些新貴金屬納米材料展現出獨特的物化性質，表現出更優異的催化性能，可以獲得貴金屬含量更少的高效催化劑並大幅降低成本，在制氫，太陽能制氫，污染處理水等關鍵領域都有很好的應用前景；

(4) 在電子貴金屬聯線材料領域，發展合金設計與力學實驗方法，支援改變在該領域中國企業市場份額超小的被動狀況及發展柔性智慧手機用貴金屬透明導電膜；

(5) 發展了 3D/4D 列印貴金屬首飾及複雜形狀貴金屬催化劑陶瓷載體的等領域的關鍵技術。這些工作為發展高性能的貴金屬納米材料開闢了新的道路。

Professor Chain Tsuan LIU 劉錦川教授

Professor Chain Tsuan LIU is a member of National Academy of Engineering (NAE), USA, a foreign member of Chinese Academy of Engineering, and an academician of Academia Silica Taiwan. He is currently a University Distinguished Professor of CityU, and a Senior Fellow at HKIAS. He served as a Professor and Distinguished Research Professor at University of Tennessee between 2005 and 2009; a Chair Professor under the World Class Scholar Program at Hong Kong Polytechnic University, and a Distinguished Professor at Auburn University, USA between 2005 and 2010. He is a world leader in the field of intermetallic and metallic materials. He has done pioneer work on mechanistically understanding the brittle fracture in intermetallic alloys and intergranular fracture in noble refractory alloys, correlation of atomic structures of bulk metallic glasses (BMGs) with their unique mechanical properties, and hardening of ferritic steels with various nanoparticles. His innovative research has led to the design of new structural materials with superior mechanical properties for engineering applications. He has published more than 600 journal papers and been granted 29 US patents. Innovative strategies on high-strength alloy design proposed by Professor Liu and his research team have been published on prestigious scientific journal *Science* in 2018, 2020 and 2021. Professor Liu has received numerous honours and awards, including Acta Metallurgica Gold Medal Award, the E.O. Lawrence Award (a US President award) from USDOE, Brown Engineering Alumni Award from Brown University, the first Henry J. Albert Award from IPMI, Fellow Awards from five professional societies – Japan Institute of Metals, the World Technology Network, TMS, ASM, and IPMI, four I•R 100 Competition Awards from Industrial Magazine USA. He was an editor and the Chief Editor of the International Journal of *Intermetallics* for almost 20 years.

劉錦川教授早年於布朗大學材料科學及工程系取得博士學位後，獲聘於橡樹嶺國家實驗室從事研究。他曾在奧本大學，田納西大學及香港理工大學任教，現時為香港城市大學之大學傑出教授及高等研究院資深院士。同時，劉教授也是美國國家工程院院士、中國工程院外藉院士及台灣中央研究院院士。他在國際著名材料科學期刊、會議文集、手冊和百科全書上已發表了600多篇學術論文。他的學術成果在國際材料科學同行中得到非常頻繁的引用。劉教授從學術界、工業界和政府部門中獲得了許多的榮譽和獎章，其中包括2001年冶金材料期刊金質獎章、1998年美國能源部的勞倫斯獎(EO Lawrence Award）—美國總統獎之一、 1998年布朗大學工學院傑出校友金質獎章、1980年國際貴金屬學會的首屆亨利–阿爾博特獎、先後榮獲5個國際著名學會院士會員：日本金屬學會、世界科技聯席組織、美國礦業金屬材料聯合學會(TMS)、美國金屬學會(ASM)、貴重金屬學會(IPMI)，先後四次獲得工業雜誌選出的IR100發明競賽獎。劉教授在新型結構材料研究領域做出了諸多具開創性研究， 獲得了29項美國發明專利， 並且擔任*Intermetallics*主編及*Journal of Materials Research*等期刊編輯。

Research Scope

The primary research interests of Professor Chain Tsuan LIU are the physical metallurgy and mechanical behaviors of alloys, nanostructured materials, intermetallic compounds, and bulk amorphous alloys. He has accumulated considerable research experience in alloy design, microstructural control, and mechanical analysis of various kinds of metallic materials, especially those for structural applications. His recent study focused on the mechanical and environmental performance of metallic materials in extreme environments, alloy design of high-temperature materials, and laser-material interactions. He aimed to provide an in-depth understanding of the thermal stability, deformation pathways, and associated mechanical properties in advanced metallic materials and accelerate the development of new-generation structural materials with superior mechanical performance.

研究範疇

劉錦川教授的主要研究興趣是合金、納米結構材料、金屬間化合物和塊狀非晶合金的物理冶金和機械性能。他在各種金屬材料，尤其是結構應用材料的合金設計、微觀結構控制和力學分析方面積累了豐富的研究經驗。他最近的研究重點是金屬材料在極端環境中的機械和環境性能、高溫材料的合金設計以及鐳射與材料的相互作用。他致力於深入瞭解先進金屬材料的熱穩定性、變形機制和相關的力學性能，開發具有優異力學性能的新一代結構材料。

Professor Xunli WANG 王循理教授

Professor Xunli WANG is presently Head and Chair Professor in the Department of Physics (PHY), CityU. He graduated from Peking University with a B.S. in Physics and went to the US as a CUSPEA scholar, receiving a PhD in Physics from Iowa State University.

Prior to joining CityU in 2012, he had been working at Oak Ridge National Laboratory in the US, rising through the ranks to Distinguished Staff Member. He was responsible for the design, construction, and commissioning of VULCAN, a powerful engineering diffractometer at the Spallation Neutron Source, Oak Ridge National Laboratory. As a senior scientist in the Neutron Science Directorate, he led innovative research, using neutron scattering as a primary tool, to understand deformation and phase transformation behavior in complex materials.

While in Hong Kong, Professor Wang has dedicated his efforts to establishing Hong Kong as an international hub for neutron scattering research. With the support from The Croucher Foundation, he started the biennial Croucher Summer Course on Neutron Scattering. He was also instrumental in launching the Gordon Research Conference series on Neutron Scattering, serving as the inaugural Chair in 2015. In addition, he and Professor Hesheng CHEN of the Institute of High Energy Physics, Chinese Academy of Sciences, co-founded a joint laboratory on neutron scattering. The joint laboratory has received financial support from The Croucher Foundation, Hong Kong's RGC, and the Chinese Academy of Sciences. In 2020, Professor Wang helped establish the Guangdong-HongKong-Macau Joint Laboratory on Neutron Scattering, serving as the Executive Director in Hong Kong. In the meanwhile, Professor Wang has maintained an active research portfolio. His current research interests include structure and dynamics in metallic glass, deformation behaviors in high entropy alloys, and magneto-elastic coupling in magnetic shape memory alloys.

Professor Wang is an elected Fellow of the American Physical Society (APS), American Association for the Advancement of Science (AAAS), Neutron Scattering Society of America (NSSA), and his early work on welding residual stresses was awarded an A. F. Davis Medal by the American Welding Society.

王循理教授現任香港城市大學物理學系系主任兼講座教授。他畢業於北京大學，取得了物理學學士學位，並以 CUSPEA 學者的身份前往美國，取得了愛荷華州立大學的物理學博士學位。

在 2012 年加入香港城市大學之前，他曾在美國橡樹嶺國家實驗室工作，晉升為傑出職員。他負責橡樹嶺國家實驗室散裂中子源的強大工程衍射儀 VULCAN 的設計、建造和測試。作為中子科學理事會的資深科學家的他領導了創新研究，使用中子散射作為主要工具，了解複雜材料中的變形和相變行為。

在香港期間，王教授致力將香港打造成國際中子散射研究中心。在裘槎基金會的支持下，他開始了兩年一度的裘槎中子散射暑期課程。 2015 年擔任首屆主席，他還協助發起了戈登中子散射系列研究會議。此外，他與中國科學院高能物理研究所陳和生教授共同創辦關於中子散射聯合實驗室。該聯合實驗室得到了裘槎基金會、香港研究資助局和中國科學院的資助。 2020 年，王教授協助建立了粵港澳中子散射科學技術聯合實驗室並擔任香港執行主任。與此同時，王教授一直積極研究。他目前的研究興趣包括金屬玻璃的結構和動力學、高熵合金的變形行為以及磁性形狀記憶合金中的磁彈性耦合。

王教授是美國物理學會 (APS)、美國科學促進會 (AAAS)、美國中子散射學會 (NSSA) 會士，他早期在焊接殘餘應力方面的工作獲得了 A. F. Davis 獎章美國焊接協會。

Research Scope

1. Neutron and synchrotron scattering
2. Phase transformation, deformation, magnetism, residual stress determination
3. Metallic glasses, high-entropy alloys, magnetic shape memory alloys

研究範疇

1、中子和同步加速器散射
2、相變、變形、磁性、殘餘應力測定
3、金屬玻璃、高熵合金、磁性形狀記憶合金

Professor Hua ZHANG 張華教授

Professor Hua ZHANG received his bachelor's and master's degrees at Nanjing University in 1992 and 1995, respectively, and completed his doctoral degree under the supervision of Professor Zhongfan LIU at Peking University in July 1998. After spending a few years as research associate/postdoctoral fellow in Katholieke Universiteit Leuven (KULeuven), Belgium with Professor Frans C. DE SCHRYVER and Northwestern University, USA with Professor Chad A. MIRKIN, he started to work at NanoInk Inc. (USA) as a Research Scientist/Chemist in August 2003. Afterward, he worked as a Senior Research Scientist at Institute of Bioengineering and Nanotechnology in Singapore in November 2005. Then he joined the School of Materials Science and Engineering in Nanyang Technological University (NTU) as an Assistant Professor in July 2006 and was promoted to Full Professor in September 2013. In 2019, he joined the Department of Chemistry (CHEM) in CityU as a Chair Professor (Herman Hu Chair Professor of Nanomaterials).

Professor Hua ZHANG's research focuses on the phase engineering of nanomaterials, including the preparation and applications of noble metal nanomaterials with unconventional phases. He has published more than 550 papers (including more than 350 papers published in journals of IF>10, such as 1 *Science* paper and more than 20 papers published in *Science/Nature* sister journals) with total cited times over 100,000 and H-index of 159 (Web of Science) and 168 (Google Scholar). He has filed more than 80 patent applications including 1 China patent, 1 European patent, 3 Singapore patents and 10 US granted patents. In 2020, he was elected as a Foreign Fellow of European Academy of Sciences. In 2015, he was elected as an Academician of the Asia Pacific Academy of Materials (APAM). In November 2014, he was elected as a Fellow of the Royal Society of Chemistry (FRSC). In 2015-2021, he was listed in the "Highly Cited Researchers" in Chemistry and Materials Science (Clarivate Analytics). In 2015, he was listed as one of 19 "Hottest Researchers of Today" in the world in the World's Most Influential Scientific Minds 2015 (Thomson Reuters, 2015). In 2014, he was listed in the "Highly Cited Researchers 2014" in Materials Science, and also listed as one of 17 "Hottest Researchers of Today" and No. 1 in Materials and More in the world in the World's Most Influential Scientific Minds 2014 (Thomson Reuters, 2014).

張華，教授，1992 年本科畢業於南京大學，1995 年獲得南京大學碩士學位，1998 年獲得北京大學化學博士學位（指導老師為劉忠范院士），1999 到 2003 年間先後在比利時魯汶大學（Frans C. De Schryver 教授研究團隊）、美國西北大學（Chad A. Mirkin 教授研究團隊）從事博士後研究。 2003 到 2006 年間先後在美國 NanoInk 公司、新加坡生物工程與納米技術研究所擔任高級研究員。 2006 年 7 月以助理教授的身份加入新加坡南洋理工大學材料科學與工程學院，2011 年 3 月晉陞為副教授，2013 年 9 月晉陞為正教授。 2019 年加盟香港城市大學化學系，任胡曉明納米材料講座教授。

張華教授長期從事貴金屬納米材料相工程相關的基礎應用研究，目前已申請專利 80 餘項，發表論文超過 550 篇（影響因數高於 10 的超過 350 篇，包括*《科學》*1 篇，*《科學》/《自然》*子刊 20 餘篇），總引用超過 10 萬次，H 因子 159（科睿唯安）和 168（谷歌學術）。2020 年張華教授被選為歐洲科學院外籍院士。2015 年，被選為亞太材料科學院院士。2014 年 11 月，被選為英國皇家化學會會士。2015 到 2021 年期間，他連續 7 年同時入選科睿唯安公司 / 湯森路透社發佈的化學與材料科學這兩個領域的“高被引學者”榜單。 根據 2015 年湯森路透社發佈的「世界最具影響力科學家」報告，他入選 2015 年度全球 19 位「最有影響力研究者」榜單。2014 年，他入選材料科學「高被引學者」並以材料科學第一名的身份入選湯森路透社發佈的 2014 年度全球 17 位「最有影響力研究者」榜單。

Research Scope

Recently, noble metal nanomaterials have received extensive attention due to their great promise for applications in catalysis, electronics, biomedicine, etc. Tremendous efforts have been devoted to tuning the composition, size, morphology, and dimensionality of noble metal nanomaterials for manipulation of their functionalities and properties. However, it is rare to use the concept of phase engineering of nanomaterials (PEN), i.e., the delicate modulation of the atomic arrangement, to adjust the intrinsic physicochemical properties of noble metal nanomaterials which normally crystallize into the conventional thermodynamically stable crystal phases. To address this challenge, we have developed novel wet-chemical methods to prepare noble metal nanomaterials with unconventional crystal phases and amorphous phase. We have also successfully achieved the synthesis of noble metal nanomaterials with heterophase, including the heterophase composed of different crystal phases and amorphous/crystalline heterophase. Moreover, we have employed the obtained noble metal nanomaterials with unconventional phases as templates to grow other metals and alloys via epitaxial growth. These novel noble metal nanomaterials with unconventional phases have shown unique physicochemical properties and enhanced catalytic performance compared to those with conventional phases. Our works pave new avenues for developing high-performance noble metal nanomaterials for various applications.

研究範疇

近年來，貴金屬納米材料因其在催化、電子器件、生物醫藥等領域的廣闊應用前景而得到了廣泛關注。通過改變貴金屬納米材料的組分、尺寸、形貌和維度等結構參數來調控其物化性質和應用性能已取得了巨大的進步。 然而，由於貴金屬納米材料通常以其常規熱力學穩定晶相的形式存在，目前採用納米材料相工程的途徑，即精準調控納米材料的原子排列方式，來調控貴金屬納米材料的本徵物化特性的研究仍然很少。為此，我們發展了新穎的濕化學合成策略來製備具有非常規晶相以及無定形相的貴金屬納米材料。我們還成功實現了異相貴金屬納米材料的製備，包括具有不同晶相結構的異質相，以及無定形 / 晶相異質相。此外，我們還用製備的非常規相的貴金屬納米材料為模板，利用外延生長策略實現了其它非常規晶相的金屬及合金納米結構的製備。這些新型的具有非常規相的貴金屬納米材料展現出獨特的物化性質，與常規晶相的貴金屬納米材料相比表現出更優異的催化性能。我們的工作為發展高性能的貴金屬納米材料開闢了新的道路。

Professor Wenjun ZHANG 張文軍教授

Professor Wenjun ZHANG obtained his Doctor of Philosophy degree in 1994 from Lanzhou University. He was a postdoc at the Fraunhofer Institute for Surface Engineering and Thin Films (1995 to 1997) and at the City U (1997 to 1998). From 1998 to 2000, he worked as a Science and Technology Agency Fellow at National Institute for Research in Inorganic Materials, Japan. He joined CityU in 2000 again as a Senior Research Fellow. He is currently Chair Professor of Department of Materials Science and Engineering (MSE). His research focuses on thin film technology, nanomaterials and devices, and surface and interface engineering. He received the Beijing Science & Technology Progress Award (2nd-class award) in 1999, Japan Society of Applied Physics (JSAP) Best Paper Award in 2002, the Friedrich Wilhem Bessel Research Award of Alexander von Humboldt Foundation, Germany, in 2003, the Outstanding Research Award of CityU in 2015, and President's Award in 2019. Professor Zhang is also the Visiting Professor in Siegen University, Germany, Cuiying Guest Professor in Lanzhou University, Guest Professors in National Chiao Tung University, Soochow University, Hefei University of Technology, Technical Institute of Physics and Chemistry (CAS), and Shenzhen Institute of Advanced Technology (CAS). Till now he has published over 400 peer-reviewed journal papers, and hold over 20 China/US patents.

張文軍教授 1994 年博士畢業于蘭州大學物理系，然後分別在德國 Fraunhofer 表面工程和薄膜研究所（1995-1997）和香港城市大學（1997-1998）進行博士後研究，1998-2000 年任日本國立無機材料研究所 Science and Technology Agency 研究員，2000 年加入香港城市大學物理及材料科學系，現任材料科學與工程系講席教授。張文軍教授的研究方向主要涉及薄膜材料、納米材料與器件、表面與界面工程等。於 1999 年獲北京市科學技術進步二等獎，2002 年獲得日本應用物理學會最佳論文獎，2003 年獲得德國洪堡基金會 Friedrich Wilhem Bessel 研究獎，2015 年獲香港城市大學傑出研究獎，2019 年獲香港城市大學校長獎。張文軍教授曾 / 現兼任德國 Siegen University 訪問教授，蘭州大學萃英講席教授，國立交通大學、蘇州大學、合肥工業大學、中國科學院理化技術研究所以及深圳先進技術研究院特聘 / 客座教授。迄今為止已主持了逾 50 項科研專案，發表期刊論文 400 餘篇，擁有 20 多項中國 / 美國專利。

Research Scope

Professor Wenjun ZHANG has a long-standing devotion to the thin-film technologies, controlled synthesis and characterization of nanomaterials, including semiconductor nanostructures, graphene and transition metal chalcogenides nanosheets, carbon nanoparticles, and diamond nanostructures. In the field of thin-film technologies, his studies involve a wide range of materials, such as diamond and diamond-like carbon, cubic and hexagonal boron nitride, and AlN etc. In the recent years, he and his group have also studied extensively the synthesis of a great variety of functional nanomaterials (e.g., diamond nanostructures, carbon nanoparticles, graphene, and semiconductor nanostructures) and their applications in various fields, including electronics, sensing, energy storage, bioimaging and cancer therapy. They have also made effort in the electrochemical applications of nanomaterials, such as electrocatalysis, photoelectrocatalysis, supercapacitors, lithium/sodium ion batteries, in the last few years. Particularly, in the field of electrocatalysis, Professor Zhang and his team have successfully synthesized a series of non-nobel meal based electrocatalysts used for water electrolysis, e.g., $Ni_{1-x}Co_xSe_2$ mesoporous nanosheet networks, nickel nitride enriched with nitrogen vacancies, and MoS_2 nanosheets grown on vertical graphene for catalyzing hydrogen evolution reaction (HER), $Co_3(PO_4)_2$-Co_3O_4 hybrid for oxygen evolution reaction, and feroxyhyte nanosheets (δ-FeOOH) with rich Fe vacancies for overall water splitting. Utilizing DFT calculations, they have demonstrated the decisive effects of doping and vacancies on the electronic structures of electrocatalysts, the adsorption and activation of reactants, and the adsorption-desorption behavior of intermediately species.

研究範疇

張文軍教授長期致力於薄膜技術、納米材料的可控合成和表徵，包括半導體納米結構、石墨烯以及過渡金屬硫化物、碳納米顆粒和金剛石納米結構等。在薄膜技術領域，其研究涉及金剛石、類金剛石碳、立方氮化硼、六方氮化硼和氮化鋁等。近年來，他和他的團隊還廣泛研究了各種功能納米材料的合成及其在電子、傳感、能量存儲、生物成像和癌症治療等多個領域的應用。在過去的幾年裡，他們也致力於開發納米材料的電化學應用，如電催化、光電催化、超級電容器、鋰 / 鈉離子電池等。特別是在電催化領域，張教授及其團隊成功地製備了一系列用於水電解的非貴金屬基電催化劑，比如 $Ni_{1-x}Co_xSe_2$ 介孔納米片、富含氮空位的氮化鎳、垂直生長在石墨烯上的 MoS_2 納米片、$Co_3(PO_4)_2$-Co_3O_4 以及富含 Fe 空位的 δ-FeOOH 納米片等。同時，利用密度泛函理論計算證明了摻雜和空位對電催化劑的電子結構、反應物的吸附和活化以及中間物種的吸附 - 解吸行為的決定性影響。

Professor Xiaoqiao HE 何小橋教授

Professor Xiaoqiao HE received his B.S. in Solid Mechanics from Wuhan University of Technology, M.S. in Computational Mechanics from Huazhong University of Science and Technology and PhD in Dynamics from National University of Singapore, respectively. After his graduation from National University of Singapore, he worked as a R&D Engineer in MAINTAINER (S) PTE LTD in Singapore for one year. Prior to joining the CityU as a lecturer in September 2005, Professor He had four years of working experience as a Research Fellow in the joint Research Center of Institute of High Performance Computing and Nanyang Technological University in Singapore. Also, he worked as a Research Fellow in CityU for two years. His main research areas include nanomechanics of carbon nanotubes, smart structures, computational mechanics, parallel computing on PC environment and multiscale modeling of CNT-reinforced composite. Over the past 15 years, Professor He's research in these fields has resulted in over 120 SCI journal papers in various top international journals and received a total of more than 3,500 citations (excluding self-cited ones) with h-index 32 from Web of Science Core Collection. Professor He has co-authored four papers with more than 200 citations each according to Web of Science Core Collection. The paper "Buckling analysis of multi-walled carbon nanotubes: a continuum model accounting for van der Waals interaction by He, X.Q., Kitipornchai, S., Liew, K.M., *Journal of the Mechanics and Physics of Solids* 53, 303-326, 2005" was evaluated as the top 1% highly influential paper by Essential Science Indicators (THOMSON ISI). This paper ranked No. 3 in Top 10 Cited articles published in *Journal of the Mechanics and Physics of Solids in 2009* and 2010. The developed explicit formulas in this paper have been applied by many researchers from USA, Japan, UK, India, Iran and China in their researches. Since Professor He joined CityU in 2005, he has been a principal investigator for 17 research grants (including seven GRF grants and two NSFC grants) with a total funding over HK$6 million. The success rate of applying GRF is 7/9.

何小橋教授分別在武漢理工大學取得固體力學學士學位、華中科技大學計算力學碩士學位和新加坡國立大學動力學博士學位。從新加坡國立大學畢業後，他在新加坡的MAINTAINER (S) PTE LTD 擔任研發工程師一年。在 2005 年 9 月加入香港城市大學擔任講師之前，何教授曾在新加坡高性能計算研究所和南洋理工大學聯合研究中心擔任研究員四年。此外，他曾在香港城市大學擔任兩年的研究員，主要研究領域包括碳納米管的納米力學、智能結構、計算力學、PC 環境下的並行計算和 CNT 增強複合材料的多尺度建模。過去 15 年，何教授在這些領域的研究已在各類國際頂級期刊發表 SCI 論文 120 餘篇，Web of Science 共收到 3,500 多篇引文（不包括自引引文）而 h-index 為 32。根據 Web of Science 的核心合集數據庫，何教授與人合著了四篇論文，每篇論文被引用超過 200 次。在 2005 年，何小橋教授、劉錦茂教授和 Kitipornchai Sritawat 在*《固體力學和物理雜誌》*發表論文“Buckling analysis of multi-walled carbon nanotubes: a continuum model accounting for van der Waals interaction" 被基本科學指標 (THOMSON ISI) 被評為最具影響力的前 1% 論文。這篇論文在 2009 年和 2010 年的*《固體力學和物理雜誌》*發表的前十篇被引用文章的排名中排行第三。其論文開發的顯式公式已被許多美國、日本、英國、印度、伊朗和中國的研究人員應用在他們的研究中。自 2005 年加入香港城市大學以來，何教授一直擔任 17 項研究資助的首席研究員，其中包括 7 項大學教育資助委員會的優配研究金 (GRF) 資助和 2 項國家自然科學基金委員會 (NSFC) 資助，總資助超過六百萬港元，而申請 GRF 的成功率為 7/9。

Research Scope

This study used the Surface Mechanical Attrition Treatment (SMAT) developed by the Center for Advanced Structural Materials (CASM) to carry out special treatment on the surface of metallic shells to achieve the control of residual stresses, so as to obtain the preparation technology of bistable and polystable nanostructured shells, and then developed the corresponding shape transition actuation system to achieve controllable morphological control of the multistable shells. Key research topics include:

1. New preparation method.
2. New design approach.
3. Technical method for preparing multistable nanostructured shells.
4. Theoretical models for predicting different morphologies of the multistable shells.
5. Morphological conversion technology of bistable shells under external excitation.
6. Theoretical model for the morphological transformation of bistable shells driven by excitation.
7. Morphological conversion technology of multistable shells.
8. Aerodynamic response of the multistable nanostructured shells in different states.
9. Aerodynamic response of the multistable nanostructured shells in different morphological transformations under wind load.

研究範疇

本研究將使用先進結構材料研究中心開發的表面處理技術（Surface Mechanical Attrition Treatment）對金屬板殼表面進行特殊處理，實現對殘餘應力的控制，從而獲取雙穩態和多穩態板殼的製備技術，然後通過使用驅動裝置與多穩態板殼有機結合，在外界激勵作用下驅動多穩態板殼多個形態的轉換，實現多穩態板殼的可控形態控制。主要研究內容包括：

1. 新的製備方法。
2. 新的設計方法。
3. 製備多穩態板殼的技術方法。
4. 預測多穩態板殼不同形態的理論模型。
5. 雙穩態板殼在外部激勵作用下的形態轉換技術。
6. 雙穩態板殼在激勵驅動下的形態轉換的理論模型。
7. 適用於多穩態板殼形態轉換的激勵系統。
8. 多穩態板殼不同形態下的空氣動力回應。
9. 多穩態板殼在風荷載下不同形態轉換中的空氣動力回應。

Professor Yang LU 陸洋教授

Professor Yang LU is a Professor in the Department of Mechanical Engineering (MNE), with a joint appointment in MSE, at the CityU. He is also Director of the Nano-Manufacturing Laboratory (NML) at the Shenzhen Research Institute of the CityU. His research focuses on the micro/nano-mechanics of metal and semiconductor materials, promoting their applications in Microelectromechanical Systems (MEMS) and advanced manufacturing. His research team discovered "cold welding" of ultrathin metallic nanowires and "ultralarge elasticity" of silicon and diamond at nanoscales, and conducted the first tensile testing of free-standing monolayer graphene. He has published over a hundred journal articles in this field, including *Science, Nature Nanotechnology, Science Advances,* and *Nature Communications*. He is currently the Associate Editor of *Materials Today*. He was funded by the inaugural (2019) National Natural Science Foundation of China (NSFC) "Excellent Young Scientists Fund (Hong Kong and Macau)" and was selected as the inaugural class of RGC of HKSAR "RGC Research Fellow (2020/21)." He received the "Outstanding Research Award (Junior Faculty)" in 2019 and "the President's Award" in 2017 from the CityU. He is also an Elected Member of the Hong Kong Youth Academy of Sciences (YASHK).

陸洋，香港城市大學機械工程學系教授，材料科學與工程系兼職教授，並擔任城大深圳研究院“納米製造實驗室”主任。致力於金屬和半導體材料的微納米力學研究，促進其在微機電系統及精密製造等應用。他與研究團隊發現了超細金屬納米線的“冷焊（cold welding）”以及微納尺度下矽與金剛石的“超大彈性”等現象，並首次實現了單層石墨烯的獨立拉伸測試。以第一或通訊作者在*Science*、*Nature Nanotechnology*、*Science Advances*、*Nature Communications* 等學術刊物發表文章百餘篇，並擔任著名期刊 *Materials Today* 的副主編。陸教授曾獲得香港城市大學2019年度“傑出研究獎．青年學者”，並入選首屆（2019）國家自然科學基金（NSFC）優秀青年科學基金（港澳）項目以及首屆（2020/21)香港研究資助局（RGC）“研資局研究學者”。陸教授2022年當選香港青年科學院院士。

Research Scope

In the aerospace, military, and automotive industries, lightweighting of structural materials has been one of the long-standing challenges. As a new material, high-entropy alloy lattice material shows extremely important application potential due to its light weight, low density, high specific strength, and high fracture toughness. Advances in additive manufacturing (AM) techniques have further provided unprecedented freedom in controlling the complex geometries and microstructures of lattice materials. Integrating material design, lattice structure optimization and 3D printing technology, it will achieve excellent mechanical properties and extreme environments tolerance and provide technical support for the development of national industries.

With the development of 5G and 6G technologies, the semiconductor industry has shown an urgent need for high-power and high-frequency devices. Diamond shows great application potential in the semiconductor field due to its outstanding physical and chemical properties (high thermal conductivity, high breakdown field, etc.). However, intrinsic single crystal diamond (SCD) exhibits electrical insulating properties due to its large band gap. The overall band structure of diamond can be fundamentally altered through deep elastic strain engineering, making it ideal for future large-scale applications in MEMS, photonic devices, quantum information processors, and arrays of microelectronic or nanoelectronic devices.

Precious metal nanomaterials prepared by phase engineering have great development potential and are expected to play an important role in catalytic reactions and clean energy. But to fully utilize these novel materials still requires comprehensive understanding on their structural reliability under external fields. Advanced in situ electron microscopy platforms can be used to study the precious metallic nanomaterials for their responses under mechanical, thermal, and electrical loads, provide solid foundation for future applications.

研究範疇

在航空航天、軍事以及汽車工業領域，結構材料的輕量化一直是長期存在的挑戰之一。高熵合金微點陣材料作為一種新興材料，由於其質輕、密度低、比強度高和斷裂韌性高等特點，具有極其重要的應用價值。增材製造技術的引入進一步提供了在控制點陣材料的複雜幾何形狀和微觀結構方面前所未有的自由度。因此，結合材料設計，點陣結構優化以及3D列印技術，將有機會實現卓越的機械性能，以及在極端環境下的耐受性，從而為國家重大產業發展提供技術性支援。

隨著5G和6G技術的發展，半導體行業展現出對於高功率高頻率器件的急迫需求。金剛石以其突出的物理化學性能（高導熱性、高擊穿場等）在半導體領域顯示出巨大的應用潛力。然而，本徵單晶金剛石（SCD）由於其較大的帶隙而顯示出電絕緣性。通過深度彈性應變工程可以從根本上改變金剛石的整體能帶結構，非常適合未來在MEMS、光子器件、量子資訊處理器以及微電子或納米電子器件陣列的規模化應用。

由相工程製備的貴金屬納米材料極具發展潛力，有望在催化反應以及潔淨能源等方面發揮重要作用。但在應用之前，仍需全面瞭解其在外場下的結構可靠性。利用先進的原位電子顯微鏡平台可以系統地研究亞穩態貴金屬納米材料在機械、熱和電負荷下的回應，為材料的工業化應用提供堅實的基礎。

Professor Yong YANG 楊勇教授

Professor Yang obtained his Bachelor degree in mechanics and economics (dual degree) from Peking University in 2001, MPhil degree from HKUST in 2003, and PhD degree in solid mechanics and materials science from Princeton University in 2007. His primary research interest is in the development and mechanical behavior of advanced structural materials, such as metallic glasses and high entropy alloys. His recent research also extends to mechanics of flexible electronics and hydrogels.

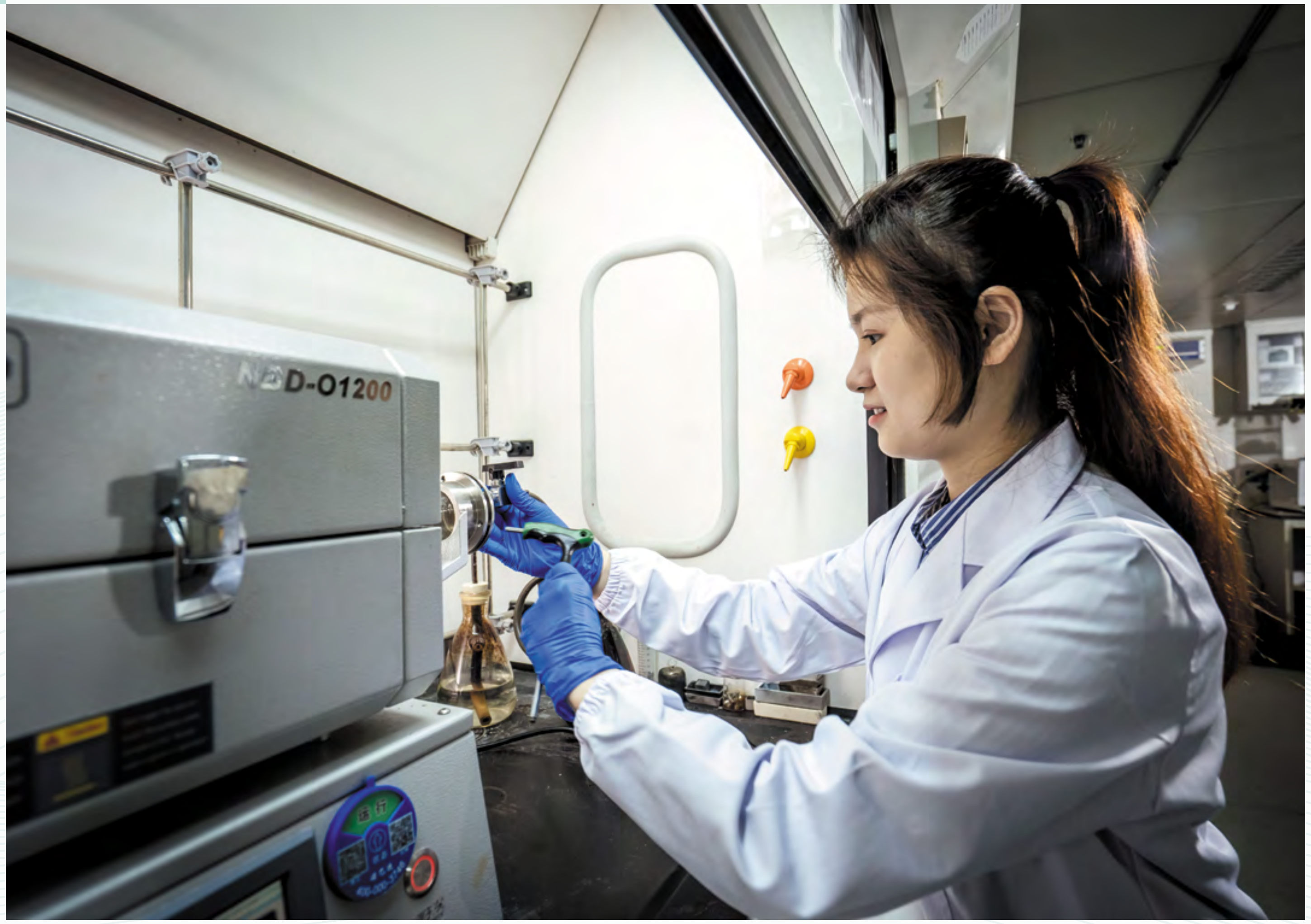
楊教授分別在 2001 年取得北京大學力學與經濟學學士學位（雙學位），在 2003 年取得香港科技大學碩士學位，在 2007 年取得普林斯頓大學固體力學與材料科學博士學位。主要研究方向為金屬玻璃和高熵合金等先進結構材料的發展和機械性能。 他最近的研究還擴展到柔性電子和水凝膠的力學。

Research Scope

The preparation of low-dimensional precious metals (including gold, silver, platinum, etc.) plays an important role in emerging industries in China, such as large-scale integrated circuits and their three-dimensional packaging, flexible electronic devices, new (clean) energy, biomedicine, environmental monitoring, etc.. Traditional low-dimensional metals (such as two-dimensional metal films) are mostly prepared by chemical methods, which have disadvantages such as small surface area and limited types of metals, so they are not suitable for large-scale integrated circuits and flexible electronic devices. The polymer surface buckling exfoliation technology we have developed (a US patent has been obtained) can prepare low-dimensional different precious metals and alloy systems on a large scale, with thicknesses ranging from 10 nm to 100 nm, and in-plane dimensions up to 1 cm, which leads to an aspect ratio that can reach one million or more. Therefore, they are very suitable for use in future large-scale integrated circuits and flexible electronics. The up-to-date research results show that low-dimensional metals, such as 2D gold, produced by our polymer surface buckling exfoliation technique have unique nanostructures that are not found in low-dimensional metals prepared by other methods, and thus possess superior physical properties.

研究範疇

低維貴金屬（包括金，銀，鉑等）的製備對現時國家的新興產業，比如大規模集成電路及其三維封裝，柔性電子器件，新（清潔）能源，生物醫藥，環境監測等，起著舉足輕重的作用。傳統的低維金屬（比如二維金屬膜）多採用化學方法製備，存在著表面積小，適應金屬的種類有限等弊端，因而不適用與大規模集成電路以及柔性電子器件等需要。而我們開發出的聚合物表面屈曲剝離技術（已獲得美國專利）可以大規模製備低維不同貴金屬以及合金體系，其厚度的範圍可從 10 nm 到 100 nm 變化，面內尺寸可達至 1 cm 以上，長厚比可達至一百萬或以上，非常適合在未來的大規模集成電路以及柔性電子裡面使用。目前的結果顯示由我們聚合物表面屈曲剝離技術所生成的低維金屬（比如二維金）具有其他方法製備出的低維金屬所不具備的獨特納米結構，因此具有優越的物理性能。



Professor Kaili ZHANG 張開黎教授

Professor Kaili ZHANG received his PhD degree from National University of Singapore in 2006. He then worked as postdoctoral researchers at French National Center for Scientific Research (LAAS-CNRS) and Swiss Federal Institute of Technology Zurich (ETH Zurich). He joined in CityU as an assistant professor in 2009. He is now working as a professor at MNE, CityU. His research interests include nanoenergetics-on-a-chip, energetic materials, and nanomaterials for energy storage applications. His research results have been published in *Progress in Materials Science, Advanced Materials, Advanced Energy Materials, Advanced Functional Materials, Combustion and Flame*, etc. with a total citation > 10,000 (h-index=55). He serves as an academic committee member of China–Belarus International Laboratory of Vacuum Plasma Technology and is a visiting professor at Francisk Skorina Gomel State University, Republic of Belarus. He received the President's Award (2016), Outstanding Teaching Award of the College of Engineering (2019/2020), and Outstanding Supervisor Award (2017, 2018).

張開黎是香港城市大學機械工程學系教授。他 2006 年在新加坡國立大學獲得博士學位，2006 年 -2008 年，在法國國家科研中心 LAAS 國家實驗室做博士後研究，2008 年 -2009 年，在瑞士聯邦理工學院 (蘇黎世) 做博士後研究，2009 年至今在香港城市大學工作。他的研究領域包括微納米含能材料和器件、儲能材料和器件。他擔任中國 - 白俄羅斯真空等離子體技術國際實驗室學術委員會成員，白俄羅斯戈梅利國立大學客座教授、以及多個國際會議大會科技委員會成員和分會主席。2004 年至今在 *Progress in Materials Science, Advanced Materials, Advanced Energy Materials, Advanced Functional Materials* 等期刊發表 160 多篇 SCI 期刊論文；被引用 10,000 多次 , h-index=55，擁有 8 項專利。獲得 2016 年度校長獎、2017 年度優秀博士生導師獎、2018 年度優秀博士生導師獎、和 2019/2020 年度工程學院傑出教學獎。

Research Scope

Nanoenergetic materials have much improved performance in terms of energy release rate, ignition, and other properties compared to conventional energetic materials (pyrotechnics, propellants, and explosives). Integration of nanoenergetic materials with silicon-based microelectromechanical systems (MEMS) to achieve functional nanoenergetics-on-a-chip (NOC) is a very promising approach. NOC has many merits including high power output, high reliability, suitability for integration and batch fabrication. NOC is one key to the great advance in microactuation, microignition, micropropulsion, microfluidics, micropower, and electro-explosive devices at the micro and nanoscale. It has promising applications in automobile airbags, unmanned aerial vehicle airbags, mining, de-construction, fuses, joining, soldering, brazing, micropropulsion systems, and many defense-related applications such as percussion or electric primers, explosive additives, propellant rate modifiers, arm fire and safe and arm devices used in missiles/rockets, etc. The actuation of NOC is achieved by passing a current through a microheater. The configurations and geometries of the microheater are crucial to the reliability and energy consumption of the ignition. We design and fabricate reliable Au/Pt/Cr/SiO_2 microheaters on the silicon substrate. A thick SiO_2 is first formed on a silicon substrate. Metal films of Au/Pt/Cr are deposited by e-beam evaporation and patterned using photolithography. The Cr acts as the adhesion layer between the Pt and SiO_2. The Pt serves as the resistor. Metal Au/Pt/Cr lift-off is performed in acetone. After cleaning, the substrate with metal films is spin-coated with resist and patterned by lithography. It is then put into Au etchant. The Au in the designed area is removed and the Pt is exposed as the resistor. Energetic materials are then integrated with the Au/Pt/Cr microheaters. We use thermogravimetric analysis and differential scanning calorimetry (TG-DSC), pressure generation test, and high-speed video recording to investigate the reaction process and mechanism of the energetic materials on the microheater chip so as to provide theoretical and experimental basis for the application of NOC.

研究範疇

煙火劑、推進劑和炸藥等傳統含能材料及其裝置在國民經濟和社會發展中起著非常重要的作用，近年來，納米材料、微機電系統（MEMS）、納機電系統（NEMS）等科學技術領域取得了巨大進步。傳統含能材料學科在與這些新興學科交叉的基礎上，逐漸形成了微型含能器件這一重要領域。由於微型含能器件具有高度微型化、集成化、多功能化、高精度、高可靠性等顯著特點和優勢，已經吸引了各國的強烈關注和大量研究投資。當前已經形成的具有誘人應用前景的微型含能器件主要包括：用於汽車安全氣囊發生器和無人機氣囊發生器的點火裝置，用於微型衛星及其陣列姿態調整的微推進器，數位化、多功能化、選擇性的點火系統，用於保密安全的微型自毀裝置等。而微加熱器是微型含能器件的一個核心組成部分，微加熱器的結構和幾何尺寸對微型含能器件的點火可靠性與能耗至關重要，我們設計並加工用於微型含能器件的 Au/Pt/Cr/SiO_2 薄膜微加熱器：首先在矽晶圓上沉積一層厚的 SiO_2 層，然後在其上面製備 Au/Pt/Cr 薄膜微加熱器。由於 SiO_2 的熱傳導係數很低，可以顯著減少熱損失；同時 Au/Pt/Cr/SiO_2 有矽基支撐，保證了器件機械強度。然後將含能材料集成到薄膜微加熱器上，利用熱重分析、產壓測試、高速攝像等方法研究含能材料及其在微型含能器件上的反應過程和機理，為微型含能器件的應用提供理論和實驗基礎。

Dr. Yangyang LI 李揚揚博士

Dr. Yangyang LI is an associate professor at MSE, CityU. Dr. Li received her bachelor's degree from Peking University, Beijing, Master's degree from National University of Singapore, Singapore, and PhD degree from University of California, San Diego, USA. She served as Research Scientist from 2004 to 2007 in Hitachi Chemical Research Center, Irvine, CA. Afterward, she joined in CityU in May 2007.

Dr. Li has extensive experience in biomineralization materials(e.g., amorphous calcium carbonate, amorphous calcium phosphate), Surface enhanced Raman spectroscopy, Electrochemical nanofabrication, electrocatalysts, etc. Dr. Li has published peer-reviewed papers in prestigious journals including *Science; Advanced Materials; Journal of the American Chemical Society; Angewandte Chemie International Edition; Advanced Functional Materials, etc. She serves as* Editorial Board of *American Journal of Nuclear Medicine and Molecular Imaging, Materials Letters, American Journal of Translational Research,* ect.

李揚揚博士是香港城市大學材料科學與工程學系副教授。 李博士分別在北京大學獲得學士學位、在新加坡國立大學獲得碩士學位和在美國加州大學聖地牙哥分校獲得博士學位。2004 年至 2007 年，她在加利福尼亞州歐文市日立化學研究中心擔任研究科學家。之後，她在 2007 年 5 月加入香港城市大學。

李博士在生物礦化材料（如無定形碳酸鈣、無定形磷酸鈣）、表面增强拉曼光譜、電化學納米製造、電催化劑等方面擁有豐富的經驗。 李博士在著名雜誌上發表了同行評審論文，例如：*《科學》*、*《先進材料》*、*《美國化學學會期刊》*、*《應用化學》*和*《先進功能材料》*等。而且她亦在*《美國核醫學與分子影像雜誌》*、*《材料快報》*和*《美國轉化研究雜誌》*等雜誌擔任編輯委員會。

Research Scope

Surface-enhanced Raman spectroscopy (SERS) technology opens vast possibilities for applications in the fields of food safety and disease screening due to its fingerprint characteristics, high sensitivity, simplicity and portability. The principle is that when the target molecule is absorbed on the surface of the noble metal with nanoscale roughness, the scattering cross section of the target molecule will be affected by the surface of the metal. When the local electromagnetic field is greatly amplified, its Raman scattering intensity will increase by 10^4-10^8 times. Apparently, preparing precious metal nanostructures with excellent properties is the core issue of SERS technology. At present, the preparation methods of commercial SERS substrates are the synthesis and subsequent assembly of nanoparticles from the ionic level, which is also known as "bottom up" method. However, this bottom-up preparation method has great limitations. First, reducing agents and stabilizers are often used in the chemical preparation of nanostructures. The remaining chemical reagents usually have high Raman background signals. Causes certain troubles in testing; secondly, the morphology and assembly process of nanomaterials in the mass production process are difficult to control; lastly, this production mode is excessively dependent on manual operation, with large errors and high costs, and it is difficult to implement automatic mass production. Therefore, it is necessary to develop a new precious metal nanostructure processing technology that is able to scale up the production.

研究範疇

表面增強拉曼光譜（Surface-enhanced Raman spectroscopy, SERS）技術因其指紋特徵、高靈敏性、簡單便攜等優勢，在食品安全，疾病篩查等領域得到迅猛發展。其原理為目標分子吸附於具有納米級粗糙的貴金屬表面時，分子的散射截面會被金屬表面的局域電磁場劇烈放大，其拉曼散射強度會增加 10^4-10^8 倍。顯然，製備性能優異的貴金屬納米結構（SERS 探針），是 SERS 技術的核心問題。目前的商用 SERS 探針通常是利用化學還原法製備貴金屬納米溶劑。然而，這種自下而上的製備方法有著極大的局限，首先納米結構在化學製備過程往往需要用到還原劑和穩定劑，殘餘的這些化學試劑通常會有較高的背景信號，對檢測造成一定的困擾；其次，納米材料在大規模生產過程中的形貌和組裝過程難以控制；最後，這種生產模式過度依賴於人工的操作，誤差大，成本高，難以實現自動化的大規模生產。因此，需要研發一種新的貴金屬納米結構處理工藝來實現低成本的自動化大規模生產高性能 SERS 探針。

Dr. Zhanxi FAN 范戰西博士

Dr. Zhanxi FAN is an Assistant Professor in CHEM and also a Core Member of NPMM at CityU. He received his Bachelor of Science degree (2010) in Chemistry from Jilin University (China), where he investigated the composites of conjugated polymers and quantum dots under the guidance of Professor Bai YANG and Professor Hao ZHANG. Then he completed his PhD (2015) in Materials Chemistry from Nanyang Technological University (Singapore) under the supervision of Professor Hua ZHANG. During the PhD study, he developed new strategies for the crystal phase-controlled synthesis and applications of precious metal nanomaterials. Afterward, he did postdoc work in Nanyang Technological University with Professor Hua ZHANG and Lawrence Berkeley National Laboratory (USA) with Professor Haimei ZHENG. His research interest lies in the fields of materials chemistry, nanoscience, catalysis, and energy conversion. Currently, his research projects mainly include the controlled synthesis of novel low-dimensional precious metal and precious metal-based nanomaterials, designed preparation of functional precious metal-based heteronanostructures, and catalytic conversion of small molecules. Until June 2022, he has published 90 SCI papers (71 with IF > 10) with a total citation of over 13,000 and H index of 49. Based on these works, Dr. Fan has been rated/honored as a global Highly Cited Researcher by Web of Science for consecutive 4 years from 2018 to 2021, a "Rising Star" by both *Advanced Materials* and *Small* in 2022, a "Vebleo Fellow" by Vebleo in 2021, a "Top 2% of the World's Most Cited Scholar" by Stanford University in both 2020 and 2021, an "Emerging Investigator" by *J. Mater. Chem.* A in 2021, and is also a recipient of multiple awards including the "Young Scientist Award" from European Materials Research Society (E-MRS) in 2015.

范戰西博士是香港城市大學化學系助理教授，也是國家貴金屬材料工程研究中心（NPMM）香港分中心的核心成員。他在吉林大學（中國）獲得了化學學士學位（2010），並在楊柏教授和張皓教授的指導下研究了共軛聚合物和量子點的複合材料。然後，他在南洋理工大學（新加坡）完成了材料化學專業博士學位（2015），師從張華教授。博士研究期間，他為貴金屬納米材料的晶相可控合成和應用開發了新的策略。之後，他在南洋理工大學與張華教授、勞倫斯伯克利國家實驗室（美國）與鄭海梅教授進行了博士後研究。他的研究興趣在於材料化學、納米科學、催化和能量轉換等領域。目前，他的研究項目主要包括新型低維貴金屬和貴金屬基納米材料的可控合成、功能性貴金屬基異質納米結構的設計製備、以及小分子催化轉化。截止 2022 年 6 月，發表 SCI 論文 90 篇（其中 IF>10 的 71 篇），總被引超過 13,000 次，H 指數 49。基於這些工作，范博士從 2018 年到 2021 年連續 4 年被 Web of Science 評為"全球高被引科學家"，2022 年 *Advanced Materials* 和 *Small* 的"學術新星"，2021 年 Vebleo 的"Vebleo 會士"，2020 年和 2021 年被斯坦福大學評為"世界前 2% 被引用最多的學者"，*J. Mater. Chem. A* 的"新銳研究者"，並獲得多項獎項，包括 2015 年歐洲材料研究學會 (E-MRS) 頒發的"青年科學家獎"。

Research Scope

Our group is devoted to addressing the fundamental problems and practical challenges in the fields of materials science, nanoscience, catalysis, and electrochemical energy conversion. Currently, our research scope mainly focus on controlled syntheses of novel metal materials, rational design of functional structures, and catalytic conversion of small molecules.

Precious metal-based material is one of the most important materials in the material industry and the catalysts industry owing to their unique d-band electronic structure and intriguing physicochemical properties. These unique properties of precious metal nanomaterials endow them with outstanding performance than their non-precious metal-based counterparts so they have been extensively used in many important applications, such as surface-enhanced Raman scattering, plasmonics, catalysis, batteries, sensing, information storage, bioimaging and photothermal therapy. However, previous studies are almost limited to the investigation of the thermodynamically stable crystal phases/structures of metal nanomaterials. Recent studies have revealed that the crystal phase, which is closely related to the electronic structure of materials, can also significantly affect the properties of metal nanomaterials. Therefore, the crystal phase-controlled synthesis of metal nanomaterials could open up new opportunities. Exploring this newly emerged research area of synthesizing novel metal nanomaterials with unusual or unprecedented crystal phases, and investigating their formation mechanism, properties, and applications are of essential meaning for material science.

Rational design of functional structures, especially the designed preparation of functional metal-based hetero nanostructures is very important to bridge the practical application and the preparation of the materials. The synergistic effects between different materials could contribute to overcoming the shortcomings of individual components, thus expanding their applications and improving their performance. We are trying to design functional metal-based hetero nanostructures with a good interface, uniform distribution, and physicochemical interaction between metal and the other types of materials using chemical conversion, site-selective overgrowth, and in-situ deposition methods. These functionalized hetero nanostructures possess different physicochemical properties and can boost their performance in various applications. In this way, we aim to decrease the cost of materials processing and increase the atomic utilization efficiency of metals (especially precious metals) for real applications.

Novel materials injected new impetus to push forward the development of energy conversion technologies. Generally, the excessive use of fossil fuels, such as coal, gas, and oil, has caused many environmental problems. Therefore, in order to guarantee a sustainable future, it is critically important and urgent to develop some fossil-free pathways to generate high-value fuels and chemicals for our daily demands and reduce the carbon dioxide emissions. To this end, we will try to develop some highly efficient catalysts that can convert small molecules (such as water, carbon dioxide, and nitrogen) into high-value fuels and chemicals (such as hydrogen, hydrocarbons and ammonia) with renewable energy as the driving force.

研究範疇

范博士的研究團隊致力於解決材料科學、納米科學、催化和電化學能量轉換領域的基本問題和實際挑戰。目前，我們的研究範圍主要集中在新型金屬材料的可控合成，功能結構的合理設計，小分子的催化轉化。

貴金屬基材料由於其獨特的 d 帶電子結構和引人入勝的物理化學性質，是材料工業和催化劑工業中最重要的材料之一。貴金屬納米材料的這些獨特性能使其比非貴金屬基材料具有出色的性能，因此它們已廣泛用於許多重要應用，例如表面增強拉曼散射、等離子體、催化、電池、傳感、信息存儲、生物成像和光熱療法。然而，以前的研究幾乎僅限於對金屬納米材料的熱力學穩定晶相 / 結構的研究。最近的研究表明，與材料的電子結構密切相關的晶相也會顯著影響金屬納米材料的性能。因此，金屬納米材料的晶體相控合成可以開闢新的機遇。探索合成具有不尋常或前所未有的晶相的新型金屬納米材料這一新興研究領域，並研究其形成機制、性質和應用對材料科學具有重要意義。

功能結構的合理設計，特別是功能性金屬基異質納米結構的設計製備，對於連接實際應用和材料製備具有重要意義。不同材料之間的協同效應有助於克服單個組件的缺點，從而擴大其應用範圍並提高其性能。我們正在嘗試使用化學轉化、位點選擇性過度生長和原位沉積方法設計具有良好界面、均勻分佈以及金屬與其他類型材料之間的物理化學相互作用的功能性金屬基異質納米結構。這些功能化的異質納米結構具有不同的物理化學性質，可以提高它們在各種應用中的性能。通過這種方式，我們的目標是降低材料加工成本並提高金屬（尤其是貴金屬）在實際應用中的原子利用效率。

新型材料為推動能源轉換技術發展注入新動力。總體來說，過度使用化石燃料，如煤、天然氣和石油，已經造成了許多環境問題。因此，為了保證一個可持續的未來，開發一些無化石的途徑來生產滿足我們日常需求的高價值燃料和化學品並減少二氧化碳排放是至關重要和緊迫的。為此，我們將致力開發一些高效催化劑，以可再生能源為基礎推動力將小分子（如水、二氧化碳和氮氣）轉化為高價值的燃料和化學品（如氫氣、碳氫化合物和氨）。

Dr. Tao YANG 楊濤博士

Dr. Tao YANG is currently an Assistant Professor at MSE in CityU. He also serves as the core members in the 3D-APT Unit and the NPMM at CityU. He has long been engaged in the research on the innovative alloy design and microstructure control of advanced metallic materials, mainly through three-dimensional atom probe tomography (3D-APT) and transmission electron microscopy (HR-TEM) and other technical means to study the composition design, material thermodynamic and dynamic behavior, solid-state phase transformation and deformation mechanism of alloys. During the past five years, he has published many high-impact research papers in various prestigious journals, such as *Science* (3 papers), *Materials Today, Nature Communications, Acta Materialia, Scripta Materialia, Advanced Material*, etc. Due to the outstanding academic achievements, he was awarded the Distinguished Postdoc Fellow (HKIAS), Rising Star Award (HKIAS), IUMRS Young Scientist Award, Early Career Award (HK), Vebleo Fellow, etc. Meantime, he serves as the Editorial Board Member of the journal of *Advanced Powder Materials*; Guest Editor of the journal of *Frontier in Materials*; Editorial Board Member of journal of *Frontiers in Metals and Alloys*; Associate Editorial Board Member of the journal of *Materials Research Letters*.

楊濤博士，現為香港城市大學材料科學與工程系助理教授，兼任香港三維原子探針聯合研究實驗室 (3D-APT Unit, HK)、國家貴金屬材料工程技術研究中心香港分中心 (NPMM) 核心成員。長期從事先進金屬材料的合金設計與組織結構調控的研究，主要通過三維原子探針層析（3D-APT）和透射電鏡（HR-TEM）等技術手段研究合金材料的成分設計、材料熱力學與動力學行為、固態相變與變形機制等。近 5 年在 *Science* (3 篇)，*Materials Today*，*Nature Communications*，*Acta Materialia*，*Scripta Materialia*，*Advanced Materials* 等知名期刊發表學術論文 60 餘篇。曾先後獲得香港高等研究院 (HKIAS) 傑出博士後研究員，Rising Star Award，國際材聯 IUMRS 青年科學家，香港傑出青年學者計畫、Vebleo Fellow 等學術獎項。與此同時，擔任 *Advanced Powder Materials* 期刊特聘編委、*Frontier in Materials* 期刊客座編委，*Frontiers in Metals and Alloys* 期刊 Editorial Board Member、*Materials Research Letters* 期刊 Associate Editorial Board Member 等相關工作 。

Research Scope

The research of Dr. Yang's group focuses on the innovative design and fabrication of advanced metallic materials for both structural and functional applications, including the high-entropy alloys, noble metals, intermetallic materials, high-temperature superalloys, deep cryogenic alloys and electrocatalysis materials. His current work is primarily focused on the control of atomic occupation, nanoprecipitation, grain-boundary characters, and atomic structures by using multiscale state-of-the-art techniques, such as the 3D atom probe tomography (3D-APT), high-resolution transmission electron microscope (HR-TEM), and 3D printing.

研究範疇

研究團隊的科學研究聚焦在先進金屬材料的創新設計和製造，探討其在結構和功能方面的應用。目前的研究內容包括高熵合金、貴金屬合金、金屬間化合物合金、高溫合金、深冷合金和電催化材料等等。核心技術手段在於通過使用跨尺度的、最先進的材料技術（如 3D 原子探針層析成像（3D-APT）、高解析度透射電子顯微鏡（HR-TEM）和 3D 列印等）對合金內部的原子佔位、納米沉澱、晶界特徵和原子結構等微觀結構進行精確調控等。

Professor Minhua SHAO 邵敏華教授

Professor Minhua SHAO is a Chair Professor in the Department of Chemical and Biological Engineering at the Hong Kong University of Science and Technology, Director of the HKUST Energy Institute. He earned Bachelor of Science (1999) and Master of Science (2002) degrees in Chemistry from Xiamen University, and a PhD degree in Materials Science and Engineering from the State University of New York at Stony Brook in 2006. Professor Shao joined UTC Power in 2007 leading the collaboration with Toyota Motor Company to develop next generation fuel cell technologies, and was promoted to UTC Technical Fellow in 2012. In 2013, he joined Ford Motor Company to conduct research on lithium-ion batteries. He then joined HKUST in 2014 and was promoted to Chair Professor in 2022. He has published over 200 peer-reviewed articles and filed over 30 patent applications (19 issued). He is an Associate Editor of *Journal of the Electrochemical Society* and one of the founding members of Young Academy of Science of Hong Kong. He has also received a number of awards, including the Supramaniam Srinivasan Young Investigator Award from the ECS Energy Technology Division (2014).

邵敏華是香港科技大學化工與生物工程系講座教授，能源研究院院長。1999 年和 2002 年在廈門大學分別獲得化學學士和碩士學位，2006 年在紐約州立大學石溪分校獲得材料科學與工程博士學位。2007 年加入 UTC Power，期間主要領導和豐田汽車的合作，共同開發車用燃料電池先進技術。2012 年被提升為 UTC Technical Fellow。2013 年加入福特汽車公司，專註下一代電動車用鋰離子電池的研究。2014 年加盟香港科大並在 2022 年成為講座教授。已發表了 200 余篇論文，並申請了 30 多項國際專利（19 項授權），是 *Journal of The Electrochemical Society* 的副主編，香港青年科學院創院院士。他獲得多個獎項，包括美國電化學會 Supramaniam Srinivasan 青年研究者獎（2014）等。

Research Scope

Minhua Shao's research is focused on electrochemical energy conversion and storage technologies. His current research projects include developing novel electrocatalysts for fuel cells, water splitting, Carbon dioxide reduction, ammonia synthesis, etc., high energy-density cathode materials for lithium-ion batteries, and lithium metal solid state batteries.

研究範疇

邵敏華教授的研究興趣主要是電化學能源轉換和存儲技術。他目前的研究團隊包括各種新型電催化劑（如燃料電池、電解水、二氧化碳還原、合成氨等）、高能量密度鋰離子電池正極材料、鋰金屬固態電池等的開發。

Professor Zijian ZHENG 鄭子劍教授

Professor Zijian ZHENG is currently Full Professor, Associate Director of University Research Facility in Materials Characterization and Device Fabrication, Associate Director of Research Institute for Intelligent Wearable Systems, and Lead Investigator of Research Institute for Smart Energy at the Hong Kong Polytechnic University (PolyU). Professor Zheng received his bachelor's degree in Chemical Engineering at Tsinghua University in 2003, and PhD in Chemistry at University of Cambridge in 2007, and postdoctoral training at Northwestern University in between 2008-2009. He joined PolyU as Assistant Professor in 2009, and was promoted to tenured Associate Professor in 2013 and Professor in 2017. He is well recognized internationally for his pioneering works on novel soft metals and their applications in wearable electronics and flexible energy storage. He has published >180 papers in high-impact international scientific journals including *Science, Nat. Mater., Adv. Mater.* He also files 40+ patents and is recipient of more than 20 academic awards. He is Editor-in-Chief of *EcoMat*, a flagship open-access journal in green energy and environment published by Wiley. He is Founding Member of The Young Academy of Sciences of Hong Kong, Chang Jiang Chair Professor by the Ministry of Education, and RGC Senior Research Fellow of Hong Kong.

鄭子劍，香港理工大學教授，材料與器件中心實驗室副主任，智慧可穿戴系統研究院副主任，以及潘樂陶慈善基金智慧能源研究院首席研究員。香港青年科學院創院院士（2018 年），教育部長江學者講座教授（2020 年），香港研資局高級研究學者（2021 年）。清華大學本科（2003 年），英國劍橋大學博士（2007 年），美國西北大學博士後（2008 年），2009 年加入香港理工大學任教職至今。研究領域包括材料表界面科學，納米製造，新型柔性材料，柔性電子應用。主持國家、香港、廣東等地區及橫向課題 60 餘項。在 *Science*，*Nature Materials*，*Advanced Materials* 等高影響因數期刊上發表論文 180 餘篇；擁有國內外專利 40 余項。於 2019 年創辦了 Wiley 綠色能源環境領域的先進材料期刊 *EcoMat* 並擔任主編。

Research Scope

Soft electronics that can bend, fold and stretch show remarkable impact in a wide variety of areas ranging from displays, information technology, energy harvesting and storage, to robotics, health, medicine, and fashion. The key research focus in this field is to develop new materials and devices that allow high degree of deformation. Among the many materials, metal conductors serving as interconnects, leads, contacts, and electrodes are indispensable cornerstones of soft electronics. However, the thermal conductivity, expansion, plastic-elastic properties of metals are largely different from polymers that are frequently used as substrates and other components in the development of soft electronics. Therefore, it is critical to study and develop soft metal conductors that are compatible for soft electronic applications.

Professor Zheng's team aims for developing high-performance soft metal conductors, both opaque and transparent, that show good mechanical, electrical, and interfacial stability under significant levels of bending, stretching, and shearing. In particular, the team has great interest in solution-processable soft conductors that can be synthesized and prepared at low temperature and ambient conditions, which are most compatible with soft substrates, e.g., plastic thin films, fibers, and elastomers that dislike vacuum and high-temperature processes associated with convectional fabrication. The key challenges are how to tackle the tradeoff between the conductivity, flexibility/stretchability, transmittance (for transparent conductors), and interfacial stability of the conductor materials through rational design of the materials synthesis, control of the micro/nano structure, and chemical modification of interfaces. These soft conductors serve as building blocks for the fabrication of various soft electronic devices including cutting-edge flexible, foldable, and stretchable (opto)electronic devices including solar cells, photodetectors, force and strain sensors, and chemical sensors. Professor Zheng's team also applied the soft metal conductors for developing high-energy-density, long-cycle-life, and highly flexible supercapacitors and batteries. The team focuses on the revolutionized structure design of the electrodes, from conventional lamellar-like stacks into composite-like interpenetrative structures.

研究範疇

柔性電子被視為新一代革命性技術，在未來的顯示與資訊技術、能源收集及存儲、健康監測及傳感、物聯網等多個領域有極其重要的應用前景。發展可靠、具有優異力學性能和功能特性的柔性器件是柔性電子領域的重點。柔性金屬電極作為各類柔性電子器件都不可或缺的關鍵材料，其機械模量、彈塑性、熱膨脹、熱傳導等性質與柔性電子中常用的高分子材料相差甚遠。因此，器件在拉伸、彎曲、剪切下等不同形變中，很容易產生由於材料性質不匹配而導致的一系列界面不穩定問題，極大限制了器件柔性和可靠性。有鑑於此，急需發展一系列新型的柔性導體材料並設計新型柔性電極和器件結構，同時系統研究其中衍生出的基礎科學問題和技術問題。

鄭子劍研究團隊在柔性電極材料及器件領域開展了一系列創新系統性的工作，發展了一系列柔性、可拉伸、可彎折、可穿戴的高性能柔性金屬導體材料，從根本上解決了金屬與高分子基底不匹配的表界面問題。團隊在該技術的應用方面也開展了大量的工作，形成了一套適用於柔性電路 / 電極的圖案化製備的方法體系，並廣泛應用於柔性光電、傳感、儲能等領域。

Dr. Ye CHEN 陳也博士

Dr. Ye CHEN received her Bachelor of Engineering and PhD degrees in Materials Science from Nanyang Technological University, Singapore, in 2015 and 2019, respectively. Her research interest focused on design and wet-chemical synthesis of novel low-dimensional noble metal nanomaterials with unconventional phases and their applications in catalysis and clean energy. In 2020, she joined Department of Chemistry, The Chinese University of Hong Kong as Assistant Professor. Over the past five years she has published over 40 peer-reviewed international top journals including *Nature Reviews Chemistry, Nature Protocols, Chemical Reviews, Nature Communications, Journal of the American Chemical Society, Advanced Materials, Chemical Science, Chem* and so on, with h-index of 29 and total citations over 3,000 (by Google scholar).

陳也博士分別于 2015 年和 2019 年在新加坡南洋理工大學材料科學與工程學院獲得學生和博士學位，期間主要從事非常規晶相的新型低維貴金屬納米材料的設計與濕化學合成，以及它們在催化、清潔能源等前沿領域的應用研究。2020 年她加入香港中文大學化學系，任助理教授。近五年以來，已在包括 *Nature Reviews Chemistry*, *Nature Protocols*, *Chemical Reviews*, *Nature Communications*, *Journal of the American Chemical Society*, *Advanced Materials*, *Chemical Science*, *Chem* 等國際頂級刊物上發表論文 40 餘篇。h-index 為 29，總引用數超 3,000 次（來自谷歌學術）。

Research Scope

- Design and wet-chemical synthesis of novel precious metal nanomaterials
- Design and synthesis of nanostructures based on precious metal alloys and compounds
- Property study and applications of novel noble metal-based nanomaterials in catalysis, optics, and biosensing

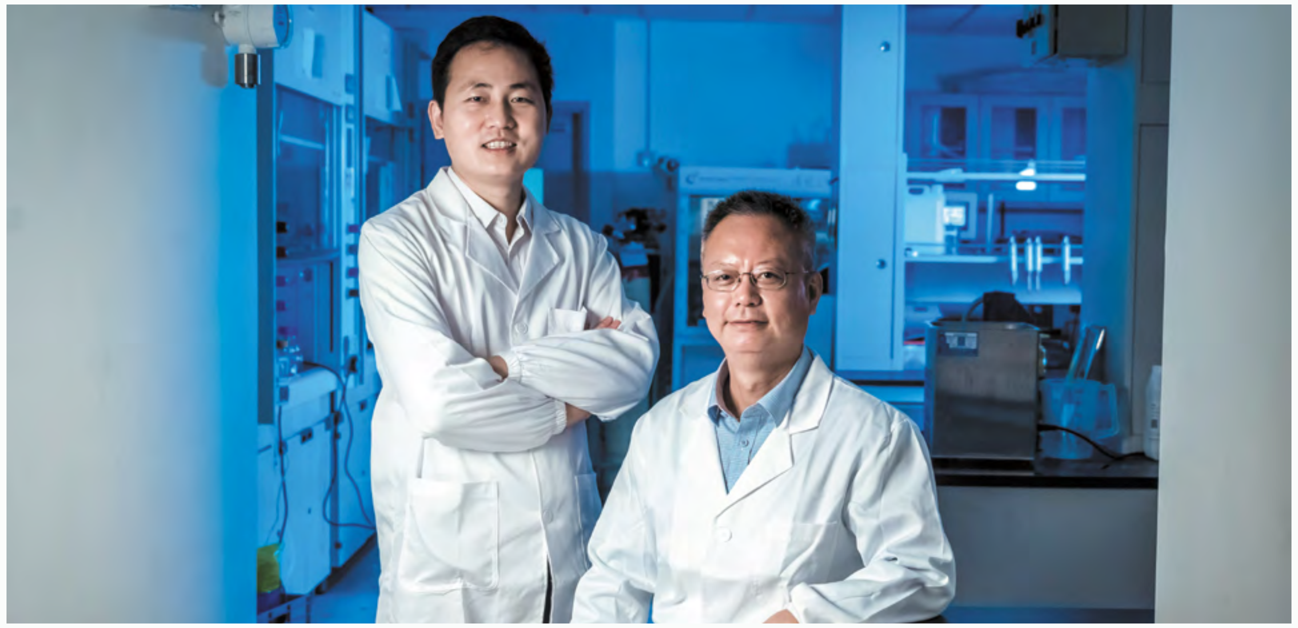
研究範疇

- 新型貴金屬納米材料的設計與濕化學合成
- 貴金屬合金、貴金屬化合物納米結構的設計與合成
- 新型貴金屬基納米材料在催化、光學、生物檢測等領域的性質研究與應用

Nurturing Talents
人才培養

NPMM aims to build a strong research team of leading international scientists and influential early-career scientists. With its wide base of support, including shared equipment and financial support, NPMM has attracted numerous prominent scholars in the field. For example, in 2019, NPMM recruited Professor Hua ZHANG and Dr. Zhanxi FAN.

貴金屬分中心吸納享譽國際的科學家和學術界的青年才俊，致力打造一支強大的研究團隊。貴金屬分中心有強大的研究設施和資金支援，供研究團隊成員共用各種儀器，吸引了這個領域中眾多著名學者。例如，貴金屬分中心於 2019 年招攬了化學系兼材料科學及工程學系胡曉明講座教授（納米材料）張華教授，以及化學系助理教授范戰西博士。



Professor Hua ZHANG (right) and Dr. Zhanxi FAN (left) joined NPMM in 2019.
張華教授和范戰西博士在 2019 年加入貴金屬分中心。

Professor Zhang is a specialist in the field of nanomaterials with excellent research achievements. In 2020, he was elected Foreign Fellow of the Brussels-based European Academy of Sciences (EurASc), which was founded in 2003 and promotes excellence in science and technology. Currently, the EurASc has approximately 600 members in its nine divisions, including 65 Nobel Prize and Fields Medal (known as the "Nobel Prize for Mathematics") winners from 45 nations. Professor Zhang's research is highly interdisciplinary and is currently focused on the phase engineering of nanomaterials (PEN), the synthesis and simultaneous control of phase and morphology of ultra-thin two-dimensional nanomaterials, such as metal nanosheets, graphene, metal dichalcogenides, metal-organic frameworks, and covalent organic frameworks. Although these nanomaterials may sound unfamiliar to the public, yet they have many promising applications in daily life. Professor Zhang's research contributes to catalysis, clean energy, (opto-) electronic devices, nano- and biosensors, and water remediation, which can all help people to improve their lives. In 2020, his research on PEN, entitled "Phase Engineering of Nanomaterials," was published in *Nature Reviews Chemistry.*

張華教授是納米材料的專家，學術研究成績斐然。他於 2020 年膺選為歐洲科學院外籍院士。歐洲科學院 2003 年於比利時布魯塞爾成立，旨在推廣卓越的科學技術。該院現時設九個分部，共有來自 45 個國家和地區的 600 多位成員，其中 65 位是諾貝爾獎或菲爾茲獎（被譽為數學界的諾貝爾獎）得主。他所進行的跨學科研究現時專注納米材料相工程、超薄二維納米材料的可控合成、晶相與形貌的同時調控，包括金屬納米層片、石墨烯、金屬二硫屬化物、金屬有機框架及共價有機框架等，雖然這些納米材料對於很多人來說都比較陌生，但其實這些材料極具發展潛力，與日常生活都息息相關，例如對於催化反應、潔淨能源、（光）電子器材、納米及生物感測器，以及整治用水等方面，都可以作出貢獻，幫助人類改善生活。他指出，納米材料相工程的概念可以擴展到其他具備獨特物理化學性質和應用前景的材料，例如鈣鈦礦，並期望為發現不同新型功能材料提供新想法，開闢新的研究策略。2020 年，他於 *Nature Reviews Chemistry* 發表了一篇題為《納米材料相工程》(Phase Engineering of Nanomaterials) 的文章，介紹納米材料相工程的研究。

Under Professor Zhang's supervision during his PhD study, Dr. Zhanxi FAN also became a member of NPMM, soon after becoming an Assistant Professor at CityU. His research projects focused mainly on the controlled synthesis of novel low-dimensional metal and metal-based nanomaterials, the design and preparation of functional metal-based heteronanostructures, and the catalytic conversion of small molecules.

Other award-winning team-members include Professor Xunli WANG, who was elected a Fellow of the Neutron Scattering Society of America in 2020, and Professor Jian LU, who received French Knight of the National Order of Légion d'Honneur (Chevalier de la Legion D'honneur) in 2017 and the 12th Guanghua Engineering Science and Technology Award in 2018. Our young members are also becoming recognized by prestigious local and non-local organizations. For example, Professor Yang LU received the Excellent Young Scientists Fund (Hong Kong and Macau) from NSFC in 2019, and Dr. Tao YANG received the Early Career Scheme Award from the RGC of HKSAR. As the saying goes, heaven rewards the diligent; accordingly, Professor Xiaoqiao HE, Professor Yang LU, Professor Yong YANG, and Professor Kaili ZHANG, were each promoted to full professor in 2017–2021, and Dr. Yangyang LI was also promoted to associate professor in 2017. NPMM is happy to witness the growth and achievement of our members throughout the years.

In 2022, NPMM further strengthened its team by appointing Associate Members from other local universities for the first time. Professor Minhua SHAO, Chair Professor of the Department of Chemical and Biological Engineering of HKUST; Professor Zijian ZHENG, Professor of the Department of Applied Biology and Chemical Technology (ABCT) of PolyU; and Dr. Ye CHEN, Assistant Professor of the Department of Chemistry of CUHK.joined NPMM to enhance academic exchange between these institutions.

According to metrics compiled by Stanford University in 2021, eight NPMM members—Professor Jian LU, Professor Chain Tsuan LIU, Professor Xunli WANG, Professor Hua ZHANG, Professor Xiaoqiao HE, Professor Yong YANG, Professor Kaili ZHANG, and Dr. Zhanxi FAN—were among the top 2% of the world's most highly cited scientists, which made up approximately 6% of the total number of CityU faculty listed on this metrics, while CityU's proportion of the world's top 2% of the most highly cited scientists is among the highest of any university in Asia relative to faculty size. Led by a team of excellent researchers, NPMM members have nurtured approximately 300 PhD students and research staff, and constructed a robust platform for cultivating talented individuals and facilitating technological exchanges. Ultimately, NPMM provides a platform that creates synergies between teaching, learning and state-of-the-art precious metals research.

張教授曾擔任范戰西博士的博士導師，范博士加入城大後亦馬上加入貴金屬分中心。他主要研究新低維金屬及以金屬為基礎的納米材料的受控合成、以金屬為基礎的功能性異質納米結構設計及製造，以及小型粒子的觸媒轉化。

其他團隊得獎成員包括 2020 年獲選為美國中子散射學會會士的王循理教授，以及於 2017 及 2018 年分別榮獲法國榮譽軍團勳章及第十二屆光華工程科技獎的呂堅教授，年輕成員也嶄露頭角，廣獲海內外機構認可。例如，陸洋教授於 2019 年獲國家自然科學基金委員會頒發優秀青年科學基金（港澳），楊濤博士則獲大學教育資助委員會傑出青年學者計劃獎。正所謂天道酬勤，何小橋教授、陸洋教授、楊勇教授和張開黎教授於 2017 年至 2021 年期間陸續擢升為正教授，而李揚揚博士則於 2017 年成為助理教授。作為科研路上的同行者，貴金屬分中心對各成員的成長和成就與有榮焉。

2022 年，貴金屬分中心首次招攬其他本地大學的學者加盟，進一步增強團隊實力。香港科技大學化學與生物工程學系教授邵敏華教授、香港理工大學應用生物及化學科技學系授鄭子劍教授，以及香港中文大學化學系助理教授陳也博士均加入貴金屬分中心，加強大學之間的學術交流。

根據史丹福大學 2021 年編製的指標，貴金屬分中心八位成員被列為全球排名前 2% 科學家，包括呂堅教授、劉錦川教授、王循理教授、張華教授、何小橋教授、楊勇教授、張開黎教授和范戰西博士，約佔 140 位榜上有名的城大教研人員的 6%。與大學教研人數相比，城大頂尖科學家比例之高，在亞洲大學中極為突出。貴金屬分中心在出色的研究團隊領導下，過去五年內培養約 300 個博士生和研究人員，成功培育人才、成為促進技術交流的強大平台，最終實現教學相長。

Professor Jian LU receives French Knight of the National Order of Légion d'Honneur (Chevalier de la Legion D'honneur) in 2017.
呂堅教授於 2017 年榮獲法國榮譽軍團勳章。

4

Midas Touch
精益求精 點石成金

Research Scope of NPMM
貴金屬分中心研究範疇

NPMM has always insisted on a pioneering, innovative, systematic, in-depth, and long-term research orientation. With this approach, the NPMM has worked on national-level research projects and developed precious metallic alloys and intermetallic compound structural and functional materials, mainly consisting of new metals and new generation base materials, and advanced fabricating and processing technology.

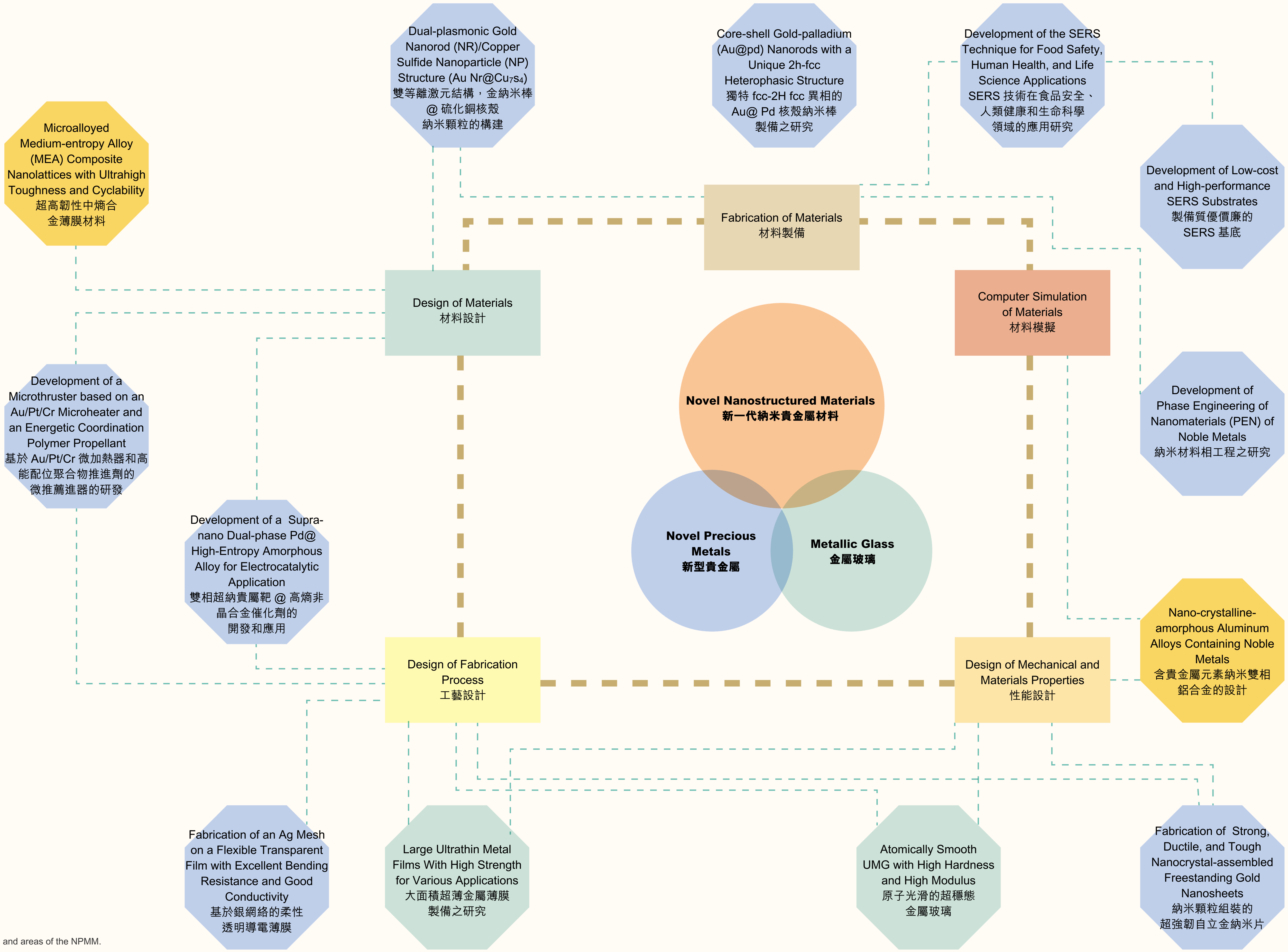
Over the past five years, NPMM members have acquired approximately HK$200 million in funding as Principal Investigator or Project Coordinator in 93 research projects, of which around 16% goes to the major state-level research and development projects such as the National Key Research and Development Program of MOST, and the Major Program of the NSFC, with a total amount of around HK$36 million. At the regional level, NPMM members have undertaken 47 research projects with a total funding amount of around HK$100 million, funded by ITF under ITC and the RGC through the Areas of Excellence (AoE) Scheme, Collaborative Research Fund (CRF), and Theme-based Research Scheme (TBRS). They also took up 19 projects from other provincial and municipal governments, which amount to around HK$55 million.

The NPMM's research scope includes new generation basic metallic materials, precious metallic nano-materials, and new materials simulation. In its fields of application, the NPMM's research concentrates on the functional realization of precious metal components, service reliability and lifespan, and quality and quality-related research through independent and innovative R&D on advanced precious metals-based materials and their core fabrication technologies. Figure 1 shows the NPMM's main research areas and directions during the reporting period. The importance of these research areas and the focus of the research undertaken in each are listed below.

貴金屬分中心始終堅持開拓創新、進行系統深入的研究。因此，貴金屬分中心承擔了多個國家級科研專案，開發貴金屬合金和金屬間化合物結構和功能材料，當中包括新貴金屬和新一代基礎材料，以及先進的製造和加工技術。

在過去五年間，貴金屬分中心成員獲批資助經費約 2 億港元，在 93 個資助研究項目中，約 16% 是國家級項目，當中包括科技部國家重點研發計畫、國家自然科學基金重大項目，合共逾 3,600 萬港元。另外，成員亦積極承擔香港政府及其他省市政府的研究項目，共承擔 47 個創新科技署創新及科技基金及研資局（包括卓越學科領域計劃、協作研究金、主題研究計劃等）的研發項目，合共約 1 億港元，同時亦承擔 19 個省部級及市級研發項目，研發經費共計約 5,500 萬港元。

貴金屬分中心的研究範圍包括新一代基礎金屬材料、貴金屬納米材料和新材料模擬。在其應用領域，貴金屬分中心注重研究貴金屬部件的功能實現、服務可靠性和壽命，以及通過對先進的貴金屬基礎材料及其核心製造技術的自主創新研發，進行品質和品質相關的研究。圖 1 顯示了貴金屬分中心在報告期內的主要研究領域和方向。下文將列出了這些研究領域的重要性和每個領域所囊括的研究重點。



Novel Nanostructured Materials
新一代納米貴金屬材料

Novel Precious Metals
新型貴金屬

Metallic Glass
金屬玻璃

Fabrication of Materials
材料製備

Design of Materials
材料設計

Computer Simulation of Materials
材料模擬

Design of Fabrication Process
工藝設計

Design of Mechanical and Materials Properties
性能設計

Microalloyed Medium-entropy Alloy (MEA) Composite Nanolattices with Ultrahigh Toughness and Cyclability
超高韌性中熵合金薄膜材料

Dual-plasmonic Gold Nanorod (NR)/Copper Sulfide Nanoparticle (NP) Structure (Au Nr@Cu$_7$s$_4$)
雙等離激元結構，金納米棒@硫化銅核殼納米顆粒的構建

Core-shell Gold-palladium (Au@pd) Nanorods with a Unique 2h-fcc Heterophasic Structure
獨特 fcc-2H fcc 異相的 Au@ Pd 核殼納米棒製備之研究

Development of the SERS Technique for Food Safety, Human Health, and Life Science Applications
SERS 技術在食品安全、人類健康和生命科學領域的應用研究

Development of Low-cost and High-performance SERS Substrates
製備質優價廉的 SERS 基底

Development of a Microthruster based on an Au/Pt/Cr Microheater and an Energetic Coordination Polymer Propellant
基於 Au/Pt/Cr 微加熱器和高能配位聚合物推進劑的微推薦進器的研發

Development of Phase Engineering of Nanomaterials (PEN) of Noble Metals
納米材料相工程之研究

Development of a Supra-nano Dual-phase Pd@ High-Entropy Amorphous Alloy for Electrocatalytic Application
雙相超納貴屬靶 @ 高熵非晶合金催化劑的開發和應用

Nano-crystalline-amorphous Aluminum Alloys Containing Noble Metals
含貴金屬元素納米雙相鋁合金的設計

Fabrication of an Ag Mesh on a Flexible Transparent Film with Excellent Bending Resistance and Good Conductivity
基於銀網絡的柔性透明導電薄膜

Large Ultrathin Metal Films With High Strength for Various Applications
大面積超薄金屬薄膜製備之研究

Atomically Smooth UMG with High Hardness and High Modulus
原子光滑的超穩態金屬玻璃

Fabrication of Strong, Ductile, and Tough Nanocrystal-assembled Freestanding Gold Nanosheets
納米顆粒組裝的超強韌自立金納米片

Recent research directions and areas of the NPMM.
本中心的研究方向和領域。

Research Scope 1:
研究範疇 1:

Preparation and Application of New Precious Metallic Materials
新型貴金屬材料的製備與應用

1

Precious metals in the information technology industry

The manufacturing of large-scale integrated circuit elements is dependent on precious metals. With the development of integrated circuit miniaturization of chips and radio components and the three-dimensional integrated circuit (3D IC) technique, the use of precious metal thick film paste and high-strength gold wire are important future directions for the information technology industry. We are investigating the mechanical properties of ultrathin metallic nanowires and exploring their potential applications in next-generation interconnects for the integrated circuit industry (as shown in Figure 1) .

1

資訊技術產業中的貴金屬

大型積體電路元件的製造離不開貴金屬。隨著芯片和無線電元件的發展，積體電路正逐步實現小型化和三維化。貴金屬厚膜漿料和高強度金線的使用是未來資訊技術產業的重要研究方向。我們正在研究超薄金屬納米線的機械性能，並探索其在積體電路行業下一代交連中的潛在應用（如圖 1 所示）。

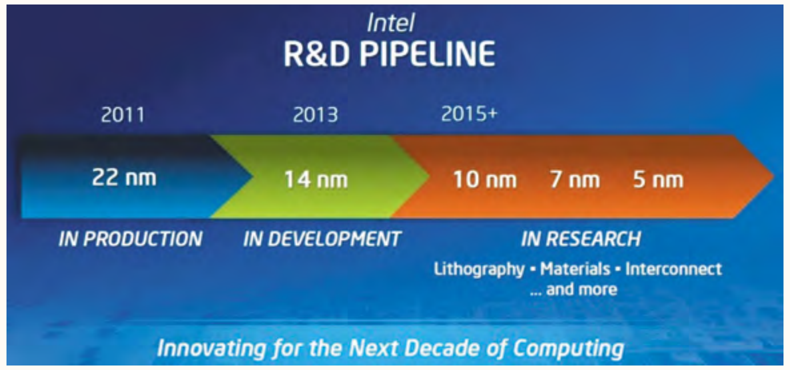


Figure 1 NPMM investigates the mechanical properties of ultrathin metallic nanowires and explores their potential applications in next-generation interconnects for the integrated circuit industry.
圖 1 我們正在研究超薄金屬納米線的機械性能，並探索其在積體電路行業下一代交連中的潛在應用。

2

Jewelry

Gold, silver, platinum, and palladium jewelry and crafts have been hugely popular from ancient to modern times. After the implementation of the gold standard in more than 50 countries at the beginning of the 20th century, gold became a symbol of permanent value. Platinum group metals are not only important strategic materials but have also become the first-choice alternative to gold as financial reserves. The NPMM is greatly increasing the surface hardness of different purity gold jewelry through advanced metallurgy technology and paying particular attention to calculating the computer-aided design and optimization of process conditions for generating targeted nanostructures. These efforts are to allow for the prediction of the mechanical properties of materials and the development of design tools for the optimization of products, including high-end electronic products (mobile phone, tablet, and computer cases). The optimized technology can also be used in other precious metal jewelry, such as platinum and palladium jewelry. This method can decrease production costs while promoting environmental protection and energy conservation.

2

珠寶

從古到今，金、銀、鉑、鈀製備的首飾和工藝品一直廣為人所愛。20 世紀初，在 50 多個國家實施金本位制後，黃金更成為永久價值的象徵。鉑族金屬不僅是重要的戰略物資，而且也已經成為替代黃金的金融儲備的首選。貴金屬分中心正在努力通過先進的冶金技術來大幅度提高不同純度黃金首飾的表面硬度，並特別關注通過電腦輔助設計，計算和優化生成目標納米結構的工藝條件。以實現能夠預測材料的機械性能和開發優化高端電子產品（手機、平板電腦和電腦外殼）設計的工具。優化後的技術也可用於其他貴金屬首飾，如鉑金和鈀金首飾。這種方法可以降低生產成本，促進環境保護和節約能源。

3

Catalysts and energy storage devices

Platinum group metals have many attractive features, such as good catalytic activity, high catalytic selectivity, a long service life, and easy recycling and regeneration. The research and development of these materials is therefore of great benefit to industry and society. The NPMM is investigating the dealloying method, which is an important and commonly used solution-based industrial technique for fabricating advanced porous nanomaterials based on gold, platinum, and other precious metals and can significantly improve the performance of a range of applications, such as catalysts, batteries, and supercapacitors. Dealloying is widely used due to its low cost, great convenience, and high compatibility with mass production. However, the current dealloying technology faces two major drawbacks: poor mechanical properties and difficulty adjusting the structure, morphology, and composition of the generated porous materials for the optimization of the specific surface area, which is due to a lack of control of the dealloying process. These difficulties hamper the practical application of precious metal-based nanoporous materials, particularly in the fields of catalysis and energy storage. To address these pain points, we have greatly advanced the current dealloying technology by investigating the surface mechanical attrition treatment (SMAT) method for generating dealloyed nanoporous gold and platinum with outstanding mechanical performance and ultrafine nanoporous structures of highly specific surface areas, while also utilizing novel tailor-made modulating dealloying voltage profiles for fine-tuning the dealloying process to produce highly porous nanostructures that feature large specific surface areas, high purity, and/or high porosity. The nanoporous gold and platinum materials that this research effort will make possible will be particularly attractive for use in high-performance and lightweight but durable catalysis and energy storage devices.

3

催化劑和儲能裝置

鉑族金屬有許多吸引人的特點，如良好的催化活性，高催化選擇性，使用壽命長，且易於回收和再生。因此，對這些材料進行的研究和開發對工業和社會益處很多。貴金屬分中心正在研究脫合金，脫合金是一種重要且常用的基於溶液的工業技術，用於製造基於金、鉑和其他貴金屬的多孔先進納米材料，可以顯著提高一系列應用的性能，如催化劑、電池和超級電容器。由於脫合金工藝的成本低，操作方便，適用於大規模生產，因此得到廣泛應用。然而，目前的處理技術面臨兩個主要的缺點：較差的機械性能和由於缺乏對處理過程的控制而引起的難以調整的多孔的結構、形態和組成。這些困難阻礙了貴金屬基納米多孔材料的實際應用，特別是在催化和儲能領域。為了克服這些難題，貴金屬分中心通過研究表面機械研磨處理（SMAT）方法來生成具有出色機械性能和高比表面積的超細納米多孔結構的多孔金和鉑，同時還利用新的擬合曲線調節多孔電壓，從而微調多孔產生的過程，以產生具有大比表面積、高純度和 / 或高孔隙率的高多孔納米結構，大大推進了當前的多孔技術。這項研究工作將使納米多孔金和鉑材料成為可能，對要求高性能、輕質但耐用的催化和儲能裝置特別有吸引力。

4

Development of gold/platinum and gold/palladium thin film microheaters for energetic chips

Energetic chips, which are based on microelectromechanical systems (MEMS) and nano-materials, have very promising applications in automobile airbags, aeronautics and astronautics, mining, oil extraction, and fireworks. Microheaters are the key components of energetic chips. The structure and dimensions of microheaters are crucial for the ignition reliability and energy consumption of energetic chips. The NPMM has been developing novel gold/platinum/chromium/silicon dioxide and gold/palladium/chromium/silicon dioxide microheaters for energetic chip applications. Multi-physics modeling will be used to predict the performance of the microheaters and thus to determine their optimal design and dimensions. Microheaters will be combined with nano-materials in modeling to forecast and then optimize the transient ignition process and determine the ignition power, ignition delay, and ignition energy. After obtaining the optimal design and dimensions through modeling, the microheaters will be fabricated using micro-machining technologies.

4

開發用於能量芯片的金 / 鉑和金 / 鈀薄膜微加熱器

基於微機電系統（MEMS）和納米材料的含能芯片在汽車安全氣囊、航空和航天、採礦、石油開採和煙花方面有非常大的應用前景。微加熱器是含能芯片的關鍵部件。微加熱器的結構和尺寸對於含能芯片的點火可靠性和能源消耗至關重要。貴金屬分中心一直在開發新型的用於含能芯片的金 / 鉑 / 鉻 / 二氧化矽和金 / 鈀 / 鉻 / 二氧化矽微加熱器，採用多種物理學建模的方法預測微加熱器的性能，從而確定其最佳設計和尺寸。在建模中，微加熱器與納米材料相結合，預測並優化瞬態點火過程，確定點火功率、點火延遲和點火能量。通過建模獲得最佳設計和尺寸後，再利用微加工技術製造微加熱器。

5

Design of oxidation-resistant alloys based on precious metals for applications in the aeronautic and aerospace industries

Nickel-based superalloys are a class of state-of-the-art materials for high-temperature structural applications. There is a shortage of commercial alloys available that offer both high melting points and adequate oxidation and corrosion resistance for extremely high-temperature applications. In view of the material limitations of conventional alloys, the NPMM has been working in tandem with our academic partners on the design of new noble alloys based on iridium, rhodium, and platinum for extremely high temperature use in oxidizing environments. A combination of computer-aided alloy design and experimental verification is expected to substantially reduce the time and effort to design these new alloys for extremely high-temperature applications.

5

設計的貴金屬抗氧化合金在航空和航天工業中的應用

鎳基超合金是用於高溫結構應用的最先進的材料之一。然而目前缺乏既能提供高熔點，又能為極高溫應用提供足夠的抗氧化和抗腐蝕能力的商用合金。鑒於傳統合金的材料局限性，貴金屬分中心一直在與其他團隊進行合作，設計用於極高溫氧化環境下的，基於銥、銠和鉑的新型貴金屬合金的應用。電腦輔助合金設計和實驗驗證的結合，將大大減少設計這些用於極高溫的新合金的時間和精力。

6

Bulk metallic glasses

Metallic glass is a newcomer to the family of glasses. First achieved based on gold alloys, metallic glasses can be synthesized using modern rapid cooling techniques. Metallic glasses differ from conventional glasses in their mixed character between solid and liquid and between metal and glass. They are also known for their excellent corrosion and erosion resistance, superior soft magneticity, and remarkable thermo-plastic formability. Due to the unique combination of these properties, metallic glasses are commonly perceived as a material with great potential for a variety of industrial applications. Furthermore, metallic glass is not only a new material with unique properties but also a model material system that can be used for studying scientific problems faced in materials science and condensed matter physics. Our research in metallic glasses mainly lies in establishing a structural model and a structure–property correlation for metallic glasses and optimizing the mechanical properties of bulk metallic glasses. The ultimate goal of our research on metallic glasses is to promote their use in different industrial sectors, which in turn can promote long-term technological upgrading and economic growth in mainland China and Hong Kong.

6

大塊金屬玻璃

金屬玻璃是玻璃家族中的一個新成員，其最早是在金合金的基礎上實現的，並且可以使用現代快速冷卻技術合成。金屬玻璃與傳統玻璃的不同之處是其兼具了固體和液體以及金屬和玻璃之間的特性。它們還以出色的耐腐蝕、耐侵蝕性、卓越的軟磁性和顯著的熱塑成型性而聞名。由於這些特性的獨特組合，金屬玻璃被普遍認為是一種在各種工業應用中具有巨大潛力的材料。此外，金屬玻璃不僅是一種具有獨特性能的新材料，也是一種可用於研究材料科學和凝聚態物理學中面臨的科學問題的模型材料體系。我們對金屬玻璃的研究主要在於建立金屬玻璃的結構模型和揭示結構 - 性能關聯，以及優化大塊金屬玻璃的機械性能。我們研究金屬玻璃的最終目標是促進其在不同工業領域的應用，從而促進中國和香港科研技術進步和經濟增長。

Research Scope 2:
研究範疇 2:

New Generation Precious Nano-materials and Process Design-related Basic Research
新一代貴金屬納米材料及工藝設計相關基礎研究

1

Prestress engineering of precious metals

Coupling thermal mechanics with phase transformation is a classic problem in the field of materials and mechanics. The development of materials science and engineering is producing more and more types of multi-phase materials. These new composite materials and devices present research problems for the present and future. As most of these generalized composite materials experience temperature variations during their manufacturing, the difference in mechanical properties and coefficients of thermal expansion in different phases or materials generates residual stress and strain on a different scale. Phase transformation is also induced in the fabrication process of materials and devices and poses additional challenges for research. Residual stresses have a significant effect on materials, devices, and structures, and the problem of multi-scaled residual stress exists in almost all new materials and new technologies. Given the significant effect of the application of multi-scaled materials, devices, and structures, the control and measurement of residual stresses in the fabrication process and their evolution over the service life is the main concern of the NPMM. In recent years, the NPMM has been improving its measurement technologies, especially the application of optical methods, micro-Raman spectroscopy, and ultrasonic non-destructive testing. To control and optimize residual stresses in materials, computer-aided design is used intensively to simulate the manufacturing process, resolve the coupled thermo-mechanical and phase transformation problems, and develop new manufacturing processes. Based on state-of-the-art computational models and measurement techniques, the residual stresses or prestressed materials will be incorporated in the design and engineering of functional or structural materials to achieve outstanding performance. The NPMM applies the concepts of prestressed engineering to the design and development of precious metallic electronic materials and devices. The NPMM also focuses on the management and optimization of ultra-fine precious metal electronic wires in electronic packaging while improving the technical applications and associated design tools.

1

貴金屬的預應力

熱力學與相變的耦合是材料和力學領域的一個經典問題。隨著材料科學和工程的發展，越來越多類型的多相材料不斷湧現。這些新的複合材料和裝置為現在和將來提出了研究問題。由於這些複合材料在製造過程中大多經歷了溫度變化，不同相或材料的機械性能和熱膨脹係數的差異會造成不同尺度的殘餘應力和應變。在材料和設備的製造過程中誘發的相變，也會給研究帶來更多挑戰。殘餘應力對材料、裝置和結構有重大影響，並且幾乎所有的新材料和新技術都不可避免地存在多尺度的殘餘應力問題。鑒於多尺度材料、裝置和結構應用的重大影響，控制和測量製造過程中產生的殘餘應力及其在使用過程中的變化是貴金屬分中心的主要關注點。近年來，貴金屬分中心一直在改進其測量技術，特別是光學方法、微拉曼光譜和超聲無損檢測。電腦輔助設計被廣泛用於類比製造過程，以實現控制和優化材料中的殘餘應力，解決熱機械和相變的耦合問題，並開發新的製造工藝。基於最先進的計算模型和測量技術，殘餘應力或預應力材料將被納入功能或結構材料的設計和工程中，以達到出色的性能。貴金屬分中心還將預應力工程的概念應用於貴金屬電子材料和設備的設計和開發，並專注於電子封裝中超細貴金屬電子線的控制和優化，同時改進技術應用和相關設計工具。

2

Formation mechanism and properties of precious metallic nano-materials

The generation of nano-grain and amorphous substances is often associated with the coupled thermo-mechanical and phase transformation problems. At certain temperatures and a certain strain rate, crystals can be refined into sub-micro-scale and nano-scale grains. Sometimes, they can also generate new sub-micro-scale and nano-scale characters (twinning, dislocation, stacking fault) by phase transition and other methods. Currently, the important issues and directions in nano-structured materials research on the innovation and invention of fabricating routes for nanocrystals and amorphous substances include the simulation and mechanism analysis for the influences of the fabrication process on the ordered and disordered structure and equilibrium and non-equilibrium state, mechanical properties, and strengthening and toughening mechanisms. The proposed research orientation can be broadly divided into two parts: the toughening of precious metals with layer gradient nanostructures, and the nanotwinning structure forming mechanism and performance design of precious metals with high strength and high ductility.

2

貴金屬納米材料的形成機理和性能

納米晶粒和非晶態物質的產生往往與熱力學和相變的耦合問題有關。在一定的溫度和應變率下，晶體可以被細化為亞微米級和納米級的晶粒。有時，它們還可以通過相變和其他方法產生新的亞微米級和納米級特徵（孿生、位錯、堆積斷層）。目前，納米結構材料研究中關於納米晶體和非晶態物質製造路線的創新和發明的重要問題和方向包括：製造過程對有序和無序結構及平衡和非平衡狀態、力學性能、強化和增韌機制的影響的模擬和機制分析。提出的研究方向大致可分為兩部分：層狀梯度納米結構的貴金屬增韌，以及高強高延性貴金屬的納米絞合結構的形成機制和性能設計。

Research Scope 3:
研究範疇 3:

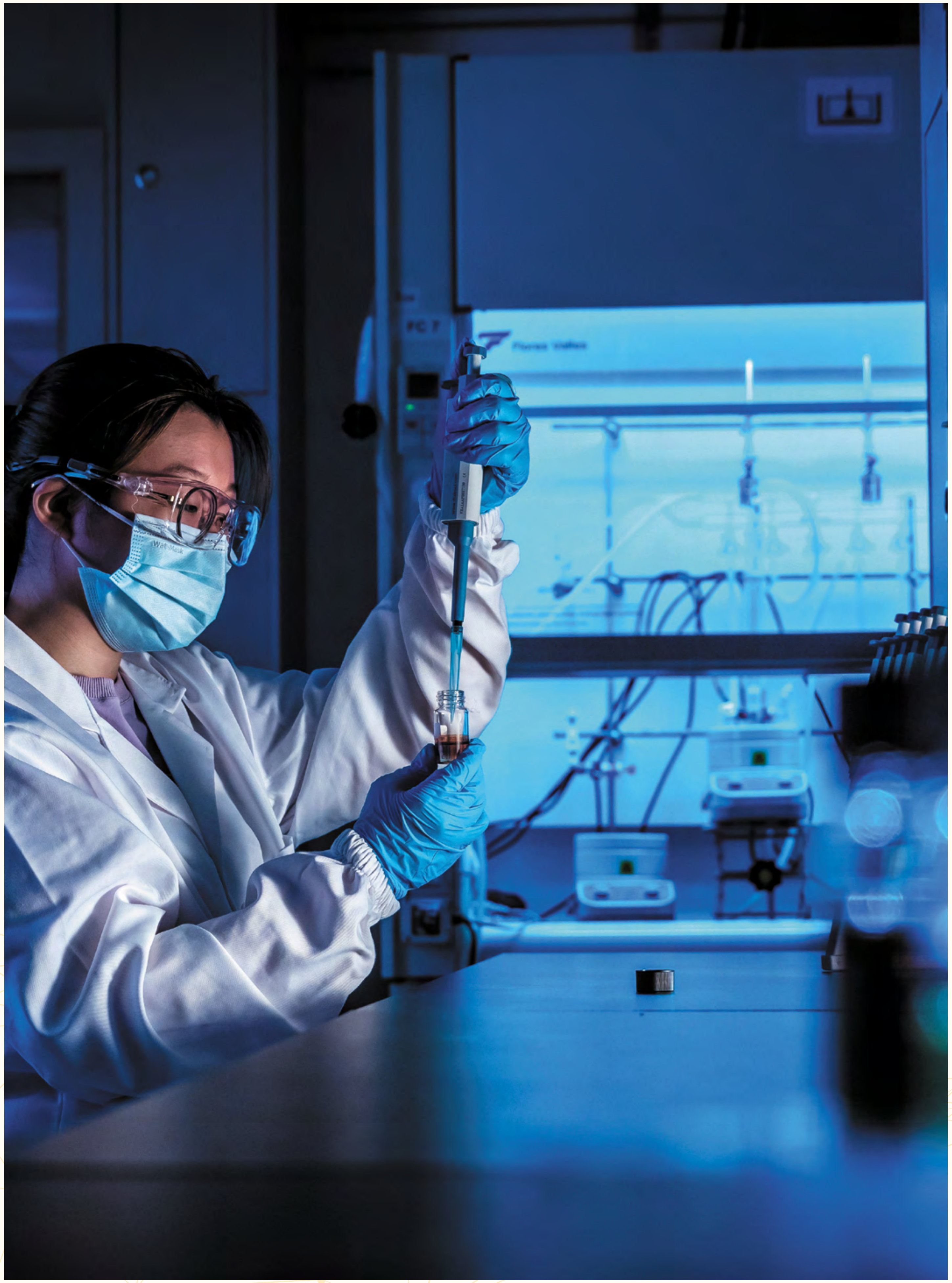
Computer Simulation and Computer-aided Design of Materials
材料的電腦類比和電腦輔助設計

This research direction is to provide guidance in experimental methods and theory. It mainly involves the modeling of functional materials and devices, of materials, mechanics, and numerical methods, and of material physics and mechanical properties under particle radiation.

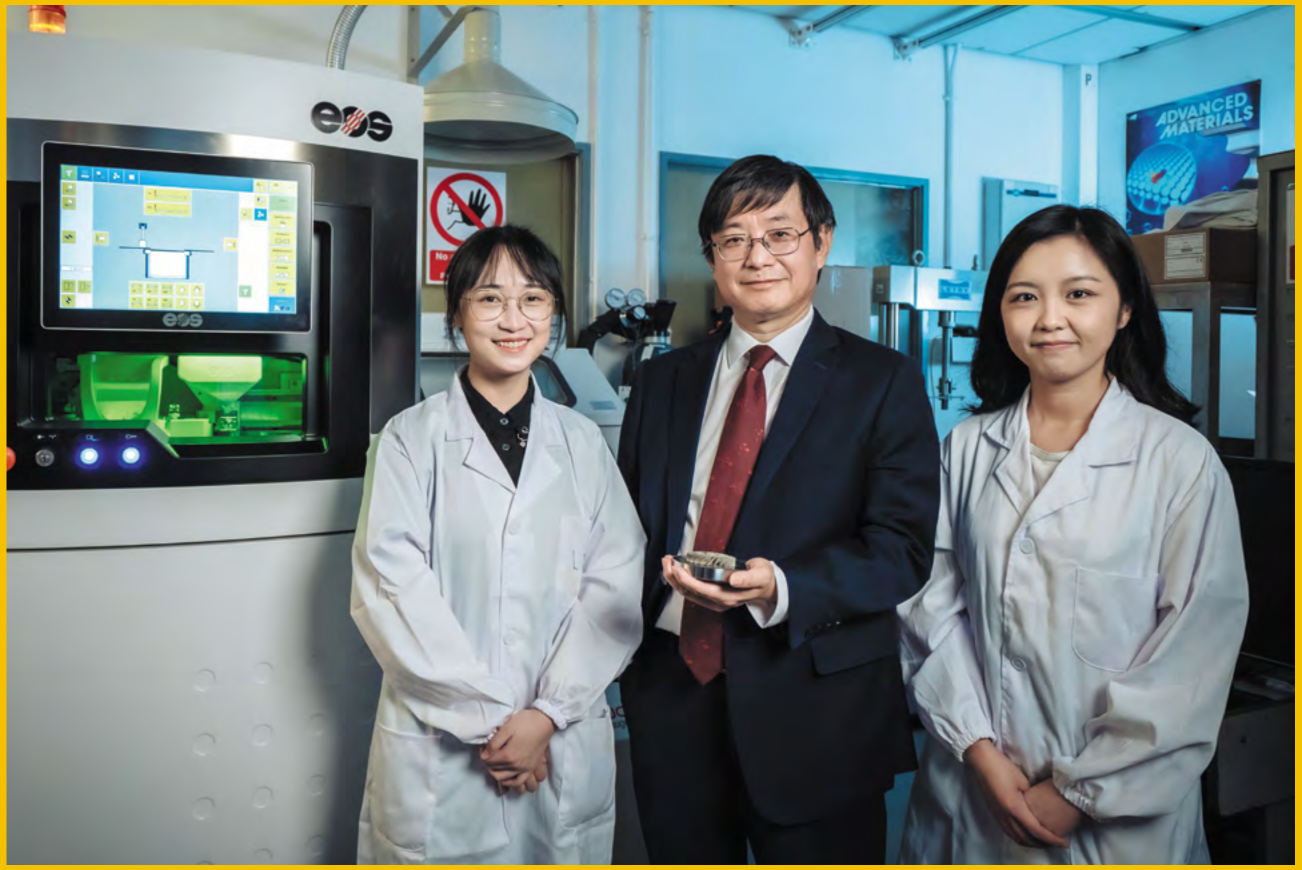
With our research excellence, the number of publications in prestigious international journals attributable to NPMM members jumped from 105 in 2017 to 188 in 2021. This 79% increase confirms the leading position of the NPMM in the fields of advanced metallic materials and nanomechanics. In the past five years, our members have published a total of 772 papers in the world's leading journals, including two papers published in *Nature*, one of which was the cover story, and five published in *Science*. During the last five years, 52 invention patents, including 36 US patents and 11 China patents, were granted to NPMM members, while 51 other patent applications were filed with NPMM members as key inventors.

這個研究方向能夠為實驗方法和理論方面提供指導。主要涉及功能材料和器件的建模，材料、力學和數值方法的建模，以及粒子輻射下的材料物理和機械性能的建模。

貴金屬分中心成員在知名國際期刊表現活躍，發布的文章由 2017 年的 105 份躍升至 2021 年的 188 份，升幅高達 79%，確立我們在先進金屬材料和納米力學的領導地位。過去五年來，成員在世界級頂尖期刊刊登了合共 772 篇論文，有兩篇文章更在《*科學*》上發表，其中一篇更成為封面故事，成員另有五篇文章刊登在《*科學*》。成員在這段期間也取得 52 項發明專利，包括 36 項美國專利和 11 項中國專利，作為主要發明者，成員尚有 51 項專利正在申請中。



Professor Jian LU's Group
呂堅教授研究團隊



1. Surface mechanical attrition treatment (SMAT)

As a symbol of prestige, a beautiful piece of jewelry, or an investment against economic uncertainty, gold has been a highly sought-after valuable metal in consumer market.

Gold is resistant to corrosion and not prone to irritate skin. Most importantly, its high degree of malleability gives rise to a diverse range of designs for personal ornaments, gifts to wedding couples or new born children.

The extreme malleability, ductility, and softness of pure gold make it practically difficult for jewelry applications. Also, to maintain the durability of the surface quality of the jewels made of pure gold is always a difficulty a user needs to face. The addition of alloying elements (other metals) to gold is used to increase the toughness and hardness of the metal. While almost any metal can be alloyed (melted) with gold, only a selected group of metals will not dramatically change the color or make the metal brittle. Also, according to the standard for jewelry, the percentage of alloying elements added will affect the karat of gold and hence the corresponding value. Thus, alloying process alone as the solution of enhancing the hardness of gold seems meeting the bottleneck.

Surface mechanical attrition treatment (SMAT) is one of the promising developed processes to form a nanocrystalline surface layer and refine grains in the subsurface layers, by actuating a number of spherical projectiles to impact the sample surface. This technique has been successfully applied in achieving surface nanocrystallization in a variety of materials including pure iron, pure titanium, pure copper, pure cobalt, aluminum alloy and stainless steel, and currently pure gold. Many experimental results show that the mechanical properties and performance of the materials could be significantly enhanced by means of the SMAT-induced surface nanocrystalline. For gold with the purity of 99.99%, the surface hardness has been successfully increased up 243% (Figure 1). The SMAT is an effective approach to upgrade the global properties of engineering materials without changing of the chemical constitution. As the SMAT is simple, flexible and low-cost, this technique showed its strong potential in the jewelry industries.

To further enhance the hardness of Au-based precious metals, microalloy hardening obtained by the addition of other elements such as Titanium (Ti) or Chromium (Cr) combined with SMAT is employed. The gold alloy's surface hardness has been increased by a factor of five from 28 HV to 150 HV and the total hardening thickness can exceed several hundred micrometers. The relationship between the improved mechanical behaviors and graded nanostructures to the composition of the microalloyed gold has been established (Figure 1). The outcome of this work paves a novel, environmentally friendly and effective way to generate microalloyed precious metals such as gold with high strength and high ductility potentially applicable to jewelry industries.

表面機械研磨處理（SMAT）

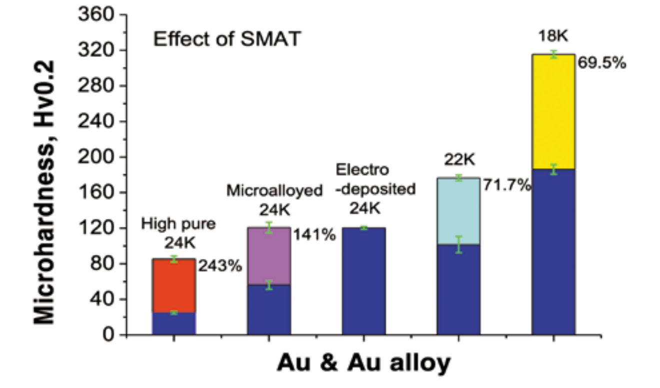
作為聲望的象徵、精美的首飾或對經濟不確定性的投資，黃金一直是消費市場上備受追捧的貴金屬。

黃金有著耐腐蝕，不易刺激皮膚的優點。最重要的是，它的高延展性能成就個人裝飾品、新婚夫婦或新生兒的禮物多樣化的設計。

然而，純金的極強延展性和柔軟性卻某程度上使在首飾應用中變得非常困難。此外，保持純金製成的首飾表面質量的耐用性始終是用家需要面對的難題。在純金中添加其他金屬成為合金是其中一個有效增加金屬的韌性和硬度的方法。雖然幾乎任何金屬都可以與純金合金化（熔化），但只有少部分金屬不會顯著改變顏色或使金屬變脆。此外，根據首飾工業的標準，合金元素的添加百分比會影響黃金的克拉數，從而影響相應的價值。因此，僅用合金化工藝來提高金硬度的解決方案近年一直處於瓶頸的位置。

表面機械研磨處理（SMAT）是近年來開發的一種用於增強合金機械性能的工藝。該工藝主要是指通過驅動許多小球沖擊樣品表面，使樣品表面形成一層納米晶，同時細化樣品的亞表面晶粒，從而提高合金表面的硬度和耐磨損性能。該技術已成功應用於實現多種材料的表面納米化，包括純鐵，純鈦，純銅，純鈷，鋁合金、不銹鋼和純金等。對於純度為 99.99% 的黃金，其表面硬度成功提高了 243%。研究結果表明，通過 SMAT 技術使合金表面形成一層納米晶可以顯著提高合金表面的機械性能。此外，在實施 SMAT 工藝的過程中，合金的化學成分並不會改變，而且該工藝簡單靈活，成本低廉，在工業生產中有廣闊的應用前景。

另外，我們採用了通過輕微添加其他金屬元素（如 Ti 或 Cr）並結合 SMAT 技術獲得的微合金硬化過程來進一步提高合金表面硬度和耐磨性。所獲得的金微合金的表面硬度從 28 HV 提高五倍至 150 HV，硬化厚度可超過數百微米。同時，我們也成功研究了金微合金的機械行為、分級納米結構與微合金成份之間的關係（圖一）。這項工作的成果為生產具有高強度和高延展性的微合金化貴金屬（如黃金）找到了一種新穎、環保且有效的方法，可應於首飾行業。



The effect of SMAT on the surface hardness of 24K, 22K and 18K Gold.

Figure 1 The effect of SMAT on the surface hardness of 24K, 22K and 18K Gold.
圖 1 表面機械研磨處理對 24K、22K、18K 黃金表面硬度的影響。

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2. Supra-nano-dual-phase Nanostructured Materials

Single crystal with ordered atom arrangement in lattice and amorphous solids, where atom arrangement is long-range disordered, are two end-structures for solid. Metals are usually prepared in the form of polycrystals with amorphous grain boundaries. The controls in phase and crystalline defects are conventional methods to improve metal properties, such as the typical metal-strengthening mechanism of precipitate strengthening and dislocation strengthening. In contrast, metallic glass is known for its amorphous structure and high strength (6 GPa for Co-based metallic glass), but deformation softening and strain localization lead to intrinsic brittleness at room temperature. Here, we proposed the super-nano-dual-phase (SNDP) nanostructured metals as a new family of nanostructural metallic materials with structural units within the size range of 1 ~ 10 nm. The properties and mechanical behaviors of the SNDP materials are totally different from the conventional crystalline material and amorphous solids. Despite the great scientific significance, the development and application of SNDP materials face several challenges: a) A scalable strategy to prepare homogeneous SNDP nanostructured films for a variety of metals (Pt, Pd, Ru, Mg, Al, etc.); b) The interaction mechanism of the supra-nanometer sized dual-phases and the effects on properties; c) The exploitations on the high-value application of the SNDP nanostructured materials.

Super-nano-dual-phase nanostructured materials with high strength and high ductility

The development of SNDP glass-crystal materials depends on sophisticated design of alloy composition that has critical glass forming ability, avoiding the formation of fully amorphous or crystalline structures. The preparation process, including power, temperature and pressure, is controlled strictly to tune the growth of super-nano-sized grains. The SNDP material is expected to comprise a crystalline core with a grain size of less than 10 nm and an amorphous shell which resembles a grain boundary zone of several nanometers. When the SNDP material is under strain, the crystalline phase could block the propagation of shear bands emitted from the amorphous shell, suppressing the strain softening of amorphous phase. Moreover, the amorphous shell might impede the gliding of the grains and the motion of dislocations, preventing the occurrence of reverse Hall-Petch effect. Therefore, the unique synergy effects of SNDP structure could contribute to the ideal strength with high ductility.

2. 超納雙相納米材料

具有高度對稱性的晶體和長程無序的非晶體是固體材料的兩種典型結構。金屬的微觀結構通常由晶粒和晶界組成。提高金屬性能的方法一般是調控相組成以及晶體缺陷，例如析出強化和位錯強化等典型金屬強化機制。相比之下，金屬玻璃以其無定形結構和高強度而聞名（例如，Co 基金屬玻璃的強度可達 6 GPa），但金屬玻璃在變形時常常表現出變形軟化和應變局部化的特點，最終導致明顯的室溫脆性。此外，金屬玻璃的各項性能高度依賴于成分的選擇，並且缺乏明確的結構單元（例如晶體的位錯）來調控其性能。在該項研究中，我們提出將超納雙相納米結構金屬（其結構單元的尺寸為 1~10 nm）作為一種新的金屬材料家族。超納雙相金屬材料的性能和力學行為與傳統的金屬材料和無定形固體完全不同。目前，超納雙相金屬材料的開發和應用面臨著幾個挑戰：1）亟需開發一種高效、低成本磁控濺射的工藝，以製備多種金屬（Pt、Pd、Ru、Mg、Al 等）的超納雙相薄膜； 2) 揭示在超納尺度下兩種不同組成相之間的交互作用以及對性能的調控機制； 3) 拓展和開發超納雙相納米金屬材料的應用範圍，應重點挖掘在一些具有高附加值的電催化、微電子器件領域的應用潛力。

超納雙相納米結構化可實現結構材料的高強度和高韌性

超納雙相晶體非晶材料的製備依賴于合金成分和磁控濺射工藝的精細設計。該類初始合金應當具有臨界的玻璃形成能力從而避免形成完全的非晶或晶體結構。在濺射過程中，需要嚴格控制功率、溫度和氣壓等工藝參數以調控超納尺度晶體的生長。超納雙相材料由小於 10 納米的晶粒和非晶殼層構成。在變形過程中，晶體相可以阻礙非晶相中剪切帶的擴展從而抑制非晶的應變軟化行為；而非晶殼層能夠阻礙晶粒的滑移和位錯的遷移，避免反 Hall-Petch 效應的出現。因此，超納雙相結構這種獨特的非晶 - 晶體協同效應可以極大地改善材料的力學性能，使得這種材料在室溫下具備近理想強度並解決尺寸效應問題。

Figure 1 The advanced physical vapor deposition instruments at NPMM, introduced for the development of SNDP materials.
圖 1 NPMM 實驗室用於製備超納雙相納米材料的磁控濺射設備。

Super-nano-dual-phase nanostructuring for efficient noble-metal catalyst

Noble-metal-based electrochemical catalysts with excellent catalytic efficiency and product selectivity are widely utilized in essential energy conversion reactions to convert atmospheric water, carbon dioxide, and nitrogen into high-value energy products (hydrogen, hydrocarbon, and ammonia). However, the large-scale industrial generation of hydrogen, the core of next-generation sustainable energy system, is constrained by the scarcity and expensiveness of platinum group noble-metal-based catalysts and the instability in complex production conditions. SNDP materials with substantial phase interfaces are competitive and promising alternatives to traditional nanomaterial catalysts for hydrogen evolution reaction (HER), possessing commercialization potential and outstanding catalytic performance.

The noble-metal SNDP materials with controllable constituted phases and substantial interfaces provide fertile active sites that primarily enhance the catalytic efficiency. Besides, the SNDP metals composed of crystalline and amorphous phase could avoid the agglomeration problem of typical nanocatalysts. The excellent solution permeability and self-stabilization behavior of the amorphous phase could further improve the electrocatalytic durability. The unique SNDP design offers more modulation degrees on microstructure compared with typical low-dimensional nanocatalysts. We could tailor the concentration of noble metals, nanocrystal orientation and crystal-glass proportion of the SNDP metals to significantly improve the HER activity with ultrahigh catalytic activity, and simultaneously maintain excellent electrochemical stability.

具有高催化特性的超納雙相納米結構催化劑

貴金屬催化劑具有優異的催化效率和產物選擇性，廣泛用於基本的能量轉換反應，將大氣中的水、二氧化碳和氮轉化為高價值的能源產品（氫、碳氫化合物和氨）。然而，作為下一代可持續能源系統核心的氫氣的大規模工業生產受到鉑族貴金屬催化劑稀缺性和高昂成本，以及複雜生產條件的制約。具有大量相界面的超納雙相納米材料是傳統的析氫反應（HER）催化劑的替代品，其具有產業化潛力和出色的催化性能。

貴金屬基的超納雙相納米材料具有可控的相組成和大量的相界面，這種獨特的納米結構特徵可為催化反應提供豐富的活性位點從而顯著地改善催化效率。二維片狀的超納雙相納米催化劑可避免常規納米材料所出現的團聚和奧斯維德熟化效應。非晶相的自穩定行為也可進一步提高超納雙相納米催化劑的穩定性。相比於常規的低維納米催化劑，這種獨特的超納雙相結構可為高性能催化劑的設計提供更多的結構調控自由度。我們計畫設計不同的貴金屬含量、晶體取向和晶體非晶比例以改善不同催化環境下的 HER 催化活性並保持極高的電催化穩定性。

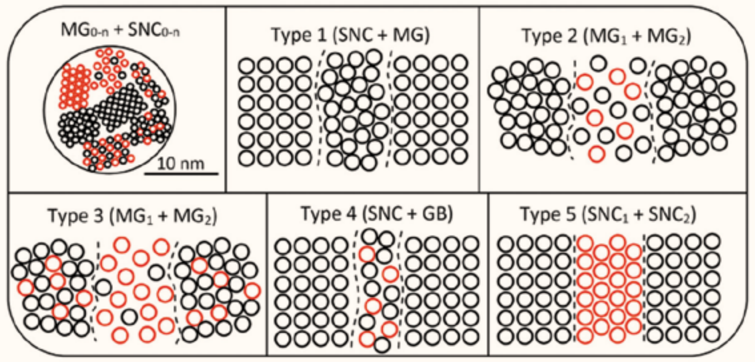

Figure 2 The schematic diagrams of SNDP nanostructures.
圖 2 超納雙相納米結構的示意圖。

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3. Study on Catalytic Properties of Disordered Alloys

The global ecological and environmental crisis has been a primary challenge for the community of shared future for mankind. Water treatment and water electrolysis technologies are of great significance for achieving sustainable utilization of water resources and promoting the development of clean energy. However, the catalytic materials currently employed for water treatment are still suffering several problems, such as low efficiency and reusability, which are scarcely meet the requirements of the modern industry; the catalytic materials employed for high-performance water electrolysis are mainly based on carbon supported noble metals. Their high-cost, poor interface stability, and complex processing method hinder the large-scale application of the water electrolysis technology. Therefore, how to construct active sites to achieve low-cost, high activity and strong stability of catalytic materials is still a bottleneck problem in this field.

Disordered alloys, also referred to as "structurally disordered" amorphous alloys and "chemically disordered" high-entropy alloys (HEAs), have a broad application prospect in the field of water treatment and water electrolysis. NPMM has equipped a well-integrated rapid quenching technology for the purposes of developing a variety of disordered alloys. With respect to the water treatment aspect, our team has developed a microalloying method of amorphous alloys that enable to regulate the atomic coordination configuration for improving catalytic efficiency, and discovered an in-situ self-reconstruction phenomenon for strengthening catalytic stability. It was found that the addition of P element into $Fe_{83}Si_2B_{11}P_3C_1$ amorphous alloy would lead to the formation of Fe-P clusters, which would facilitate electronic delocalization to improve the electron transfer efficiency (Figure 1a). A variety of industrial dyes were completely decolorized within 20 minutes (Figure 1b). Moreover, the in-situ self-reconstruction phenomenon of the amorphous alloy provided a favorable guarantee for active site protection, oxidant adsorption, and excellent ion permeability, which sharply elevate the reusability to more than 40 times. Compared to the crystalline zero-valent iron and Fe_2O_3 catalysts employed in industry, the amorphous alloy has a higher catalytic activity and stability, exhibiting a great potential in future industrial application. [*Adv. Funct. Mater., 2019, 29: 1807857*]. In terms of the water electrolysis, our team developed a structural design strategy by disordered - ordered coupling, and discovered a constructive method of active sites through lattice distortion and elemental synergistic coupling. According to these alloy design concepts, a new high-entropy intermetallic compound (HEI) and a high-entropy amorphous alloy were successfully developed for effective water electrolysis. Firstly, to break through the limitation of single principal component in amorphous alloy design, our team developed a high-entropy amorphous alloy with five principal components. Dealloying method was employed to construct a nanosponge surface morphology (Figure 2a-c). It was found that the high entropy amorphous alloy spontaneously formed nanocrystals surrounding at the nanopores (Figure 2c), while the nanocrystals presenting a certain lattice distortion effect (Figure 2d). Theoretical calculations revealed that lattice distortion effect and synergistic function of the high entropy amorphous alloy could effectively reduce the energy barrier of the hydrogen proton adsorption/desorption, resulting in an excellent hydrogen evolution reaction. At the current density of 10 mA cm^{-2}, the achieved overpotentials were only 32 mV and

3. 無序合金催化功能特性研究

能源短缺、氣候變化、環境污染造成的全球生態危機已經成為人類命運共同體需要面臨的首要挑戰。環境水處理技術與電解水綠氫製備技術對於實現水資源可持續利用，促進清潔能源領域發展具有重要意義。然而，水處理催化材料循環使用次數少、催化效率低以及易引起二次污染等問題難以滿足現代工業需求；高性能電解水催化材料多以碳載體負載貴金屬為主，其價格昂貴、界面穩定性差且工藝複雜等問題制約電解水製氫技術規模化應用。如何構築有效反應活性位點，實現催化材料低成本、高催化活性、高穩定性兼得是該領域瓶頸問題。

無序合金，即“結構無序”非晶合金與“化學無序”高熵合金，作為綠色節能材料在環境水處理與電解水製氫領域應用前景廣闊，是解決上述瓶頸問題理想材料之一。本團隊緊密圍繞無序合金探索製備與催化性能研究，基於貴金屬分中心溶體快淬技術，開發出多種具有優異催化功能特性無序合金。在環境水處理方面，本團隊提出了微合金化成分設計方法，改善了非晶合金原子配位構型提高催化效率，發現了原位自重構現象提升催化穩定性作用機制。採用微合金化成分設計方法開發出 $Fe_{83}Si_2B_{11}P_3C_1$ 非晶合金，P 元素添加導致 Fe-P 團簇形成，表面電子發生離域促使電子轉移效率極大提升（圖 1a），多種工業染料在 20 分鐘內即可實現全部褪色（圖 1b）。此外，該非晶合金在催化過程中會發生原位自重構現象（圖 1c,d），自發形成多層梯度結構，對活性位點保護、氧化劑吸附以及良好離子滲透性提供有利保障。研究表明其循環使用次數可達 40 餘次。同比與工業使用的晶態零價鐵、Fe_2O_3 催化劑，具有更高催化活性與穩定性 [*Adv. Funct. Mater., 2019, 29: 1807857*]。在電解水催化方面，本團隊提出了無序 - 有序耦合結構設計方法，發現了晶格畸變與多元協同耦合作用構築有效活性位點策略，成功開發出新型高熵金屬間化合物與高熵非晶合金。首先，為突破非晶合金單一主族成分在催化領域限制，本團隊將高熵合金多主元成分與非晶合金無序結構相結合，開發出具有等原子比五主元高熵非晶合金。利用脫合金方法成功構築納米海綿狀多孔結構（圖 2a-c）。發現該高熵非晶合金自發形成納米晶並富集在納米孔周圍（圖 2c），同時伴有一定的晶格畸變效應（圖 2d）。理論計算證實，晶格畸變效應與多元協同作用在水分子分解與氫質子吸附 / 脫附過程有效降低析氫反應能壘，導致反應物在合金表面具有優異吸附行為。在 10 mA cm^{-2} 電流密度下，鹼性及酸性析氫過電勢僅為 32 mV 和 62 mV。此外，強固溶效應可大幅提高該合金結構穩定性，使其服役 100 小時仍保持優異催化活性（圖 2e）[*Adv.*

62 mV at the basic and acidic conditions. Moreover, the strong solid solution effect significantly improves the structural stability of the alloy, enabling it to maintain excellent catalytic activity over 100 hours (Figure 2e). [*Adv. Funct. Mater., 2021, 31: 2101586*]. Secondly, we also combined the advantages of synergistic function in HEAs and the site isolation effect in intermetallic compounds to develop a new HEI (Figure 3a-d) that can significantly reduce the adsorption/desorption energy barrier of the water molecules and hydrogen proton during hydrogen evolution reaction. The achieved overpotential (88.2 mV@10 mA cm^{-2}) was comparable with noble-metal-based electrocatalysts, providing a low-cost technical support for high-performance integrated electrode design. [*Adv. Mater., 2020, 32: 2000385*].

Funct. Mater., 2021, 31: 2101586]。其次，本團隊將高熵合金多主元協同作用與金屬間化合物結構位點分離優勢相結合，開發出具有明確原子週期性排列高熵金屬間化合物（圖 3a-d），該合金兼具獨特亞點陣佔位與多元協同效應，可大幅降低水分子與氫質子吸附 / 脫附能壘。由於其與貴金屬催化劑媲美的優異催化活性（88.2 mV@10 mA cm^{-2}）及廉價成本（圖 3e），該合金為高性能一體化電極設計提供了一種技術方案 [*Adv. Mater., 2020, 32: 2000385*]。

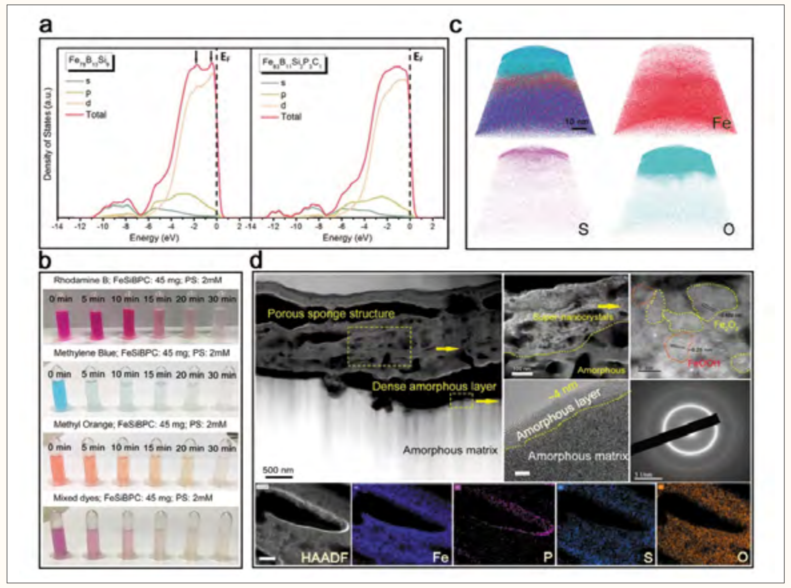


Figure 1(a) Comparison of density of electronic states between $Fe_{83}Si_2B_{11}P_3C_1$ and $Fe_{78}Si_9B_{13}$ amorphous alloy;$Fe_{83}Si_2B_{11}P_3C_1$ amorphous alloy (b) Degradation of industrial dyes after reaction of 20 times (c) composition (d) structural changes

圖 1 (a) $Fe_{83}Si_2B_{11}P_3C_1$ 與 $Fe_{78}Si_9B_{13}$ 非晶合金電子態密度對比；$Fe_{83}Si_2B_{11}P_3C_1$ 非晶合金 (b) 不同染料降解實物圖，反應 20 次後 (c) 成分及 (d) 結構變化

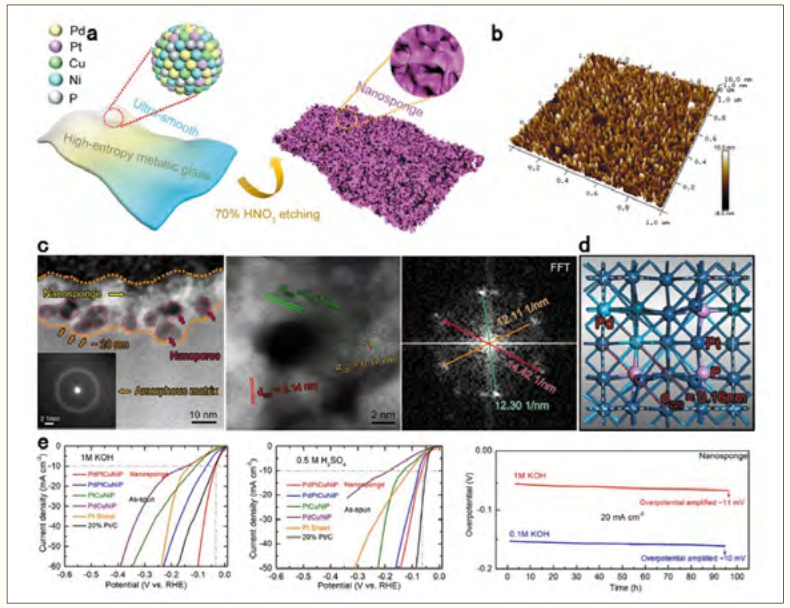


Figure 2 Entropy amorphous alloy (a) Preparation after dealloying (b) Surface topography (c) cross-section structure and nanocrystals (d) Theoretical calculation model of the lattice distortion of nanocrystals (e) Hydrogen evolution behavior and stability

圖 2 高熵非晶合金 (a) 製備示意圖，脫合金後 (b) 表面形貌，(c) 截面結構及納米晶結構，(d) 納米晶晶格畸變理論計算模型 (e) 析氫行為及穩定性

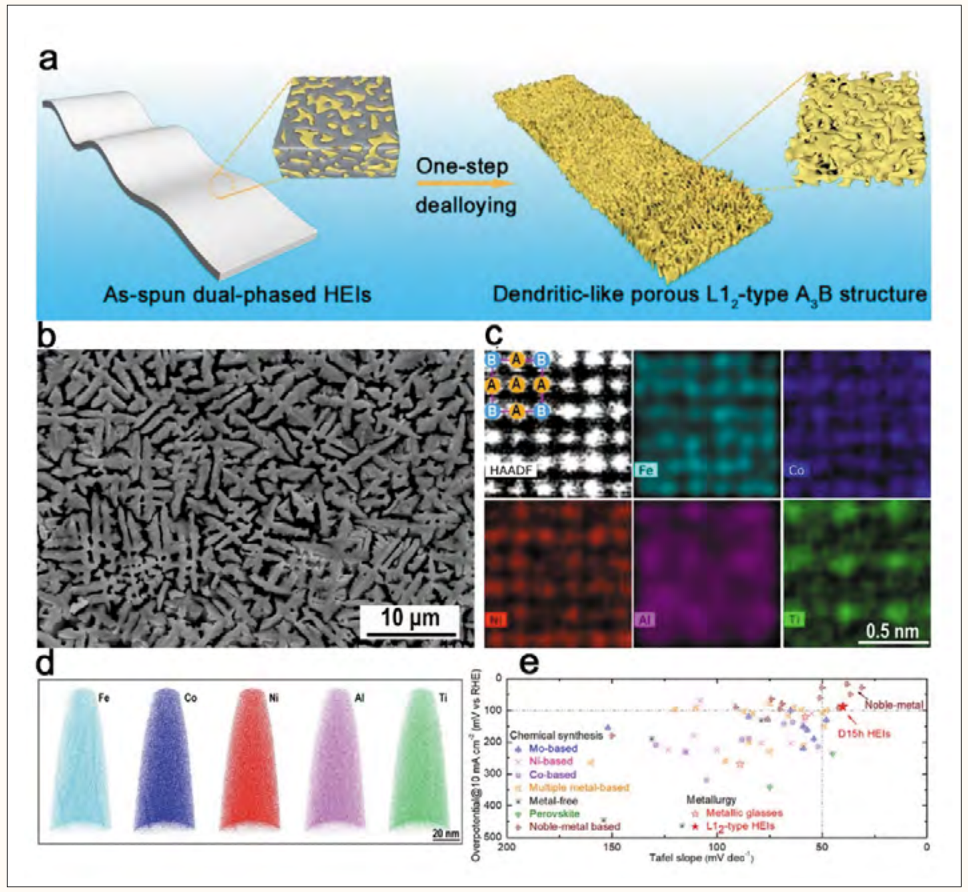


Figure 3 High-entropy intermetallic compound (a) Preparation after dealloying (b) Surface topography (c) Atom distribution (d) Composition analysis (e) Comparison of electrochemical hydrogen evolution

圖 3 高熵金屬間化合物 (a) 製備示意圖，脫合金後 (b) 表面形貌 (c) 原子分佈 (d) 成分分析 (e) 電化學析氫性能對比

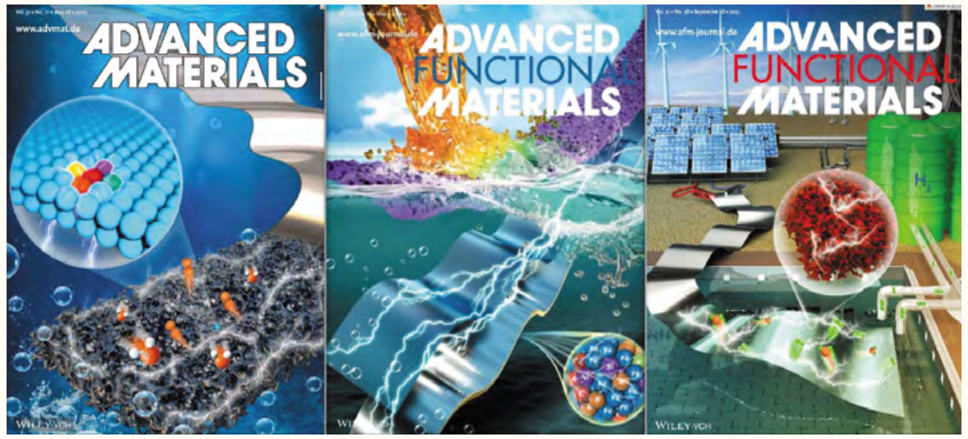


Figure 4 Cover of *Advanced Materials* and *Advanced Functional Materials*

圖 4 學術雜誌封面 *Advanced Materials* 和 *Advanced Functional Materials*

4.Design and structure-activity relationship of "crystal-amorphous" nano-dual-phase aluminum alloy containing noble metal elements based on thermodynamic calculation

Research background:

The structure of a metal material has a significant impact on its performance. Designing and controlling the structure is a crucial way for developing a new generation of catalysts and high-strength, high-toughness alloys. The study found that the prepared dual-phase new composite structure can obtain more excellent catalytic and mechanical properties after combining the crystalline and amorphous phases. According to reports, AlMn alloy catalysts exhibit good hydrogen evolution catalytic activity and mechanical properties. The corresponding Al alloy catalysts are prepared by magnetron sputtering technology and can obtain the Al-based "crystalline-amorphous" nano-dual-phase structure. In addition, the local chemical inhomogeneity, short-range order, and severe lattice distortion exhibited by the multicomponent alloys can further optimize the catalytic activity during the hydrogen evolution reaction. It can expect that by adding noble metal elements Ru or Pd to AlMn alloy and using the above advantages of nano-dual-phase structure and multicomponent alloy compositions, a new type of "crystalline-amorphous" nano-dual-phase AlMnRu high-performance alloy catalyst is prepared. It will play an important role in promoting the development of a new generation of hydrogen evolution catalysts and high-strength, high-toughness alloys.

In the process of preparing thin-film materials by magnetron sputtering, the system is far from the equilibrium state, and the metastable phase is easy to obtain. Combining calculation methods such as CALculation of PHAse Diagrams (CALPHAD) with experiments can construct the metastable phase formation diagram of the system and study the influence of chemical composition and preparation process on the material structure. Then the performance of materials under different structures can be evaluated. For example, the ternary aluminum-based metastable phase formation diagram constructed according to CALPHAD and critical experiments is used to describe the phase formation of AlTiN, a hard coating material commonly used in industrial production. Similarly, the construction of the thermodynamic database of the AlMnRu thin-film system will help understand the effect of chemical composition in the alloy on the phase formation and then provide theoretical guidance for the development of high-performance Al-based nano-dual-phase alloys. If only consider traditional experimental methods, it will take more time and resources to achieve the above purposes. Hence, this project envisages expanding the existing research methods, combining theoretical calculation, experimental preparation, electrochemical testing, and advanced characterization to efficiently construct the "component-structure-property" structure-activity relationship of the $(AlMn)_{1-x}Ru_x$ system. Finally, high-performance AlMn-based nano-dual-phase alloys are prepared.

4. 基於熱力學計算的含貴金屬元素“晶體 - 非晶”納米雙相鋁合金的設計與構效關係

研究背景：

金屬材料的結構對其性能產生重要影響，通過對結構進行設計與調控，是開發新一代催化劑與高強高韌合金的關鍵途徑。研究發現，將晶體相與非晶相進行結合，製備兩相的新型複合結構可以獲得更加優異的催化與力學性能。據報導，AlMn 系合金催化劑表現出良好的析氫催化活性與力學性能。通過磁控濺射技術製備相應的 Al 合金催化劑，可以得到 Al 基“晶體 - 非晶”納米雙相結構。此外，多元合金表現出的局部化學不均勻性、短程有序性和嚴重晶格畸變，可以進一步優化析氫反應過程中的催化活性。可以預期，向 AlMn 合金中加入貴金屬成分 Ru 或 Pd，並利用納米雙相結構和多元合金成分的上述優點，製備新型的“晶體 - 非晶”納米雙相 AlMnRu 高性能合金催化劑，將對新一代析氫催化劑與高強高韌合金的發展起到重要的推動作用。

在磁控濺射製備薄膜材料的過程中，系統遠離平衡態，容易獲得亞穩相。通過將 CALPHAD 等計算手段與實驗相結合，構築體系的亞穩相形成圖，可以研究化學成分與製備工藝對材料結構的影響，進而評價不同結構下材料的性能。比如根據 CALPHAD 與關鍵實驗構建的三元鋁基亞穩相形成圖，被用來描述工業生產中常用的硬質塗層材料 AlTiN 的相形成情況。同樣地，構建 AlMnRu 薄膜體系的熱力學數據庫，有助於理解該合金中化學成分對相形成的影響，進而為高性能鋁基納米雙相合金的研製提供理論指導。如果僅考慮傳統的實驗手段，達成上述目的將花費更多的時間與資源。因此，本項目設想拓展現有的研究方法，將理論計算、實驗製備、電化學測試與先進表徵相結合，高效率地構築 $(AlMn)_{1-x}Ru_x$ 體系的“成分 - 結構 - 性能”構效關係，最終製備出高性能 AlMn 基納米雙相合金。

Prediction of composition range of AlMnRu "crystalline-amorphous" dual-phase formation based on thermodynamic calculations (Work 1)

The binary phase diagram and thermodynamic data in the AlMnRu system already available in the literature can be used as the basis for calculating the CALPHAD phase diagram of the ternary system. Based on the CALPHAD thermodynamic calculation method, coupled with the first-principles calculations and essential experimental methods, I applied the computational simulation to the construction of the phase formation model of the aluminum-based material system. For example, the thermodynamic database and metastable phase formation diagram of ternary aluminum-based thin-film materials AlVN and AlTiN systems are constructed *[Acta Mater., 2020, 196: 313-324]*, and the thermodynamic calculation results were highly consistent with the experimental data, which laid a theoretical foundation for the development of this project. Based on the above work, I constructed a thermodynamic database of $(AlMn)_{1-x}Ru_x$, and initially obtained the composition prediction range of the "crystal-amorphous" dual-phase formation, as shown in Figure 1.

基於熱力學計算的 AlMnRu“晶體 - 非晶”雙相形成的成分範圍預測（工作 1）

文獻中已有的 AlMnRu 體系中的二元相圖和熱力學數據，可作為三元體系 CALPHAD 相圖計算的基礎。基於 CALPHAD 熱力學計算方法，並與第一性原理計算和關鍵實驗方法相耦合，本人將計算模擬應用到鋁基材料體系的相形成模型的構建中。例如對三元鋁基薄膜材料 AlVN 和 AlTiN 體系的熱力學數據庫與亞穩相形成圖進行構建 *【Acta Mater., 2020, 196: 313-324】*，其熱力學計算結果與試驗數據高度吻合，為本項目的開展奠定了理論基礎。基於以上工作基礎，本人構建了 $(AlMn)_{1-x}Ru_x$ 的熱力學數據庫，並初步得到了“晶體 - 非晶”雙相形成的成分預測範圍，如圖 1。

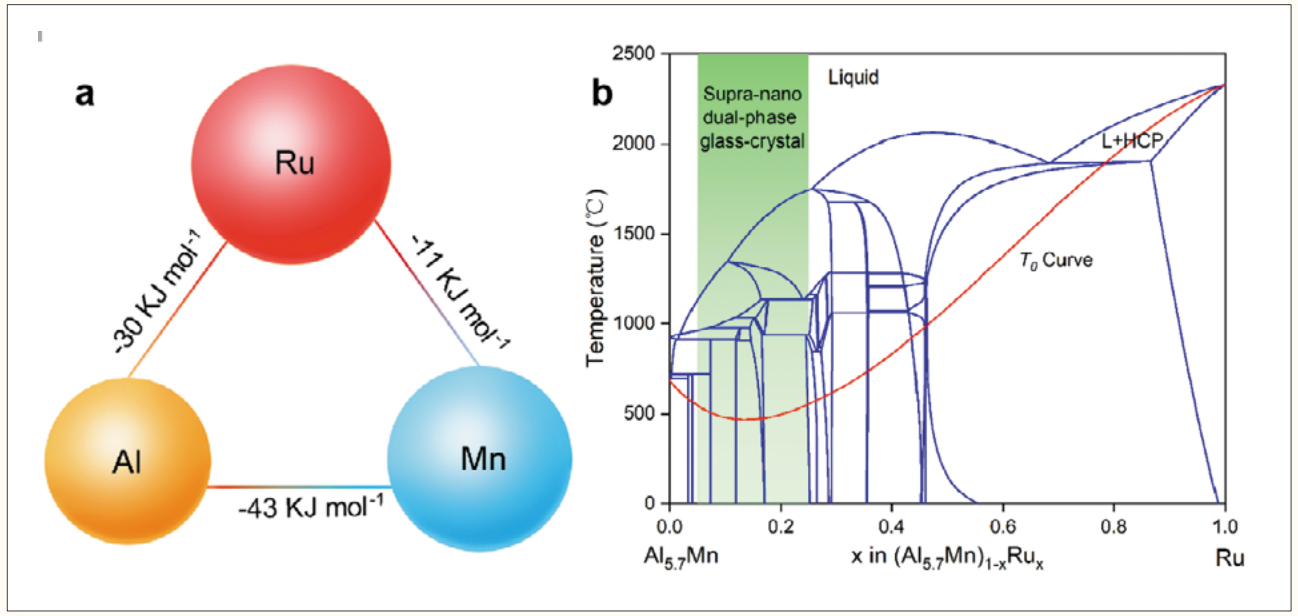


Figure 1 Thermodynamics-guided design of a crystal-glass nano-dual-phase Al-Mn-Ru system. a, Heat of mixing values between Al-Mn, Al-Ru, and Ru-Mn. The size of the sphere represents the relative sizes of Al, Mn, and Ru atoms. b, CALPHAD-calculated $(Al10Mn1)_{1-x}Ru_x$ vertical section and T_0 curve for the HCP (thin red line) formation of the ternary system. The calculated T_0 curve reaches a minimum value at ~13 at.% Ru, revealing a weaker glass formation ability than representative glass-forming systems. The highlighted green region corresponds to the formation conditions for a crystal-glass nano-dual-phase structure.
圖 1 水晶玻璃納米雙相 Al-Mn-Ru 系統的熱力學引導設計。 a，Al-Mn、Al-Ru 和 Ru-Mn 之間的混合熱值。球體的大小代表 Al、Mn 、Ru 原子的相對大小；b, CALPHAD 計算的（$Al_{10}Mn_1$）$_{1-x}Ru_x$ 垂直截面和 T_0 曲線，用於三元體系的 HCP（細紅線）形成。計算得到的 T_0 曲線表明在 ~13 at.% Ru 處達到最小值，顯示出比典型的玻璃成型系統更弱的玻璃成型能力。突出顯示的綠色區域對應於水晶玻璃納米雙相結構的形成條件。

Development of high-performance AlMnRu nanocatalysts for dual-phase hydrogen evolution (Work 2)

Renewable clean energy technologies are rapidly developing, and abundant clean fuels, such as hydrogen, are expected to replace fossil fuels in the future. Electrocatalytic water splitting is a reliable hydrogen-production technique. Pt-based catalysts are widely used in hydrogen evolution reactions; however, their applications are restricted owing to a cost-efficiency trade-off. Therefore, developing low-cost and reliable electrocatalysts is crucial. Here, we present a new thermodynamics-based design strategy to synthesize an AlMnRu metal catalyst with a crystal-glass nano-dual-phase structure via combinatorial magnetron co-sputtering. The developed electrocatalyst is composed of ~2 nm medium-entropy nanocrystals surrounded by ~2 nm amorphous regions (Figure 2).

The catalyst exhibits exceptional performance, similar to that of single-atom catalysts and better than that of nanocluster-based catalysts with little noble metal loading (Figure 3). The large differences in composition and bonding structure between the crystal and glass phases considerably reduce the energy barrier for hydrogen evolution, enhancing H_2O/H* adsorption/desorption. Considering costs, we use Al rather than a noble metal as the catalyst principal element, and Ru, which is cheaper than Pt, as the noble metal component. The new design strategy, based on the composition-structure-property relationship, and the one-step co-sputtering synthesis process provides an efficient route for the development of electrocatalysts for large-scale hydrogen production. Moreover, the superior hydrogen reaction evolution from the synergistic effect of the nano-dual-phase structure is expected to guide the development of high performance catalysts in other alloy systems.

高性能 AlMnRu 納米雙相析氫催化劑的開發（工作 2）

可再生清潔能源技術正在迅速發展，氫等豐富的清潔燃料有望在未來取代化石燃料。電催化水分解是一種可靠的製氫技術。 Pt 基催化劑廣泛用於析氫反應；然而，由於成本效益的權衡，它們的應用受到限制。因此，開發低成本且可靠的電催化劑至關重要。在這裡，我們提出了一種新的基於熱力學的設計策略，通過組合磁控濺射合成具有水晶玻璃納米雙相結構的 AlMnRu 金屬催化劑。研發的電催化劑由 ~2 nm 中熵納米晶體組成，其周圍有 ~2 nm 無定形區域 （圖 2）。

該催化劑表現出優異的性能，與單原子催化劑相似，優於幾乎沒有貴金屬負載的納米簇基催化劑的效果（圖 3）。晶相和玻璃相之間的組成和鍵合結構的巨大差異顯著降低了析氫的能壘，增強了 H_2O/H* 吸附 / 解吸。考慮到成本，我們使用 Al 而不是貴金屬作為催化劑主元素，並且使用比 Pt 便宜的 Ru 作為貴金屬成分。基於成分 - 結構 - 性能關係的新設計策略和 one-step co-sputtering 合成工藝為開髮用於大規模製氫的電催化劑提供了一條有效途徑。此外，納米雙相結構的協同效應帶來的更強的析氫反應有望指導其他合金體系中高性能催化劑的開發。

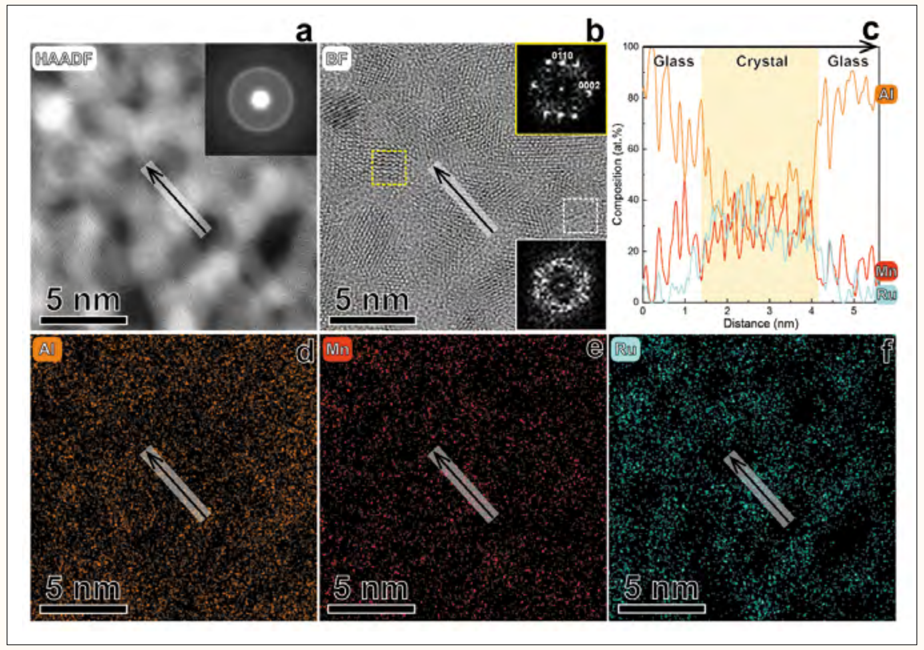


Figure 2 Structure and composition of the medium-entropy crystal-glass nano-dual-phase Al-based catalyst. a, High-angle annular dark-field (HAADF) image probed from a cross-sectional sample. The z-contrast reflects the atomic weight difference (i.e., Al-enriched amorphous regions are darker). The inset shows a typical selected-area electron diffraction pattern with a halo ring feature, attributed to the extremely small-size nanocrystals and amorphous phase. b, BF-STEM image probed from the same region. Fast Fourier transform image (upper right inset) of the crystalline region (yellow dashed square) of an HCP pattern from the <2-1-1-0> zone axis. By contrast, the Fast Fourier transform image (lower right inset) of the cyan dashed square region shows a diffused pattern, indicating an amorphous structure. c, 1D compositional profile, generated from (d-f) near-atomic-resolution energy-dispersive X-ray spectrometry mapping. The arrows in a-b and d-f indicate the investigated region of the 1D compositional profile.
圖 2 中熵水晶玻璃納米雙相鋁基催化劑的結構和組成。 a，從橫截面樣本探測到的 HAADF 圖像。 Z 對比度映了原子量的差異（即富鋁的非晶區域更暗）。插圖顯示了具有 halo Ring feature 的典型選區電子衍射圖，歸因於極小尺寸的納米晶體和非晶相；b，從同一區域探測到的 BF-STEM 圖像。來自 <2-1-1-0> 區域軸的 HCP 圖案的結晶區域（黃色虛線正方形）的快速傅里葉變換圖像（右上插圖）。相比之下，青色虛線方形區域的快速傅里葉變換圖像（右下插圖）顯示出擴散圖案，表明是無定形結構；c，一維成分剖面，由 (d-f) 近原子分辨率能量色散 X 射線光譜映射生成。 a-b 和 d-f 中的箭頭表示一維組成剖面的研究區域。

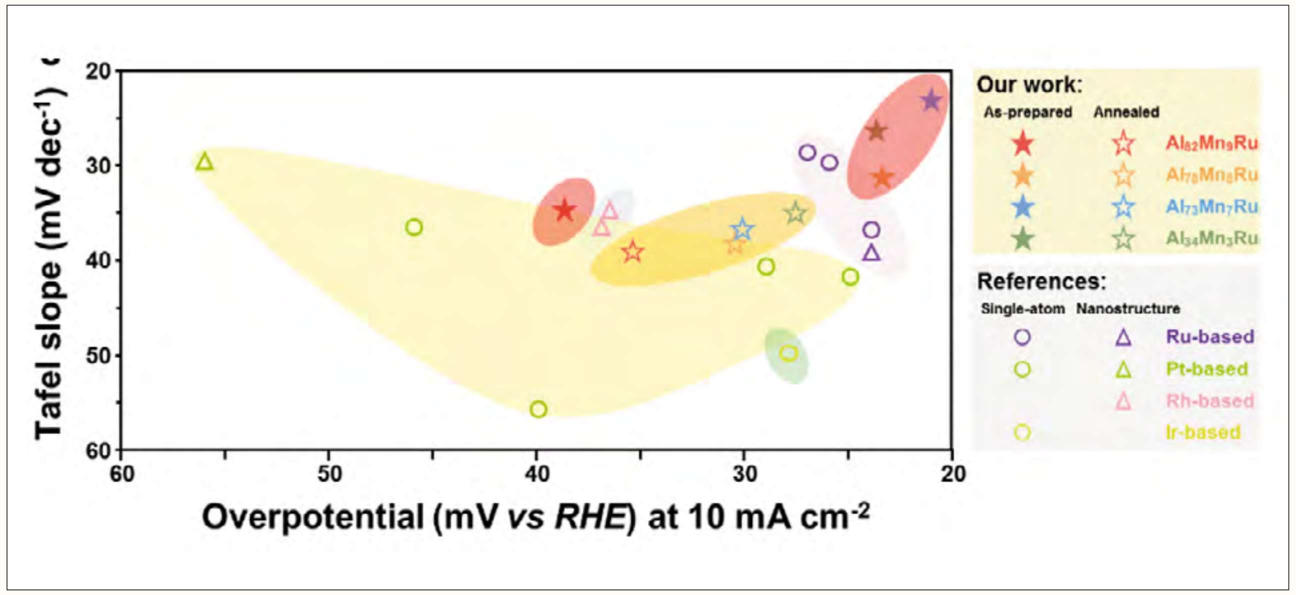


Figure 3 Electrocatalytic performance of as-received samples in 1 M KOH solution. HER catalytic performance comparison with some previously reported noble metal-based catalysts.
圖 3 製備的樣品 1 Mol KOH 溶液中的電催化性能。 HER 催化性能與一些先前報導的貴金屬基催化劑的比較。

Innovations

(1) Establish the phase equilibrium relationship of AlMnRu alloy through thermodynamic calculation, predict the composition range of "crystal-amorphous" dual-phase formation, and then obtain AlMnRu "crystal-amorphous" nano-dual-phase alloy by experimental means. It is the research idea and research feature of this year's work.

(2) AlMnRu "crystal-amorphous" nano-dual-phase alloys is prepared by combined magnetron sputtering experiments. It is found that the hydrogen evolution catalytic performance of AlMnRu exceeds that of most noble metal catalysts represented by Pt/C, which is an important discovery of this year's work. It is of great significance for the design and process optimization of high-performance alloy catalysts in the future.

(3) This project intends to establish the structure-activity relationship between the AlMnRu "amorphous-crystalline" nano-dual-phase structure and the catalytic performance of hydrogen evolution. And reveal the efficient hydrogen evolution catalysis mechanism under the synergistic effect of nano-dual-phase, which is expected to become an important theoretical innovation of this year's work.

創新點

（1）通過熱力學計算，建立 AlMnRu 合金的相平衡關係，預測“晶體 - 非晶”雙相形成的成分範圍，再通過實驗手段製得 AlMnRu“晶體 - 非晶”納米雙相合金，這是本年度工作的研究思路與研究特色。

（2）通過組合磁控濺射實驗制得 AlMnRu“晶體 - 非晶”納米雙相合金，並發現 AlMnRu 的析氫催化性能超過以 Pt/C 為代表的多數貴金屬催化劑，這是本年度工作的重要發現。其對未來高性能合金催化劑與高強高韌鋁合金的設計與工藝優化具有重要意義。

（3）本項目擬建立 AlMnRu“非晶 - 晶體”納米雙相結構與析氫催化性能之間的構效關係，並揭示納米雙相協同作用下的高效析氫催化作用機理，這有望成為本年度工作的重要理論創新。

Professor Chain Tsuan LIU’s Group
劉錦川教授研究團隊

1. Superlattice Alloy with Disordered Interfacial Nanolayers

Superlattice alloys have an atomically close-packed and ordered structure. The strong chemical binding and low atomic mobility make them very attractive to high-temperature structural applications in a range of engineering fields such as aerospace, automotive, gas turbine engine, and many other industries. However, the highly ordered crystalline structure makes them brittle. The research team led by Professor Liu has discovered a new approach via fabricating multicomponent superlattice alloys with disordered interfacial nanolayers to resolve this dilemma. The findings have been published in the prestigious scientific journal *Science* under the title “Ultra high-strength and ductile superlattice alloys with nanoscale disordered interfaces” [1].

According to conventional wisdom, adding trace amounts (0.1 to 0.5 atomic percent (at. %)) of boron substantially improves tensile ductility by increasing grain-boundary cohesion, but when more than 0.5 at. % of boron were added, this traditional approach would not work well. However, the team came up with the idea to add excessive amounts of boron to the multi-component alloys, and the results were to their surprise. By increasing the boron concentration to 2.5 at. %, the synthesized alloy has an ultra-thin disordered interfacial nanolayer along the grain boundary. The ultra-thin layer contains multiple principal elements with disordered atomic structures that prevent brittle intergranular fractures. The general structure of superlattice alloys is made of individual crystalline areas known as “grains”. The brittleness in these alloys is generally ascribed to cracking along their grain boundaries during tensile deformation. Such superlattice materials have ultra-high strengths of 1.6 gigapascals with tensile ductilities of 25% at room temperature, which makes them a lot more ductile than expected.

In addition, the team also discovered that the increase in grain size was negligible even after 120 hours of heating at temperatures of 1050°C. Most traditional structural materials suffer from thermally driven structural instability because of rapid grain growth at high temperatures. As a result, the strength of these materials decreases quickly, severely limiting their applications. We believe that the nanolayer is pivotal in suppressing growth in grain size and maintaining its strength at high temperatures. The thermal stability of the disordered nanolayer will render this type of alloy suitable for high-temperature structural applications.

The discovery of this disordered nanolayer along the grain boundaries in the alloy will positively impact the development of high-strength materials in the future and may open a pathway for further optimization of alloy properties.

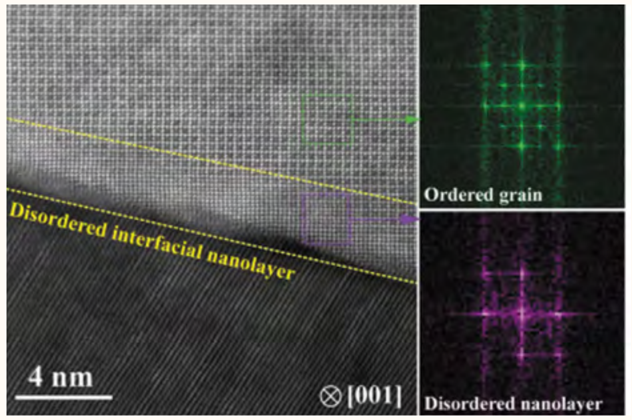
1. 具有無序界面納米層的超晶格合金

超晶格合金具有原子緊密排列的有序結構。強大的化學結合力和低原子遷移率使其在航空航天、汽車、燃氣渦輪發動機和許多其他行業等一系列工程領域的高溫結構應用非常有吸引力。然而，高度有序的晶體結構使它們容易變脆。劉教授領導的研究團隊發現了一種新方法，即通過製造具有無序界面納米層的多組分超晶格合金來解決這一難題。該研究結果已發表在著名的科學雜誌*《科學》*上，標題為“具有納米級無序界面的超高強度和延展性超晶格合金”[1]。

根據傳統觀點，添加痕量（0.1 至 0.5 原子百分比）的硼可通過增加晶界聚合力來顯著提高拉伸延展性，但當添加了超過 0.5 原子百分比的硼時，這種傳統方法效果不佳。該團隊提出了在多組分合金中添加過量硼的想法，實驗結果令人感到驚訝。通過將硼濃度增加到 2.5 原子百分比時，合金沿晶界形成超薄無序界面納米層。超薄層包含多種具有無序原子結構的元素，可防止脆性沿晶斷裂。超晶格合金的一般結構由稱為“晶粒”的單個結晶區組成，這些合金的脆性通常歸因於在拉伸變形過程中沿晶界開裂。這種具有無序界面納米層的超晶格材料具有 1.6 吉帕的超高強度，室溫下的拉伸延展性為 25%，這比預期的要高得多。

此外，該團隊還發現，即使在 1050°C 的溫度下加熱 120 小時後，晶粒尺寸的增加也可以忽略不計。大多數傳統結構材料由於高溫下的快速晶粒生長而遭受熱驅動帶來的結構不穩定性。這會使得這些材料的強度迅速下降，嚴重限制了它們的應用。納米層對於抑制晶粒尺寸的增長和在高溫下保持其強度至關重要，這將使這種合金非常適用於高溫結構應用。

這種沿合金晶界的無序納米層的發現將對未來高強度材料的發展產生積極影響，並為進一步優化合金性能開闢一條新途徑。



The ultra-thin disordered layer at the grain boundaries is about 5 nm thick [1].
晶界處的超薄無序層厚度約為 5 納米 [1]。

2. Nanoparticle-strength High-Entropy Alloys with Unprecedented Mechanical Properties

The research team led by Professor Chain Tsuan LIU has worked out a novel strategy for developing new super alloys that are extremely strong yet ductile and flexible. The breakthrough solution addresses a daunting, decades-long dilemma in materials science. The new alloys were developed based on multiple-principal-element alloys, which are also referred to as high-entropy alloys (HEAs). These are new materials constructed with equiatomic or nearly equiatomic percentages of five or more elements. Most conventional alloys are made of one or two major elements, such as nickel and iron. The team found that adding aluminum and titanium to form massive complex nanoparticles resulted in a significant increase in both the strength and ductility of the alloys. Previously, the stronger an alloy was, the less ductile and tough it was, meaning stronger alloys tended to fracture when deformed or stretched. This new alloy is five times stronger than iron-cobalt-nickel based alloys and is 1.5 times more ductile. The cutting-edge research was published in the latest issue of the prestigious journal *Science*, in an article titled "Multicomponent intermetallic nanoparticles and superb mechanical behaviours of complex alloys" [2].

The deformation of high-strength alloys can easily cause necking fracture (localized deformation), but the research team found that adding complex nanoparticles consisting of nickel, cobalt, iron, titanium, and aluminium atoms enables extended uniform deformation. Replacing some of the nickel components with iron and cobalt atoms helped to improve the ductility of the new alloy, and replacing some of the aluminium with titanium helped to reduce the embrittlement effect caused by ambient moisture in the air.

The research team believed the new alloy developed with this novel strategy would perform well in temperatures ranging from -200°C to 1000°C, thus providing a good base for developing new cryogenic devices, as well as aircraft and high-temperature systems, such as aeronautical engineering applications.

The new high-entropy alloy is extremely strong, yet ductile and flexible [2].
新的高熵合金非常堅固，且具有良好的延展性和柔韌性 [2]。

2. 具有無序界面納米層的超晶格合金

劉錦川教授領導的研究團隊提出了一種新的策略來開發新的超級合金，這種超級合金具有極高的強度、延展性和柔韌性。大多數傳統合金由一種或兩種主要元素製成，例如鎳和鐵。這種新合金是基於多主元素合金開發的，也稱為高熵合金，是由等原子或接近等原子百分比的五種或更多元素構成的新材料。研究團隊發現，添加鋁和鈦以形成大量成分複雜的納米顆粒會顯著提高合金的強度和延展性。通常來説，合金越堅固，其延展性和韌性就越差，這意味著強度更高的合金在變形或拉伸時往往會更早斷裂。這種新合金的強度是鐵鈷鎳基合金的五倍，延展性是其 1.5 倍。這項前沿研究發表在最新一期著名的*《科學》*雜誌上，題為“多組分金屬間化合物納米粒子和復雜合金的卓越機械行為”[2]。

高強度合金的變形很容易引起頸縮斷裂（局部變形），但研究團隊發現，添加由鎳、鈷、鐵、鈦和鋁原子組成的複雜納米顆粒，可以延長均勻變形。用鐵和鈷原子代替一些鎳成分有助於提高新合金的延展性，用鈦代替一些鋁有助於降低空氣中的環境水分引起的脆化現象。

研究團隊認為，採用這種新策略開發的新合金將在 -200°C 至 1000°C 的溫度範圍內都有良好機械性能，從而為開發新的低溫裝置以及飛機和高溫裝置提供新思路。

3. Additive Manufacturing of Heterogeneous Ti-Based Alloy

Professor Liu's team recently unveiled the promising possibility of utilizing additive manufacturing to design unique heterogeneous alloys with novel microstructure and supreme properties, which opens a new area in manufacturing for the design of titanium (Ti) alloys that are unachievable by conventional manufacturing methods and that hold great promise for a wide variety of structural applications. His paper was published recently in the prestigious scientific journal *Science*, titled "In situ design of advanced titanium alloy with concentration modulations by additive manufacturing" [3].

Most people consider 3D printing as a revolutionary technology that can produce machine parts with complex shapes within just one step; however, the research team unveiled that it has important potential in designing materials rather than simply designing geometries.

Metallurgists think that a lack of uniformity in alloy components is undesirable because it leads to harmful properties, such as brittleness. One of the critical issues in the additive manufacturing process is how to eliminate this inhomogeneity during fast cooling. His team found that a certain degree of heterogeneity in the components can actually produce unique and heterogeneous microstructures that enhance the alloy's properties. The proposed method involves the melting and mixing of two different alloys, i.e., titanium alloy powders and stainless steel powders, using a focused laser beam. By controlling parameters like the laser power and its scanning speed during the 3D printing process, the team successfully created the non-uniform composition of the elements in the new alloy in a controllable way.

In addition to the use of additive manufacturing, the composition of the two powder mixture is another key to creating unprecedented lava-like microstructures with a high metastability in the new alloy. These unique microstructures give rise to the supreme mechanical properties, allowing the alloy to be very strong but ductile, and also in light weight.

While stainless steel is generally 7.9 grams per cubic centimeter, the new alloy is only 4.5 grams per cubic centimeter, resulting in around 40% lighter weight. The titanium alloy with lava-like microstructures exhibited a high tensile strength of ~1.3 gigapascals with a uniform elongation of about 9%. It also had an excellent work-hardening capacity of over 300 megapascals, which guarantees a large safety margin prior to fracture and is useful in structural applications. These excellent properties are promising for structural applications in various scenarios, such as the aerospace, automotive, chemical, and medical industries.

3. 異質鈦基合金的增材製造

劉教授的團隊最近提出了利用增材製造設計具有新穎微觀結構和卓越性能的獨特異質合金的新思路，這為鈦合金的設計開闢了一個新的製造領域。這是傳統製造方法所無法實現的，並且具有廣泛的結構應用前景。該論文最近發表在著名的科學雜誌*《科學》*上，題為“通過增材製造進行濃度調製的先進鈦合金的原位設計”[3]。

大多數人認為 3D 列印是一項革命性的技術，只需一步即可生產出形狀複雜的機器零件；然而，研究團隊透露，不止於簡單地列印幾何形狀，它在設計材料方面也具有重要潛力。

冶金學家通常認為合金如果缺乏均勻性會導致脆性。增材製造過程中的關鍵問題之一是如何在快速冷卻過程中消除這種不均勻性。他的團隊發現，組件中具有一定程度的異質性實際上可以產生獨特且異質的微觀結構，從而增強合金的性能。所提出的方法是使用聚焦雷射光束熔化和混合兩種不同的合金，即鈦合金粉末和不銹鋼粉末。通過在 3D 列印過程中控制鐳射功率及其掃描速度等參數，該團隊成功地以可控的方式列印了新型非均勻成分的合金。

除了使用增材製造之外，兩種粉末混合物的成分是在新合金中創造具有高亞穩性的前所未有的熔岩狀微結構的另一個關鍵。這些獨特的微觀結構使合金非常堅固且具有延展性。

雖然不銹鋼的重量通常為每立方釐米 7.9 克，但新合金僅為每立方釐米 4.5 克，重量減輕了約 40%。具有熔岩狀微觀結構的鈦合金表現出約 1.3 吉帕斯卡的高抗拉強度和約 9% 的均勻伸長率。它還具有超過 300 兆帕的出色加工硬化能力，可在斷裂前保證較大的安全裕度，這在結構應用中很有用。這些優異的性能有望在航空航天、汽車、化工和醫療等行業的各種場景中進行結構應用。

The titanium alloy developed by Professor Liu's team is super-strong, highly ductile and ultra-light [3].
劉教授團隊開發的異質鈦合金非常堅固，且具有良好的延展性和較低的密度 [3]。

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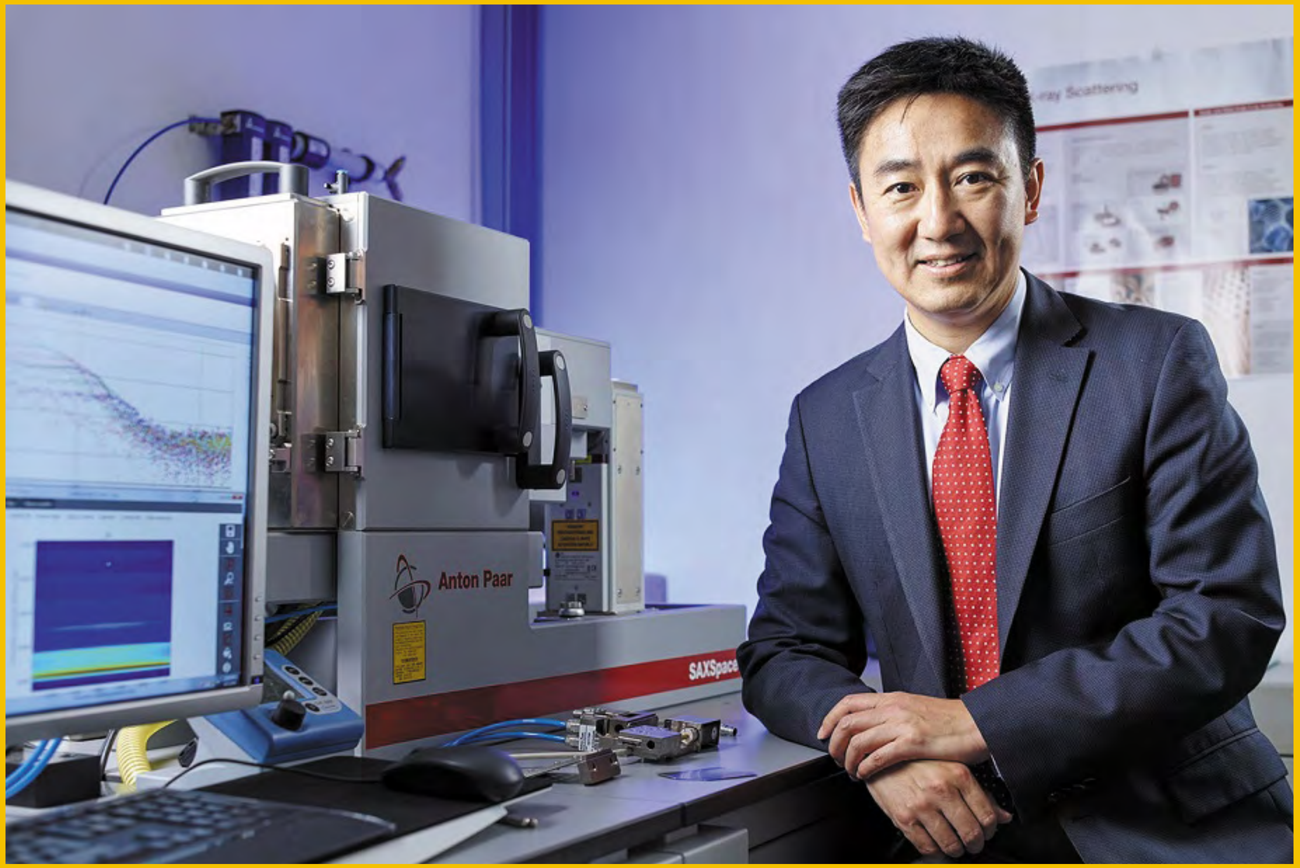
Professor Xunli WANG's Group
王循理教授研究團隊



Understanding Complex Materials through Neutron Scattering

Breakthroughs in materials development, which are essential for advances in technology, are based on scientists' understanding of material structure and dynamics. Neutron scattering is one of the most powerful techniques for exploring the nature of materials. Professor Xunli WANG has applied this state-of-the-art experimental technique to find out the deformation and transformation behaviors in complex materials, in particular at ultra-low temperatures, opening up a new area of materials research.

Neutron scattering is like a giant microscope. It can reveal the structure and dynamics of a material, such as how the atoms are packed and how they move, thus enhancing our understanding of a material's properties. It can be applied to physics, chemistry, biology, biomedical science, materials science and engineering.

A giant microscope for materials

Neutrons are uncharged particles, so they can easily pass through material. The ways in which they bounce off a material and scatter provide scientists with important information about the material's structure and properties.

For example, experimental studies on the physical properties of amorphous materials have been very difficult owing to their disordered atomic arrangement. But using the neutron-scattering technique, Professor Wang led an international research team to overcome this challenge, and measured the atomic dynamics in zirconium-copper-aluminium metallic glass. They demonstrated the existence of high-frequency transverse phonons in metallic glass for the first time. Their findings have provided new insight into understanding the atomic structure-dynamics relationship in disordered materials.

Unveiling HEA deformation at ultra-low temperature

With the neutron-scattering instrumentation, Professor Wang and his team also discovered that high-entropy alloys (HEAs), a new class of structural materials consisting of multiple principal elements, exhibit exceptional mechanical properties at ultra-low temperatures owing to the coexistence of multiple deformation mechanisms. They revealed the sequence of deformation mechanisms in HEAs at ultra-low temperatures for the first time, opening up new terrain that very few have examined.

Professor Wang was awarded the Croucher Senior Research Fellowship 2021 and will use the grant to conduct an in situ neutron diffraction study to pursue his research on phase transformation and deformation behaviors in HEAs at ultra-low temperatures.

通過中子散射了解複雜材料

材料研發的突破是促進技術進步的關鍵所在，這就要求科學家對材料結構和動力學有很好的理解。中子散射技術是探索材料本質的眾多強大技術之一。王循理教授將這種最先進的實驗技術應用於研究複雜材料的變形和相變行為，特別是在超低溫下，開辟了材料研究的新領域。

中子散射就像一台巨大的顯微鏡，可以揭示物質的結構和動力學，比如原子是如何堆積的，又是如何運動的，從而加強我們對物質性質的理解。 它可應用於物理、化學、生物學、生物醫學、材料科學和工程。

一台巨大的材料顯微鏡

由於中子是不帶電的粒子，它們很容易穿透物質，而它們在物質上反射和散射的方式也為科學家提供了關於物質結構和特性的重要信息。

例如，由於非晶材料具有無序排列的原子結構，對其物理性質的研究一直非常棘手。不過王教授帶領的國際研究團隊利用中子散射技術克服了這一挑戰，測量了鋯銅鋁 (Zr-Cu-Al) 金屬玻璃中的原子動力學。他們首次證實了金屬玻璃中高頻橫聲學支聲子的存在，這一發現為了解非晶材料的原子結構與其原子動力學的關係帶來了新啟示。

揭示高熵合金在超低溫下的形變

通過使用原位中子衍射技術，王教授及其研究團隊還發現高熵合金，一種由多種主元素組成的新型結構材料，在超低溫下表現出卓越的機械性能，其原因是多種變形機制的共同存在。研究團隊首次揭示了高熵合金在超低溫時出現各種變形機制的次序，開辟了很少有人研究的新領域。

王教授榮獲“2021 年裘槎優秀科研者獎”，並將利用該基金進行原位中子衍射實驗，進一步研究高熵合金在超低溫下的相變及變形行為。

Advantage of close proximity to a neutron source facility

Riding on Hong Kong's proximity to the China Spallation Neutron Source (CSNS), Professor Wang has dedicated his efforts to establishing Hong Kong as a hub for neutron-scattering science in the region.

The CSNS is one of the largest national scientific facilities in China and is situated in Dongguan, which is about a two-hour drive from Hong Kong. It offers tremendous opportunities for researchers in Hong Kong and the region. Since there are only four neutron sources in the world, there is huge demand to use the facility for experiments and research.

Therefore, Professor Wang and his collaborators have supported the construction of a multiphysics instrument (a total scattering diffractometer) at the CSNS, with the support of the Collaborative Research Fund (CRF), in exchange for dedicated access to a suite of instruments there. This will greatly enhance education and research activity in Hong Kong and encourage the rapid growth of a strong user community.

Promoting neutron-scattering research

Professor Wang and Professor Hesheng CHEN, of the Institute of High Energy Physics of the Chinese Academy of Sciences (CAS), co-founded the Joint Laboratory on Neutron Scattering at CityU, with sponsorship from the CAS and the Croucher Foundation, to carry out a variety of cutting-edge research projects. Supported by Joint Laboratory Funding from the University Grants Committee, Professor Wang and his collaborators are developing an isotope labeling platform for functional materials, which will enable precise structure identification at the CSNS. The project aims to enhance the research infrastructure of Hong Kong laboratories, utilizing the neutron source at CSNS to study structural and energy materials.

Previously, with the support of the Croucher Foundation, Professor Wang started the biennial Croucher Summer Course on Neutron Scattering. By boosting collaboration between the Hong Kong scientific community and the CSNS and nurturing more scientists to work in neutron scattering, Professor Wang hoped Hong Kong can benefit from the enhancement of this science and technology research.

This research article originated from CityU RESEARCH.

靠近中子源設施的優勢變

王教授利用香港毗鄰中國散裂中子源的地理優勢，致力將香港打造為區內中子散射科學的中心。

中國散裂中子源是中國最大的國家科學設施之一，位於東莞，離香港約兩小時車程，為香港和區內的研究人員提供了大量的機會。由於目前世界上只有四台中子源，利用該設施進行實驗和研究的需求巨大。

因此，王教授與其團隊成員得到香港研究資助局協作研究金的支持，大力推動中國散裂中子源建造一台多物理譜儀（全散射譜儀），以獲得在中國散裂中子源使用一整套儀器的專用權，這將大大促進香港的教育和科研活動的展開，並帶動用戶群體迅速增長。

促進中子散射研究

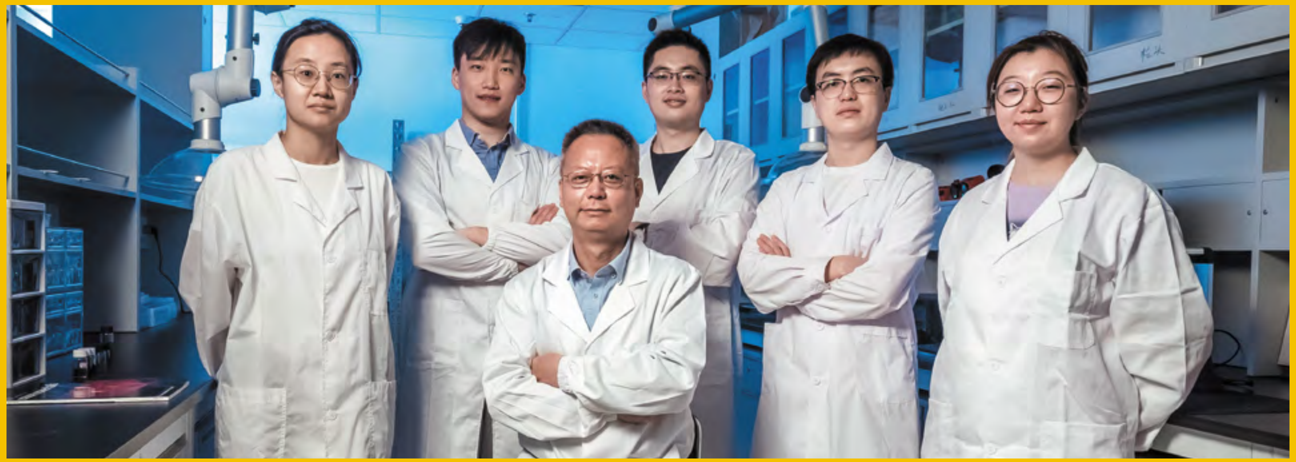
王教授與中國科學院高能物理研究所陳和生教授在中國科學院高能物理研究所及裘槎基金會的贊助下，在城大共同成立了中子散射科學技術聯合實驗室，用以開展多項尖端研究項目。在香港的大學教育資助委員會聯合實驗室資助計劃的支持下，王教授及其團隊成員正在開發一個功能材料的同位素標記平台，以便在中國散裂中子源進行精確的結構識別。該項目利用中國散裂中子源的中子來研究結構和能源材料，旨在加強香港實驗室的研究基礎設施。

此前，在裘槎基金會的支持下，王教授開辦了兩年一度的裘槎中子散射暑期課程。通過加強香港科學界與中國散裂中子源之間的合作，培育更多從事中子散射研究的科學家，我們希望香港能受惠於這項不斷加強的科研活動。

此文章收錄於 CityU RESEARCH。

The multiphysics instrument supported by Professor Wang's CRF project being installed in the CSNS.
王教授的協作研究金項目支持的多物理儀器正在中國散裂中子源中安裝。

Professor Hua ZHANG's Group
張華教授研究團隊



After Professor Zhang joined CityU in 2019, 100 papers have been published/accepted. The representative research work mainly related to preparation and applications of noble metal nanomaterials are listed below.

從 2019 年張華教授加入香港城市大學至今，張華教授研究團隊發表和接受發表的學術論文超過 100 篇，其中和貴金屬納米材料製備與應用相關的主要代表性的工作列舉如下：

1.

We report the controlled synthesis of Pd-based alloy nanoparticles with an unconventional hexagonal close-packed (*hcp*, 2H type) crystal phase via a facile and general seeded method. By using 2H-Pd nanoparticles as seeds, 2H-PdCu alloy nanoparticles with tunable Cu contents can be synthesized by simply changing the reaction time. Furthermore, by using the aforementioned 2H-PdCu nanoparticles as templates, the partial galvanic replacement of Cu atoms by Pt can be conducted to induce the incorporation of Pt into PdCu nanoparticles, realizing the preparation of trimetallic PdCuPt alloy nanomaterials with unconventional 2H phase (Figure 1). As a proof-of-concept application, the as-synthesized Pd-based alloy nanoparticles can be used as highly efficient catalysts towards electrochemical oxygen reduction reaction (ORR) in alkaline media. In particular, the trimetallic 2H-PdCuPt alloy nanoparticles exhibit excellent catalytic activity, outperforming most of the reported Pd-based ORR electrocatalysts in alkaline electrolytes. This work was published in *Journal of the American Chemical Society*, 2021, 143, 17292-17299.

1.

我們報導了一種簡便且普適的晶種合成法來實現具有非常規六方密堆（hcp，2H 型）晶相的 Pd 基合金納米材料的可控製備，通過簡單調控反應時間可以實現對所得 PdCu 納米合金顆粒的組分的有效控制。此外，利用已合成的 2H-PdCu 合金納米顆粒為範本，借助 Pt 原子對部分 Cu 原子的置換反應，可以誘導 Pt 在 2H-PdCu 合金納米顆粒中的摻雜，進而製備得到具有非常規 2H 相的三金屬 PdCuPt 合金納米材料（圖 1）。研究結果表明，該類非常規 2H-Pd 基納米合金材料可以在鹼性條件下的電化學氧還原反應（ORR）中表現出優異的催化性能。尤其，通過 Pt 摻雜得到的三金屬 PdCuPt 納米合金顆粒展示出了卓越的 ORR 活性，優於大多數已報導的 Pd 基鹼性 ORR 電催化劑。該工作發表於 *Journal of the American Chemical Society*, 2021, 143, 17292-17299。

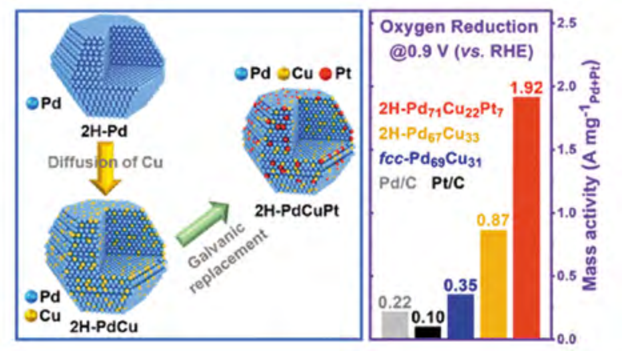


Figure 1 Schematic illustration of the seeded synthesis of 2H-PdCu and 2H-PdCuPt alloy nanoparticles from 2H-Pd (left) and ORR performance of various catalysts. (right)

圖 1 以非常規 2H 相 Pd 納米顆粒為原料生長 2H-PdCu 以及 2H-PdCuPt 合金納米顆粒的示意圖（左圖）以及多種催化劑的電化學氧還原反應性能比較圖。（右圖）

2.

We develop a facile two-step method for the lattice expansion on specific facets, i.e., Pt(100) and Pt(111), of Pt catalysts. We first prepare the Pd@Pt core-shell nanoparticles exposed with the Pt(100) and Pt(111) facets via the Pd-seeded epitaxial growth and then convert the Pd core to $PdH_{0.43}$ by the hydrogen intercalation. The lattice expansion of the Pd core induces the lattice enlargement of the Pt shell, which can significantly promote the alcohol oxidation reaction (AOR) on both Pt(100) and Pt(111) facets. Impressively, the Pt mass-specific activities of 32.51 A mg_{Pt}^{-1} for methanol oxidation and 14.86 A mg_{Pt}^{-1} for ethanol oxidation, which are 41.15 and 25.19 times those of the commercial Pt/C catalyst, respectively, have been achieved on the Pt(111) facet. Density functional theory (DFT) calculations indicate that the remarkably improved catalytic performance on both Pt(100) and Pt(111) facets through the lattice expansion arises from the enhanced OH adsorption. This work not only paves the way for lattice engineering on specific facets of nanomaterials to enhance their electrocatalytic activity but also offers a promising strategy towards the rational design and preparation of highly efficient catalysts. This work was published in *Journal of the American Chemical Society*, 2021, 143, 11262-11270.

2.

我們開發了一種簡單的兩步策略，成功實現了 Pt 催化劑特定晶面的晶格調控。我們分別以立方體 Pd 納米顆粒與八面體 Pd 納米顆粒作為晶種，通過外延生長法製備得到了分別暴露 Pt(100) 和 Pt(111) 晶面的立方體和八面體 Pd@Pt 核殼結構納米顆粒，然後通過氫插層將 Pd 核轉化為 $PdH_{0.43}$，最終分別獲得具有晶格拉伸應變的立方體 $PdH_{0.43}$@Pt 和八面體 $PdH_{0.43}$@Pt 核殼結構催化材料。我們發現晶格拉伸應變可以顯著促進 Pt(100) 和 Pt(111) 晶面表面的電催化醇氧化反應。其中所製備的暴露 Pt(111) 晶面的催化劑（八面體 $PdH_{0.43}$@Pt）在甲醇氧化反應中的 Pt 品質比活性達到 32.51 A mg_{Pt}^{-1}，在乙醇氧化反應中的 Pt 品質比活性達到 14.86 A mg_{Pt}^{-1}，分別為商業 Pt/C 催化劑的 41.15 和 25.19 倍。該工作發表於 *Journal of the American Chemical Society*, 2021, 143, 11262-11270。

3.

We report a chemical method for synthesis of hierarchical Rh nanostructures composed of ultrathin nanosheets, composed of hexagonal close-packed structure embedded with nanodomains that adopt a vacated Barlow packing with ordered vacancies. The obtained Rh nanostructures exhibit remarkably enhanced electrocatalytic activity and stability toward the hydrogen evolution reaction (HER) in alkaline media. Theoretical calculations reveal that the exceptional electrocatalytic performance of Rh nanostructures originates from their unique vacancy structures, which facilitate the adsorption and dissociation of H_2O in the HER. This work was published in *Science Advances*, 2021, 7, eabd6647.

3.

我們報導了一種簡易的濕化學方法合成得到了由超薄納米片組裝的多級 Rh 納米結構，重要的是，這些 Rh 納米片展現出新型的密排六方晶相，並且在密排六方晶相中觀察到有序空位缺陷結構。在鹼性條件下的電催化析氫反應中，這種獨特的 Rh 納米結構顯示出優異的電催化活性和穩定性。理論計算表明，這種新型的非本征晶相及空位缺陷結構有利於 H_2O 的吸附和解離，從而大幅提升電催化析氫反應性能。該工作發表於 *Science Advances*, 2021, 7, eabd6647。

4.

Two-dimensional (2D) square-like Au nanosheets with an unconventional 2H/face-centered cubic (fcc) heterophase, composing of two pairs of opposite edges with 2H/fcc heterophase and fcc phase, respectively, and two 2H/fcc heterophase basal planes, are prepared and then used as templates to grow one-dimensional (1D) Rh nanorods. The effect of different phases in different regions of the Au templates on the overgrowth of Rh nanorods has been systematically investigated. By tuning the reaction conditions, three

4.

我們合成了具有非常規 2H/fcc 異相的二維金納米片，並以其為範本來生長一維銠納米棒。這種金納米片是類正方形的，其兩組對邊分別具有 2H/fcc 異相及 fcc 相，其上下兩個基面具有 2H/fcc 異相。我們對金納米片範本的不同區域及其不同晶體結構對於銠納米棒的二次生長的影響進行了系統的研究。通過調控反應條件，我們構建了三種一維 / 二維銠 - 金異質結。在 A 類異質結中，銠納米

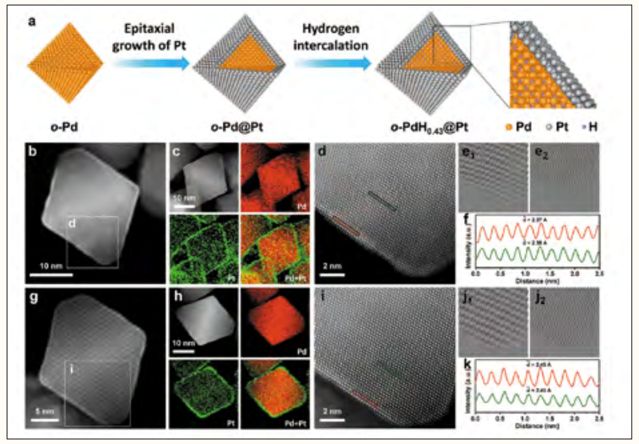


Figure 2 Preparation and structure characterization of o-Pd@Pt and o-$PdH_{0.43}$@Pt NPs.

圖 2 具有晶格拉伸應變的八面體 $PdH_{0.43}$@Pt 核殼結構催化材料的製備與結構分析。

types of 1D/2D Rh-Au heterostructures are prepared. In the type A heterostructure, Rh nanorods only grow on the fcc defects including stacking faults and/or twin boundaries (denoted as fcc-SF/T) and 2H phases in two 2H/fcc edges of the Au nanosheet. In the type B heterostructure, Rh nanorods grow on the fcc-SF/T and 2H phases in two 2H/fcc edges and two 2H/fcc basal planes of the Au nanosheet. In the type C heterostructure, Rh nanorods grow on four edges and two basal planes of the Au nanosheet. Furthermore, the type C heterostructure shows promising performance towards the electrochemical HER in acidic media, which is among the best reported Rh-based and other noble-metal-based HER electrocatalysts. This work was published in *Journal of the American Chemical Society*, 2021, 143, 4387–4396.

5.
We report a general, facile wet-chemical method to synthesize ultrathin amorphous/crystalline heterophase Rh and Rh-based bimetallic alloy nanosheets, including RhCu, RhZn, and RhRu. Impressively, the amorphous/crystalline heterophase Rh nanosheets exhibit enhanced catalytic activity toward the direct synthesis of indole compared to the crystalline counterpart. Importantly, the obtained amorphous/crystalline heterophase RhCu alloy nanosheets can further enhance the selectivity to indole of >99.9% and the conversion is 100%. Our work demonstrates the importance of PEN and metal alloying in the rational design of Rh-based catalysts, providing a new avenue for developing efficient metal nanocatalysts for the fine chemical synthesis. This work was published in *Advanced Materials*, 2021, 33, 2006711.

6.
We report the crystal-phase engineering of Co and Ni nanostructures by quasi-epitaxial growth. Specifically, by using 4H-Au nanoribbons as templates, 4H-Au@14H-Co nanostructures are successfully prepared via the quasi-epitaxial growth. Notably, due to the large lattice mismatch between Co and Au, ordered misfit dislocations are formed at the Au/Co interface, resulting in a new phase of Co, namely 14H. By fine tuning the reaction conditions, Co can form branches or thin layers on 4H-Au surfaces, resulting in two kinds of nanostructures that are denoted as 4H-Au@14H-Co nanobranches and 4H-Au@14H-Co nanoribbons, respectively. Moreover, by using a different synthetic method, 4H-Au@2H-Co nanoribbons with thicker Co layer are also prepared, in which ordered dislocations with different periodicity are observed. This method can also be used to prepare 4H-Au@2H-Ni nanoribbons. This work was published in *Advanced Materials*, 2021, 33, 2007140.

棒僅生長在金納米片的兩個 2H/fcc 邊上的 fcc 缺陷（包括層錯及孿晶面）區域以及 2H 區域。在 B 類異質結中，銠納米棒生長在金納米片的兩個 2H/fcc 邊及兩個 2H/fcc 基面上的 fcc 缺陷（包括層錯及孿晶面）區域以及 2H 區域。在 C 類異質結中，銠納米棒無選擇地生長在金納米片的四個邊和兩個基面上。此外，C 類異質結被用作酸性介質電催化析氫反應的催化劑，表現出優異的催化性能，其性能在銠基及其它貴金屬基酸性介質析氫催化劑中名列前茅。該工作發表於 *Journal of the American Chemical Society*, 2021, 143, 4387—4396。

5.
我們應用濕化學法合成出了一類新型銠基二維材料：無定形 / 結晶異相超薄 Rh 及 Rh 基雙金屬合金（包括銠銅（RhCu），銠鋅（RhZn），銠釕（RhRu）），並對其在串聯合成吲哚中的催化特性進行了詳細探究。我們發現，在溫和溫度（90 ℃）的甲醛稀釋水溶液中還原 Rh(acac)$_3$，反應 18 小時即可獲得無表面活性劑的具有無定形 / 結晶異相的超薄 Rh 納米片。此外，通過將 Rh(acac)$_3$ 和 Cu(acac)$_2$、Zn(acac)$_2$ 或 Ru(acac)$_3$ 簡單混合，在相同實驗條件下亦可實現系列超薄雙金屬合金（RhCu，RhZn，RhRu）異相納米片的可控合成。這種獨特的異相結構和 Cu 的合金作用使得超薄 RhCu 納米片成為直接合成吲哚的高效異相串聯催化劑。與傳統結晶相比較，無定形 / 結晶異相的存在可顯著提高催化活性。通過進一步地 Cu 合金化，無定形 / 結晶異相 RhCu 納米片可獲得 100% 的轉化率和 99.9% 以上的吲哚選擇性。這項工作突出了納米材料相工程和金屬合金化在 Rh 基催化劑合理設計中的重要性，為開發精細化學品合成中高效價廉的金屬異相催化劑提供了一條新途徑。該工作發表於 *Advanced Materials*, 2021, 33, 2006711。

6.
我們利用准外延生長法對 Co 和 Ni 納米結構實現晶相調控。採用 4H-Au 納米帶作為範本，Co 可以外延生長在 Au 表面，得到了 4H-Au@14H-Co 納米枝結構。由於 Au 和 Co 之間的晶格不匹配度較大，在 Au/Co 界面處形成了有序的失配位錯，從而產生了一種 Co 的新相，即 14H。濕化學反應中表面配體含量的增加會導致外延生長的 Co 納米枝逐漸變短，最終僅形成一層極薄的均勻的覆蓋層並保持 14H 相，得到 4H-Au@14H-Co 納米帶結構。此外，利用不同的濕化學合成法，可以改變 Au/Co 界面處位錯的週期，因此外延生長的 Co 覆蓋層可以形成 2H 相，得到 4H-Au@2H-Co 納米帶結構。和 14H-Co 相比，2H-Co 和 Au 之間的晶格不匹配度較小，因此 2H-Co 覆蓋層比 14H-Co 覆蓋層更厚。這個方法也可以用於外延生長 2H 相的 Ni 覆蓋層，得到 4H-Au@2H-Ni 納米帶結構。由於 Co 和 Ni 的晶面間距不同，在 4H-Au/2H-Co 和 4H-Au/2H-Ni 界面處的位錯週期也不同。該工作發表於 *Advanced Materials* 2021, 33, 2007140。

7.
We report the preparation of Pd nanoparticles with an unconventional hexagonal close-packed (2H type) phase, referred to as 2H-Pd nanoparticles, via a controlled phase transformation of amorphous Pd nanoparticles. Impressively, by using the 2H-Pd nanoparticles as seeds, Au nanomaterials with different crystal phases epitaxially grow on the specific exposed facets of the 2H-Pd, i.e., face-centered cubic (fcc) Au (fcc-Au) on the $(002)_h$ facets of 2H-Pd while 2H-Au on the other exposed facets, to achieve well-defined fcc-2H-fcc heterophase Pd@Au core-shell nanorods. Moreover, through such unique facet-directed crystal-phase-selective epitaxial growth, a series of unconventional fcc-2H-fcc heterophase core-shell nanostructures, including Pd@Ag, Pd@Pt, Pd@PtNi, and Pd@PtCo, have also been prepared. Impressively, the fcc-2H-fcc heterophase Pd@Au nanorods show excellent performance toward the electrochemical carbon dioxide reduction reaction (CO_2RR) for production of carbon monoxide with Faradaic efficiencies of over 90% in an exceptionally wide applied potential window from -0.9 to -0.4 V (versus the reversible hydrogen electrode), which is among the best reported CO_2RR catalysts in H-type electrochemical cells. This work was published in *Journal of the American Chemical Society*, 2020, 142, 18971–18980.

8.
We report a one-pot wet-chemical synthesis of well-defined heterophase fcc-2H-fcc gold nanorods at mild conditions. Single particle-level experiments and theoretical investigations reveal that the heterophase gold nanorods demonstrate a distinct optical property compared to that of the conventional fcc gold nanorods. Moreover, the heterophase gold nanorods possess superior electrocatalytic activity for the CO_2RR over their fcc counterparts under ambient conditions. First-principles calculations suggest that the boosted catalytic performance stems from the energetically favourable adsorption of reaction intermediates, endowed by the unique heterophase characteristic of gold nanorods. This work was published in *Nature Communications*, 2020, 11, 3293.

9.
We report the crystal phase-controlled synthesis of PtCu alloy shells on 4H Au nanoribbons, referred to as 4H-Au nanoribbons, to form the 4H-Au@PtCu core–shell nanoribbons. By tuning the thickness of PtCu, 4H-PtCu and fcc-PtCu alloy shells are successfully grown on the 4H-Au nanoribbon cores. This thickness-dependent phase-controlled growth strategy can also be used to grow PtCo alloys with 4H or fcc phase on 4H-Au nanoribbons. Significantly, when used as electrocatalysts for the ethanol oxidation reaction (EOR) in alkaline media, the 4H-Au@4H-PtCu nanoribbons show much better EOR performance than the 4H-Au@fcc-PtCu nanoribbons, and both of them possess superior performance compared to the commercial Pt black. Our study provides a strategy on phase-controlled synthesis of nanomaterials used for crystal phase-dependent applications. This work was published in *Nano Research*, 2020, 13, 1970–1975.

7.
我們通過精准調控無定形鈀（Pd）納米顆粒的相變過程實現了非常規六方密排 2H 相 Pd 納米顆粒（2H-Pd）的可控制備。隨後，進一步以 2H-Pd 納米顆粒為晶種，實現了金（Au）在其表面上的各向異性晶相選擇性外延生長，即面心立方（fcc）相 Au 生長在 2H-Pd 的 $(002)_h$ 晶面上，而 2H 相 Au 則生長在 2H-Pd 的其他暴露晶面上，從而形成 fcc-2H-fcc 異相 Pd@Au 核殼納米棒。這種獨特的相選擇性外延生長策略可作為一種通用方法來製備一系列其它具有 fcc-2H-fcc 異相結構的金屬納米核殼異質材料，包括 Pd@Ag、Pd@Pt、Pd@PtNi 及 Pd@PtCo。此外，我們發現 fcc-2H-fcc 異相 Pd@Au 核殼納米棒作為催化劑可在電催化二氧化碳還原製備一氧化碳的反應中表現出優異的性能。其在 -0.9 至 -0.4 V 的寬電位區間內均呈現出 90% 以上的法拉第效率，這是目前利用 H 型電解池所測得的最好的催化性能之一。該工作發表於 *Journal of the American Chemical Society*, 2020, 142, 18971—18980。

8.
我們發展了一種濕化學一鍋法合成策略，在溫和條件下製備了具有精准異相結構的 fcc-2H-fcc Au 納米棒。對單根 Au 納米棒的實驗和理論模擬結果表明，與常規的 fcc 相 Au 納米棒相比，異相 Au 納米棒具有截然不同的光學性質。此外，在電催化二氧化碳還原反應中，異相 Au 納米棒比常規 fcc 相 Au 納米棒表現出更加優異的催化性能。第一性原理計算揭示了 fcc-2H-fcc Au 納米棒的異相結構界面更有利於吸附二氧化碳還原的中間產物，從而提高了其電催化性能。該工作發表於 *Nature Communications*, 2020, 11, 3293。

9.
我們通過在 4H Au 納米帶上晶相可控地生長鉑銅（PtCu）合金實現了 4H-Au@PtCu 核殼納米帶的製備。通過調控 PtCu 殼的生長厚度，我們可以分別在 4H Au 核上生長 4H 晶相和 fcc 晶相結構的 PtCu 合金。該合成策略也可用於在 4H Au 納米帶上生長 4H 晶相或 fcc 晶相的鉑鈷（PtCo）合金。所製備的 4H-Au@4H-PtCu 納米帶作為電催化乙醇氧化催化劑在鹼性條件下表現出比 4H-Au@fcc-PtCu 納米帶更好的催化性能，且二者性能均優於商用鉑黑催化劑。這項工作為探索晶相可控的納米材料的合成及其基於晶相的性質和應用研究提供了一種新思路。該工作發表於 *Nano Research*., 2020, 13, 1970—1975。

10.

We report a crystal phase-dependent catalytic behavior of Cu, after the successful synthesis of high-purity 4H Cu and heterophase 4H/fcc Cu using the 4H and 4H/fcc Au as templates, respectively. Remarkably, the obtained unconventional crystal structures of Cu exhibit enhanced overall activity and higher ethylene (C_2H_4) selectivity in CO_2RR compared to the fcc Cu. Density functional theory calculations suggest that the 4H phase and 4H/fcc interface of Cu favor the C_2H_4 formation pathway compared to the fcc Cu, leading to the crystal phase-dependent C_2H_4 selectivity. This study demonstrates the importance of crystal phase engineering of metal nanocatalysts for electrocatalytic reactions, offering a new strategy to prepare novel catalysts with unconventional phases for various applications. This work was published in *Journal of the American Chemical Society*, 2020, 142, 12760–12766.

11.

We report the synthesis of binary (Pd-P) crystalline@amorphous heterostructured nanoplates using $Cu_{3-\chi}P$ nanoplates as templates via a cation exchange method. The obtained nanoplate possesses a crystalline core and an amorphous shell with the same elemental components, referred to as *c*-Pd-P@*a*-Pd-P. Moreover, the obtained *c*-Pd-P@*a*-Pd-P nanoplates can serve as templates to be further alloyed with Ni, forming ternary (Pd-Ni-P) crystalline@amorphous heterostructured nanoplates, referred to as *c*-Pd-Ni-P@*a*-Pd-Ni-P. The atomic content of Ni in the *c*-Pd-Ni-P@*a*-Pd-Ni-P nanoplates can be tuned in the range from 9.47 to 38.61 at%. When used as a catalyst, the *c*-Pd-Ni-P@*a*-Pd-Ni-P nanoplates with 9.47 at% Ni exhibit excellent electrocatalytic activity toward EOR, showing a high mass current density up to 3.05 A mg_{Pd}^{-1}, which is 4.5 times that of the commercial Pd/C catalyst (0.68 A mg_{Pd}^{-1}). This work was published in *Advanced Materials*, 2020, 32, 2000482.

10.

我們以 4H 和 4H/fcc Au 為範本實現了高純度 4H 晶相和 4H/fcc 異質晶相銅（Cu）的製備，並揭示了 Cu 的晶相依賴的催化特性。與常規的 fcc 晶相 Cu 相比，具有非常規晶相的 Cu 納米材料在二氧化碳電還原反應中表現出更高的活性和乙烯選擇性。密度泛函理論計算結果進一步證實與 fcc Cu 相比，4H 晶相 Cu 和 4H/fcc 相界面更有利於乙烯的產生，從而導致了晶相依賴的乙烯選擇性。這項工作揭示了金屬納米催化劑的晶相工程對提高其電催化性能的重要性，同時也提供了一種製備具有非常規晶相新型催化劑的新方法。該工作發表於 *Journal of the American Chemical Society*, 2020, 142, 12760—12766。

11.

我們通過陽離子交換的合成策略，以 $Cu_{3-\chi}P$ 納米片為範本製備了 Pd-P 二元晶相 @ 無定形異質納米片（命名為 *c*-Pd-P@*a*-Pd-P）。該納米片具有結晶核心以及無定形殼層。此外，所獲得的 *c*-Pd-P@*a*-Pd-P 納米片也可作為範本，進一步通過合金化反應得到具有晶相 @ 無定形核殼結構的 Pd-Ni-P 三元納米片（命名為 *c*-Pd-Ni-P@*a*-Pd-Ni-P）。我們發現 *c*-Pd-Ni-P@*a*-Pd-Ni-P 納米片中 Ni 的含量可在 9.47 至 38.61 at% 的範圍內進行調控。此外，所獲得的 *c*-Pd-Ni-P@*a*-Pd-Ni-P 納米片（Ni 含量為 9.47 at%）作為催化劑在電催化乙醇氧化反應中表現出優異的活性，其品質活性高達 3.05 A mg_{Pd}^{-1}，是商用 Pd/C 催化劑（0.68 A mg_{Pd}^{-1}）的 4.5 倍。該工作發表於 *Advanced Materials*, 2020, 32, 2000482。

12.

We report a systematic study of surface-plasmon-driven hot-electron-induced photocatalytic reduction of para-nitrothiophenol (*p*NTP) to *p,p*'-dimercaptoazobenzene under visible light on Au nanostructures with different crystal phases by in-situ surface-enhanced Raman spectroscopy (SERS). Our results indicate that the photocatalytic rate of unconventional 4H Au is nearly 6-8 times that of conventional fcc Au, suggesting the greater activity of hot electrons on 4H Au. Further electrochemical reductions of *p*NTP on the 4H and fcc Au nanostructures in aqueous solutions also confirm the higher catalytic activity of the 4H Au. Our study demonstrates that the synthesis of Au nanomaterials with controlled crystal phases paves the way for developing highly efficient catalyst. This work was published in *ACS Materials Letters*, 2020, 2, 409–414.

13.

We report a systematic study on the thermal effect of ultrathin 4H Au nanoribbons by using in situ transmission electron microscopy characterization. Despite Rayleigh instability upon moderate electron beam-induced heating below ~400 K, there is no obvious phase transition observed in ultrathin 4H Au nanoribbons. However, phase transition from 4H to fcc occurs when heating temperature reaches ~800 K, which agrees well with the molecular dynamics simulations. This work provides key insights into the thermal stability of ultrathin 4H Au nanostructures and may facilitate their future practical application in nanoelectronics, plasmonics, and catalysis. This work was published in *Matter*, 2020, 2, 519–521.

14.

We report the discovery of a unique thiol molecule, namely bismuthiol I, which can induce the transformation of Pd nanomaterials from fcc phase into amorphous phase without destroying their integrity. This ligand-induced amorphization is realized by post-synthetic ligand exchange under ambient conditions, and is applicable to fcc Pd nanomaterials with different capping ligands. Importantly, the obtained amorphous Pd nanoparticles exhibit remarkably enhanced activity and excellent stability toward electrocatalytic hydrogen evolution reaction (HER) in acidic solution. This work provides a facile and effective method for preparing amorphous Pd nanomaterials, and demonstrates their promising electrocatalytic application. This work was published in *Advanced Materials*, 2020, 32, 1902964.

12.

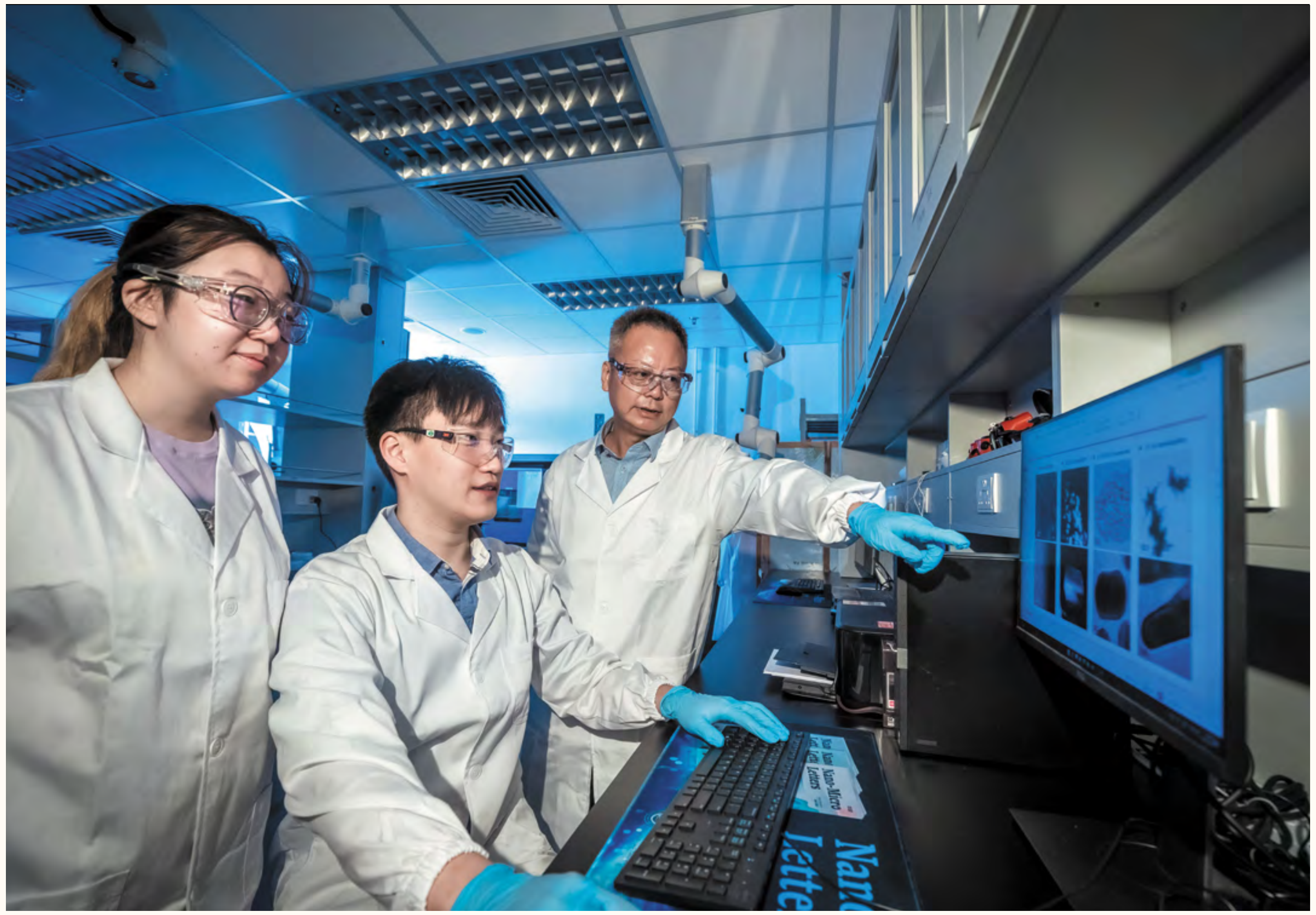
我們利用原位表面增強拉曼光譜（SERS）系統研究了吸附在不同晶相的 Au 納米結構上的對硝基苯硫酚（*p*NTP）在表面等離激元驅動產生的熱電子誘導下發生光催化反應，生成 *p,p*’- 二巰基偶氮苯的過程。我們發現在非常規晶相的 4H Au 上的光催化速率是在常規晶相的 fcc Au 上的約 6-8 倍，說明 4H Au 上所產生的熱電子擁有更高的催化活性。進一步的電化學催化結果表明，在 4H Au 上將 *p*NTP 還原為對氨基苯硫酚的活性也高於 fcc Au。這項工作揭示了基於 Au 納米材料不同晶相的可控合成對製備高效催化劑的重要性。該工作發表於 *ACS Materials Letters*, 2020, 2, 409—414。

13.

我們利用原位透射電子顯微鏡系統研究了超薄 4H Au 納米帶的熱回應。我們發現在電子束輻射加熱到 400 K 以下時，可以逐漸觀察到 4H Au 納米帶幾何結構明顯的“瑞利失穩”現象，然而其特殊的 4H 相依然保持穩定。而當加熱溫度達到 800 K 時，Au 納米帶會發生從 4H 相到 fcc 相的相變，並且整個過程與分子動力學模擬獲得的結果非常吻合。這項工作揭示了超薄 4H Au 納米結構的熱穩定性，並將促進其在納米電子器件、等離子和催化等領域的實際應用。該工作發表於 *Matter*, 2020, 2, 519—52。

14.

我們發現了一種獨特的硫醇分子——1,3,4- 噻二唑 -2,5- 二硫醇，其可誘導 Pd 納米材料從 fcc 晶相轉變為無定形相而不會破壞材料的完整性。這一配體誘導的無定形化在室溫條件下通過配體交換的方式實現，並可實現具有不同表面封端配體的 fcc Pd 納米材料的無定形化。所獲得的無定形 Pd 納米顆粒在酸性條件下具有顯著提高的電催化析氫活性和良好的穩定性。這項工作提供了一種製備無定形 Pd 納米材料的簡單、有效方法，並展現了該材料在電催化領域的良好應用前景。該工作發表於 *Advanced Materials*, 2020, 32, 1902964。



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Professor Xiaoqiao HE's Group
何小橋教授研究團隊

Nanostructured bistable and multistable metal shells are derived from the independent intellectual property rights of the CASM, by using a large number of random high-speed moving balls to bombard the surface of the shell material in localized regions, introduce high-density nanotwin in the shell material and refine the metal grains into nano size, thereby significantly improving the yield strength of the local nanostructured material and increasing the elastic deformation ability of the processed shell. At the same time, a large number of high-speed bombardments gradually accumulate a large number of plastic deformations on the front and back of the shell material, stretching the locally treated region under the constraint of the area without treatment, and the lateral buckling deformation of the shell happens in the two directions under the compressive stress state, which increases with the increase of the further nanostructuring treatment. Due to the significant increase in the elastic deformation ability of the nanostructured metallic material, the two stable post-bulked states can be elastically switched under the action of external load, so as to achieve the local bistable effect.

Multistable shells can be constructed by nanostructuring multiple local regions in the same shell. The coupling and superposition of multiple local bistable effects on the same shell realize the designable morphology of the multistable shell, and its multiple stable states are related to the shape, size, nanostructuring degree and distribution of the local nanostructured regions. In order to better design the multistable shell, the research team also undergo mechanical plastic reprocessing of the nanostructured shell, such as plastically folding or overall plastic bending deformation, etc. The multistable shell after mechanical reprocessing can maintain the multistable characteristics after the overall deformation, that is, the stress field in the local nanostructured region will not lose the bistable effect due to the superposition of residual stress fields generated by the future plastic processing.

表面納米化多穩態金屬板殼技術源自先進結構材料研究中心自主智慧財產權的表面納米化技術，通過使用大量隨機方向高速運動的小球轟擊材料表面，在板殼局部區域進行特殊的納米化處理，在金屬板殼材料中引入高密度納米孿晶和將金屬晶粒細化至納米尺寸，從而顯著提高局部納米化材料的屈服強度和增加板殼的彈性變形能力。同時，大量高速轟擊在金屬板殼材料的正反面逐漸積累大量塑性變形，受限於沒有處理的區域的約束作用，金屬板殼在壓應力狀態下沿法向上下的兩個方向發生橫向的屈曲變形，並隨著納米化處理程度的增加而增加。向上或者向下的兩個屈曲變形後的形態由於納米化材料彈性變形能力的顯著增加，兩個穩定形態可以在外荷載作用下放生形態轉換，從而實現局部雙穩態效應。

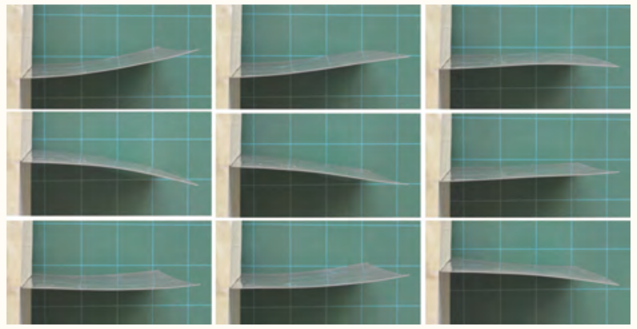
通過在同一塊金屬板殼中處理多個納米化區域，由多個局部雙穩態區域構建多穩態板殼。多個局部雙穩態效應在同一塊板殼上的耦合疊加，可以實現可設計形態的多穩態金屬板殼，其多個穩定形態跟局部納米化區域的形狀、尺寸、納米化程度及其分佈關係相關。另一方面，為更好地設計多穩態金屬板殼，研究團隊還將經過表面納米化處理實現的多穩態金屬板殼進行機械塑性再加工，比如彎折或者整體塑性彎曲變形等，經過機械再加工的多穩態金屬板殼可以在整體發生形變後保持多穩態特性，即局部納米化區域的應力場並不會因為塑性加工產生的殘餘應力場疊加而失去雙穩態效應。

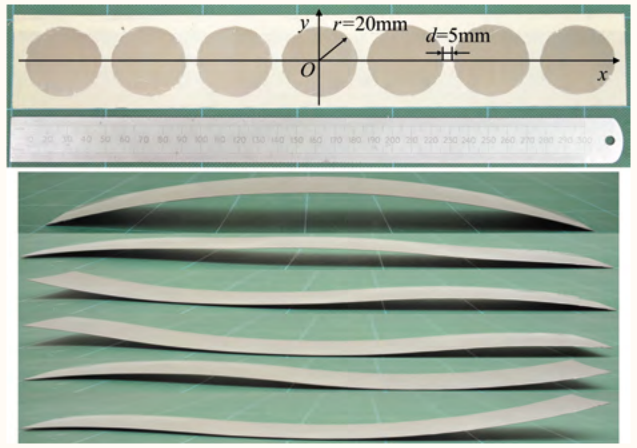
The research team established a corresponding theoretical model to predict and guide the stable states of the multistable shells. After the theoretical model study and the preparation process of the multistable metal shells, the research team carried out the study of the morphological conversion characteristics of the local bistable region under the action of external point, line and surface loads, and obtained the corresponding optimal arrangement form of the external loads that stimulated its morphological conversion. The research team further proposed the remote wireless controllable morphological conversion approaches for the bistable and multistable shells using mechanical drive rods and pneumatic suction cups, and developed the corresponding driving system to achieve the morphological conversion of the bistable and multistable metal shells.

The research team applied the bistable and multistable nanostructured shells to underwater equipment and variable wings. An underwater profile water quality monitoring system and a variable wing structure model were realized. The corresponding technique has won the special gold medal of the China University Science and Technology Achievement Fair, the gold medal of the China (Shanghai) International Invention and Innovation Exhibition, and the gold medal of the "Invention and Entrepreneurship Award Project Award" of the National Invention Exhibition.

研究團隊針對表面納米化多穩態金屬板殼建立了相應的理論模型用於預測和指導其形態加工，在獲得其穩定形態的預測理論模型和製備工藝的基礎上，研究團隊開展了局部雙穩態區域在外部點、線、面荷載作用下的形態轉換特性的研究，並獲取了激發其形態轉換的相應的外部荷載最優佈置形式。研究團隊進而提出了使用機械驅動杆和氣動吸盤的形式進行雙穩態和多穩態金屬板殼的遠端無線可控的形態轉換，並開發了相應的驅動系統，實現了雙穩態和多穩態金屬板殼的形態轉換。

研究團隊將雙穩態和多穩態金屬板殼應用于水下設備和可變機翼，開發了由結構形態轉換實現的水下剖面水質監測系統和可變機翼結構模型。相應的技術方案獲得了中國高校科技成果交易會特別金獎，中國（上海）國際發明創新展覽會金獎，全國發明展覽會“發明創業獎項目獎”金獎等獎項。





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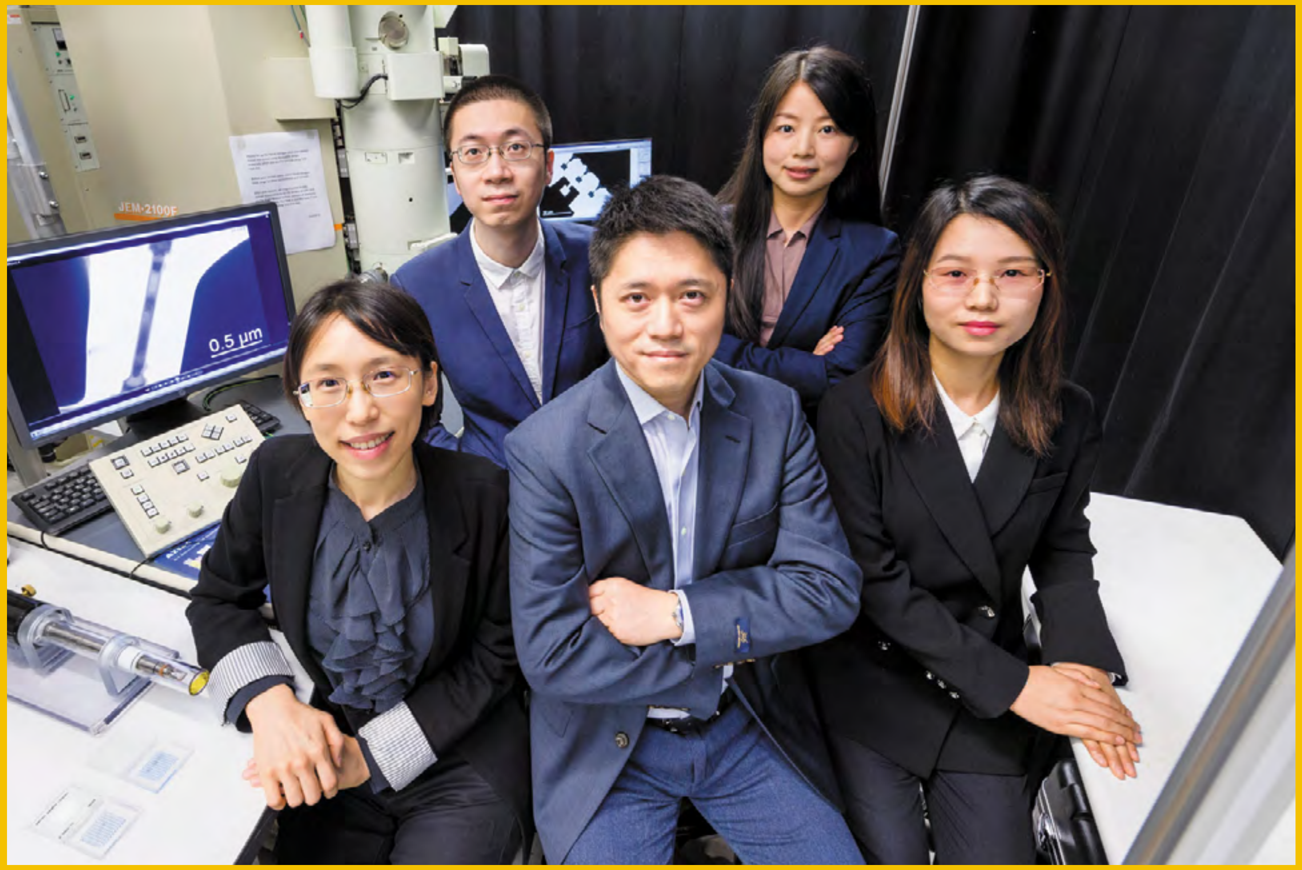
Professor Yang LU's Group
陸洋教授研究團隊



Breakthrough Research Heralds a New Diamond Age

A team co-led by Professor Yang LU, in collaboration with experts from Massachusetts Institute of Technology (MIT), Harbin Institute of Technology (HIT) and so on, has successfully achieved elastic straining of diamond at an unprecedented level, a breakthrough that heralds a new diamond age in the utilization of the gemstone in microelectronics, photonics, and quantum information technologies. Their findings have been published in the prestigious journal Science under the title "Achieving large uniform tensile elasticity in microfabricated diamond".

The research results show that microfabricated single-crystalline diamond tensile sample can attain a maximum uniform elastic strain of up to 9.7%, which is close to the theoretical elastic deformation limit of diamond.

With its ultra-high thermal conductivity and exceptional carrier mobility, diamond is not only the hardest material in nature but also a promising electronic material that can tolerate high power and high frequency applications.

However, one obstacle to the development of diamond-based electronic and optoelectronic devices is the "doping" challenge caused by the ultra-wide bandgap and its small lattice parameter. Professor Lu's team was determined to resolve this hurdle by applying elastic lattice strain to control and change the electronic property of diamonds through a mechanical way.

Professor Lu microfabricated single-crystalline diamond into bridge-like structures from a solid piece of diamond crystal with a well-defined crystalline orientation, and achieved sample-wide large uniform strains under our tensile platform. The team also showed that in the process of uniaxial tensile straining, the change in the crystal structure of diamond will reduce its electronic bandgap, making its application in electronic devices possible.

In 2018, Professor Lu and collaborators revealed for the first time that diamond nanoneedles could undergo ultra-large and fully reversible bending deformation. However, those samples were difficult to control and the resulting strain field was highly localized, which was not ideal for practical device application. This time the team has developed advanced microfabrication processes for bulk diamond crystals in obtaining well-defined diamond bridge samples.

突破性研究邁向新鑽石時代

由陸洋教授與來自麻省理工學院及哈爾濱工業大學等學者合作的聯合研究團隊成功實現鑽石的均勻彈性拉伸應變，達至前所未有的水平。這項突破可令鑽石在微電子、光子學與量子資訊技術的應用進入嶄新時代。研究成果最近在著名的《科學》期刊上發表，題為〈實現微加工鑽石的超大均勻拉伸彈性〉。

研究結果表明，微加工製造的單晶鑽石微橋拉伸樣品可實現高達 9.7% 的最大均勻拉伸應變，接近鑽石在理論上所能達到的彈性變形極限。

鑽石具有超高熱導率與出色載流子遷移率，不僅是自然界最堅硬的材料，也是一種可容許大功率電壓的高性能電子材料。

然而，鑽石的超寬帶隙及緊固晶體結構引起摻雜問題，也是影響鑽石應用到電子與光電器件的一個障礙。陸博士的團隊透過施加彈性晶格應變來解決這個問題，以機械方式來控制與改變鑽石的電子特性。

陸教授團隊這次從具有明確晶體取向的塊體單晶鑽石中微加工出橋狀微納陣列結構，在我們的原位電鏡拉伸平台下實現了幾乎全樣品範圍內超大均勻的拉伸彈性應變，並展示在拉伸應變中鑽石能帶結構的變化，從而改善其器件應用。

陸教授及合作團隊在 2018 年首次發現鑽石在納米尺度下能承受極大彎曲變形並能完全恢復原狀；但是那些納米鑽石針樣品難以控制，所產生的應變分布也極不均勻且局限在較小的區域，對於器件應用並不理想。在是次研究中，團隊以先進微加工工序在大塊高質量人造鑽石晶體中製備鑽石微橋樣品。

Experiment results found that diamond bridges of about 1 micrometer in length and 100 nanometer thickness can sustain a highly uniform elastic strain distribution of about 7.5% across the sample, as characterized by Professor Lu's tailor-made nanomechanical tensile platform in a controllable manner.

By further optimizing the sample geometry according to the American Society for Testing and Materials (ASTM) standard, the team demonstrated that some bridge samples achieved a maximum tensile strain of up to 9.7%. It surpasses the local maximum strain value in our 2018 research.

To assess the impact of such large elastic strains on the electronic property of diamond, the team performed theoretical calculations according to the applied tensile strains in experiments and found that the bandgap of diamond generally decreases as the tensile strain increases, with the largest bandgap reduction rate down from about 5 eV (electron volt) to 3 eV at about 9% strain along a certain crystallographic orientation, which would greatly facilitate diamond's electronics applications and boost a device's performance.

To demonstrate the concept of strained diamond device, the team successfully microfabricated diamond array samples with multiple bridges, and realized the large, uniform, reversible straining of diamond bridge arrays.

The world had been entering a new diamond age. In the near future, the team will be able to apply strained diamonds in the production of electronic devices.

Professor Lu, Dr. Alice HU, also from MNE, and Professor Ju LI from MIT as well as Professor Jiaqi ZHU from HIT are the corresponding authors of the paper. The co-first authors are Dr. Chaoqun DANG, PhD graduate, and Dr. Jyh-pin CHOU, former postdoctoral fellow at MNE, Dr. Bing DAI from HIT and Chang-ti CHOU from National Chiao Tung University. The other researchers from CityU are Dr. Rong FAN and Weitong LIN, both from MNE. Other collaborating researchers are from Lawrence Berkeley National Laboratory and Southern University of Science and Technology.

The research was funded by the RGC of HKSAR and NSFC.

This research article originated from the Research Stories on CityU Website.

實驗結果顯示，基於陸教授實驗室的納米力學拉伸平台，讓長度及厚度分別約為 1 微米及 100 納米的鑽石橋在整體上可往返拉伸至約 7.5% 的高度均勻彈性應變。

團隊參考美國材料與試驗協會的標準，進一步優化樣品的幾何形狀，成功使得部份樣品實現了高達 9.7% 的最大均勻拉伸應變，這超出了我們在 2018 年彎曲鑽石研究中得到的局部應變最大值。

為評估如此巨大的彈性應變對鑽石電子性能的影響，研究團隊根據實驗中施加的拉伸應變量進行了理論計算，發現鑽石的電子帶隙通常隨著拉伸應變的增加而減小，沿著一定的晶體取向，在約 9% 的應變下，鑽石擁有的帶隙從約 5 電子伏特降至 3 電子伏特，這將大大促進鑽石的微電子應用並提高器件性能。

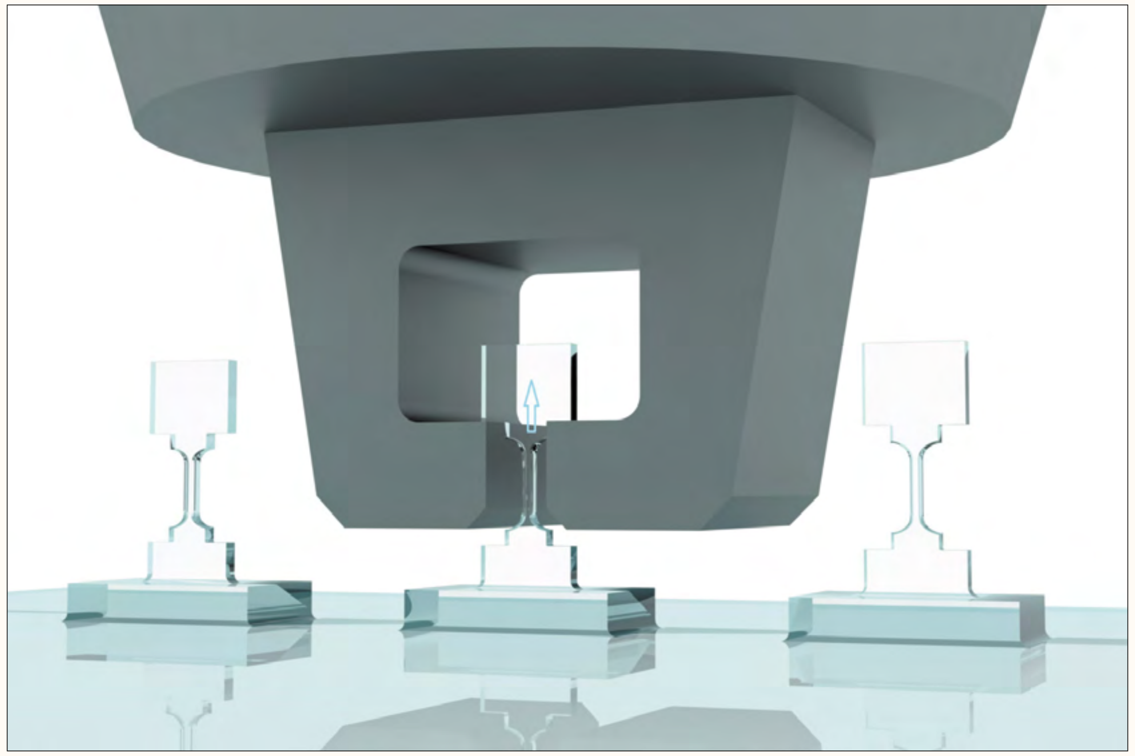
團隊更進一步成功微加工出具有多個微橋的金剛石陣列樣品，並實現了均勻並可逆的陣列拉伸應變，以演示應變鑽石裝置的概念。

人們即將迎來嶄新的鑽石時代。在不久的將來，陸教授團隊能把拉伸鑽石能應用於電子器件的生產。

此研究的通訊作者包括陸教授及同樣來自機械工程學系的胡琪怡博士，麻省理工學院李巨教授，哈爾濱工業大學朱嘉琦教授；共同第一作者包括城大機械工程學系黨超群博士與前博士後研究員周至品博士，哈爾濱工業大學代兵博士，台灣國立交通大學周常棣；其他研究員包括城大機械工程學系的范蓉博士與林為彤。合作團隊亦包括來自勞倫斯伯克利國家實驗室及中國南方科技大學等研究人員。

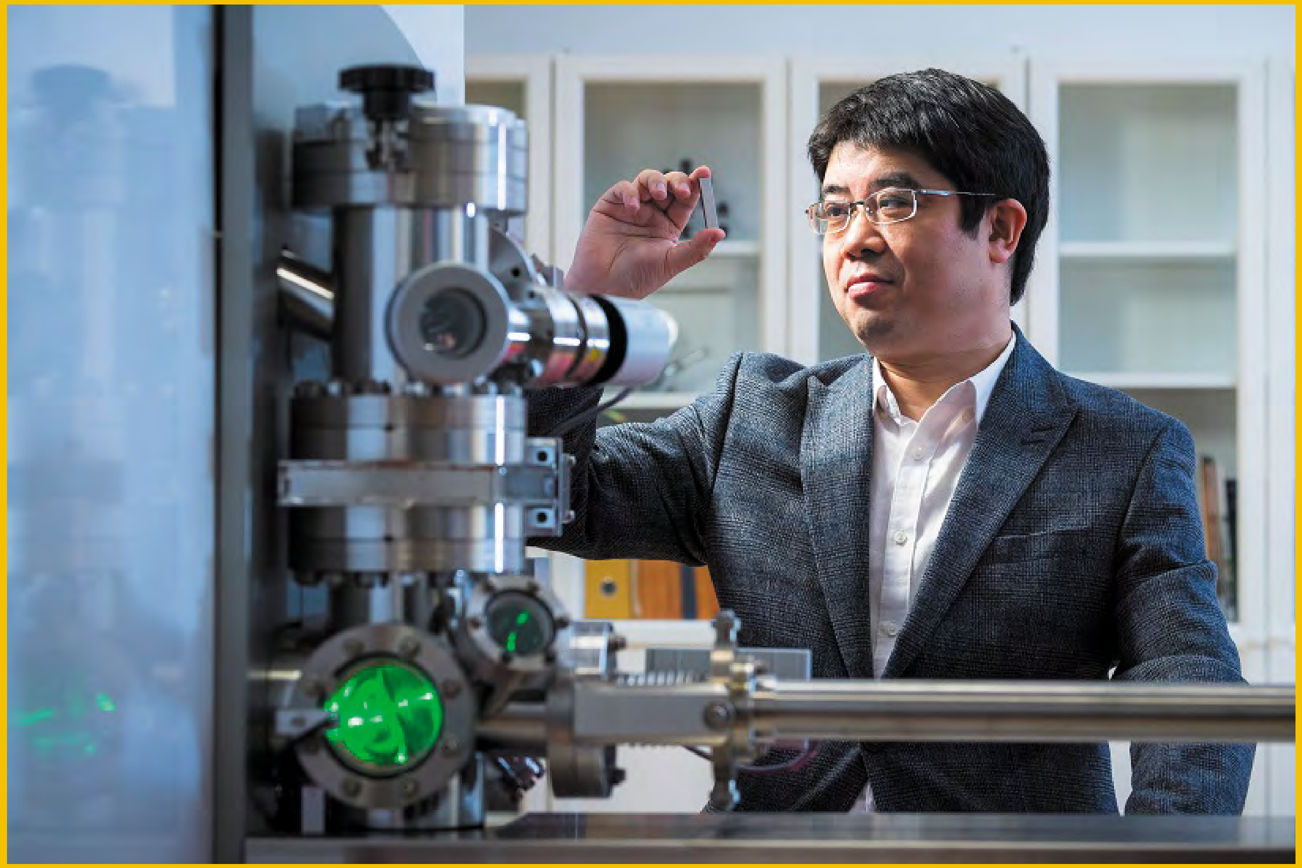
該項研究得到香港研究資助局及國家自然科學基金等資助。

此文收錄於城大《研究故事》。



A joint research team led by Professor Lu from CityU has successfully achieved the unprecedented elastic straining of diamond.
由城大陸洋教授領導的聯合研究團隊成功實現微加工鑽石的拉伸彈性應變，達至前所未有的水平。

Professor Yong YANG's Group
楊勇教授研究團隊



Super-elastic High-Entropy Elinvar Alloy Discovered with Potential for Aerospace Engineering

Metals usually soften when they expand under heating, but a research team led by Professor Yong YANG, together with his collaborators have discovered a first-of-its-kind super-elastic alloy that can retain its stiffness even after being heated to 1,000K (about 727˚C) or above, with nearly zero energy dissipation. The team believes that the alloy can be applied in manufacturing high-precision devices for space missions. The findings were published in the prestigious science journal *Nature* under the titled "A Highly Distorted Ultraelastic Chemically Complex Elinvar Alloy".

Challenging thermal expansion principles

Usually the elastic modulus i.e. stiffness, of most solids including metals, decreases when the temperature increases as a result of thermal expansion. However, Professor Yang and his team discovered that a high entropy alloy, called $Co_{25}Ni_{25}(HfTiZr)_{50}$,or "the high-entropy Elinvar alloy", reveals the "Elinvar effect". This means that the alloy firmly retains its elastic modulus over a very wide range of temperature changes.

When this alloy is heated to 1,000K, i.e. 726.85 °C, or even above, it is as stiff as, or even slightly stiffer than, it is at room temperature, and it expands without any notable phase transition. This changes our textbook knowledge, as metals usually soften when they expand under heating.

This was an accidental discovery. The team discovered this phenomenon in 2017 and spent several years trying to understand the underlying mechanisms to determine why the alloy's stiffness does not change with increased temperature. The experiment verified that the microstructure and mechanical properties of the alloy were insensitive to annealing at 1,273 K (1,000 °C) for different time durations.This means the stiffness of the alloy remains invariant to temperature. According to the literature, no known metals have been found to behave this way before the team's findings.

顛覆定律！城大發現超彈性高熵艾林瓦合金，具潛力應用於航天工程

金屬一般在加熱時會膨脹並軟化，不過由楊勇教授與合作的研究人員領導的團隊，首次發現了一種超彈性合金會反其道而行，即使被加熱至 1,000K（約 726.85˚C）甚至更高溫仍能維持剛度（stiffness），更幾乎沒有能量耗損。研究團隊相信，該合金可以用於製作航天任務所需的高精準度裝置。研究結果已於最新一期國際權威學術期刊《*自然*》（*Nature*）上發表，題為〈A highly distorted ultraelastic chemically complex Elinvar alloy〉。

顛覆金屬遇熱變軟的定律

一般來說，大部分固體包括金屬由於遇熱時會膨脹，因此它們的彈性模量（elastic modulus，即剛度）會隨著溫度上升而下降。但楊教授和團隊卻發現一種化學組成為 $Co_{25}Ni_{25}(HfTiZr)_{50}$ 的高熵合金（以下簡稱為「高熵艾林瓦合金」），會出現「艾林瓦效應（Elinvar effect）」，即合金於大幅度的溫度改變中，仍能維持其彈性模量。

將上述合金加熱至 1,000K（約 726.85˚C）甚至更高溫後，它的剛度與室溫時一樣，甚至更剛硬了一點，而且膨脹時也沒有出現任何明顯的相變（phase transition）。這顛覆了我們認為金屬通常會在受熱膨脹時變軟的一貫認知。

這是意外的發現，團隊早在 2017 年已發現了此現像，於是花上數年時間嘗試了解為何它的剛度沒有隨著溫度上升而改變的潛藏機理。實驗證明，該合金即使被加熱到 1,273K（1,000˚C）並維持不同時間後再慢慢冷卻，其微觀結構和機械性能都不受影響。這意味著該合金的剛度不會隨溫度而變化。在翻查文獻後，至今並無發現有任何相關文獻記載過金屬會出現這種現像，這意味著我們首次發現這個現像。

The stiffness of the the high-entropy Elinvar alloy remains invariant with temperature. (CityU)
研究發現高熵艾林瓦合金的剛度不會隨溫度而變化。

Special structure leads to unique properties

Professor Yang and his team recently discovered the reason behind the discovery: a special highly distorted lattice structure with a complex atomic-scale chemical composition. Because of the combination of the unique structural features, the high-entropy Elinvar alloy has a very high energy barrier against dislocation movements. Consequently, it displays an impressive elastic strain limit and a nearly 100% energy storage capacity.

The team also discovered that the high-entropy Elinvar alloy has an elastic limit – the maximum strain that can be developed within it without causing permanent deformation – of about 2% in bulk forms at room temperature, in sharp contrast to conventional crystalline alloys which have an elastic limit of less than 1%.

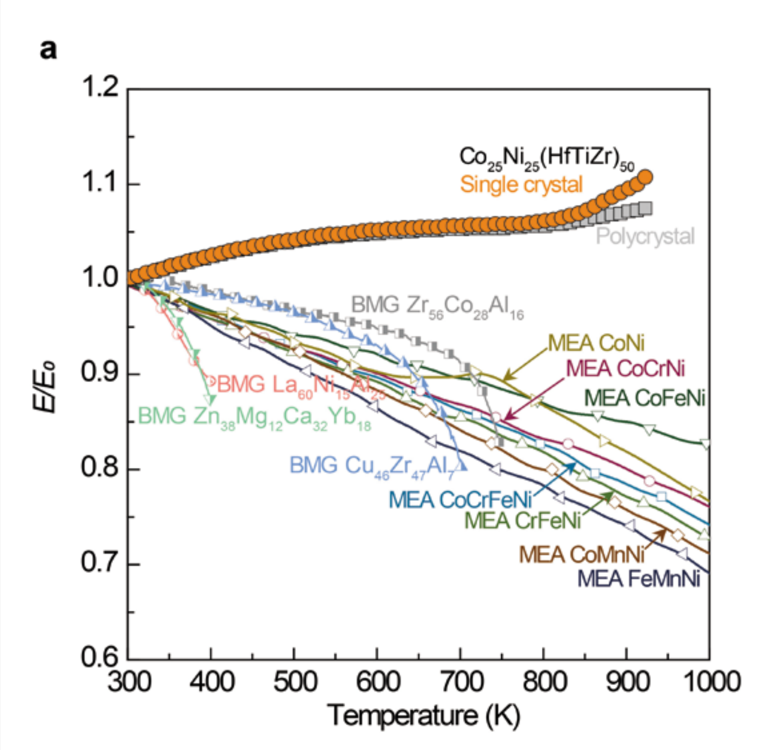
While an alloy with a similar composition was reported several years ago, its structure and behaviour were not understood at the time. In this study, the team developed three atomic structural models for the same alloy with different distributions of the element atoms and compared the properties. They patented the discovery based on this systematic investigation of the alloy system.

特殊的晶格結構衍生罕見特性

楊教授和團隊近日更拆解了高熵艾林瓦合金出現這種現像的原因，原來是因為它擁有一種特殊、高度扭曲的晶格結構（highly distorted lattice structure），以及相當複雜的原子級化學元素分布。由於結合了獨特的結構特征，這種高熵艾林瓦合金具有非常高的能量勢壘（energy barrier），阻止了位錯移動（dislocation movements），因此展現出極佳的彈性應變極限，和近乎 100% 的儲能能力（energy storage capacity）。

研究團隊還發現，塊狀的高熵艾林瓦合金在室溫時，可以達到約 2% 的彈性極限（即金屬材料在出現永久變形前，可承受的最大彈性應變）；相反，傳統的結晶合金的彈性極限一般都少於 1%，兩者形成鮮明的對比。

雖然與高熵艾林瓦合金成份類似的合金，早在幾年前已面世，但科學界當時尚未弄清楚其結構和行為。在今次研究中，楊教授和團隊為該合金制作了三種元素原子分布各有不同的原子結構模型，並比較了三者的特性。團隊對該合金系統作出系統性的研究，並為發現申請了專利。



The figure shows that the elastic modulus of the alloy remains almost constant (a slight increase) when the temperature rises from 300K to 950K, i.e. from 26.85 ̊c to 676.85 ̊c . The finding suggests that the structure is stable even at very high temperatures. (Credit: Q.F. He, et al./DOI number: 10.1038/s41586-021-04309-1)

此圖顯示將高熵艾林瓦合金加熱至 300K 到 950K（即由 26.85 ̊c 至 676.85 ̊c）時，其剛度幾乎不變，甚至稍為增加了。實驗結果表明高熵艾林瓦合金的結構在高溫時仍然穩定。（DOI number: 10.1038/s41586-021-04309-1）

Potential for making high-precision devices

Interestingly, the team found that the alloy is “very springy” and can store a large amount of elastic energy. Professor Yang pointed out that the alloy could be used for energy storage for subsequent energy conversion. Since elasticity does not dissipate energy and therefore will not generate heat, which can cause devices to malfunction, this super-elastic alloy will be useful in high-precision devices, such as watches and chronometers.

The research team envisions many applications for the alloy, particularly in aerospace engineering, in which devices and machinery are expected to undergo drastic temperature changes. For example, the temperature ranges from 122°C to -232°C on the surface of the moon. This alloy will remain strong and intact in an extreme environment, and so it would fit very well with future mechanical chronometers operating within a wide range of temperatures during space missions.

Professor Yang, Professor David Joseph SROLOVITZ (a former CityU scholar, now at the University of Hong Kong (HKU)) and Professor Chun-Wei PAO from Academia Sinica are the corresponding authors of the paper. The first author is Dr. Quanfeng HE from CityU’s MNE (one of Professor Yang’s former PhD students) and the contributing authors are Dr. Jianguo WANG from MNE (one of Professor Yang’s former post-docs) and Dr. Hsin-An CHEN from Academia Sinica (one of Professor Pao’s former PhD students). Also contributing to the research were Professor Chain Tsuan LIU, Professor Yang REN from CityU’s Department of Physics, and Dr. Junhua LUAN, Dr. Zhaoyi DING, Mr. Ziqing ZHOU and Dr. Jichao QIAO, all from CityU.

The research was supported by CityU, RGC of the HKSAR, the Guangdong Major Project of Basic and Applied Basic Research, China, and the Academia Sinica Career Development Award.

This research article originated from the Research Stories on CityU Website.

用於製作高精準度裝置的潛力

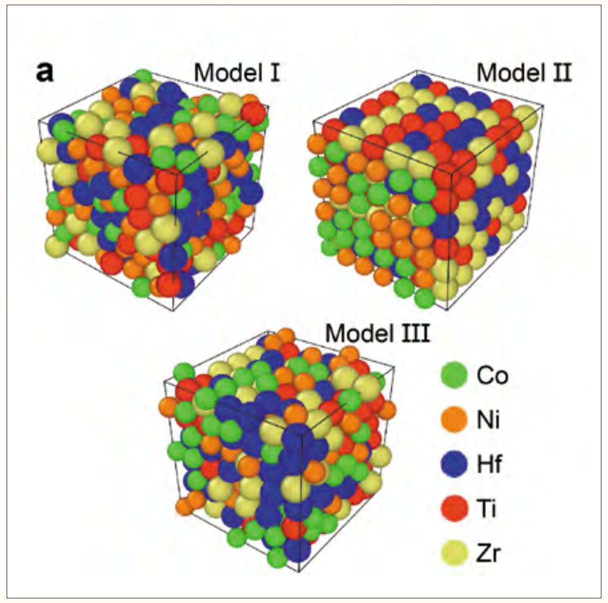
有趣的是，團隊發現高熵艾林瓦合金非常有彈力，並可以儲存大量的彈性能（elastic energy）。楊教授指出這種合金可用於儲存能量，以便之後能量轉換。由於彈性不會耗散能量，所以不會產生熱能而令裝置發熱故障，因此這種超彈性合金適用於製作高精準度的裝置，例如錶和精密計時器等。

研究團隊預視這種合金可具備多種應用，特別是用於預計要應付急劇溫度變化的航天工程裝置和機械。月球表面溫度可高至 122˚C 及低至零下 232˚C，但高熵艾林瓦合金於極端環境中仍能保持堅固和完整，因此非常適合應用於太空任務中，需在巨大溫差環境下運行的機械精密計時器。

楊教授、David Joseph Srolovitz 教授（前城大學者，現職於香港大學）及來自中央研究院的包淳偉教授是研究論文的通訊作者。城大機械工程學系的赫全鋒博士（楊教授曾指導的博士生）、王建國博士（楊教授曾指導的博士後）及來自中央研究院的陳信安博士（包教授曾指導的博士生）為第一作者。劉錦川教授，城大物理學系的任洋教授，以及城大的欒軍華博士、丁肇夷博士、喬吉超博士以及周子清先生亦有參與這次研究。研究的其他主要合作學者包括北京高壓科學研究中心的曾橋石教授，和里昂大學的 Jean-Marc Pelletier 教授。

是次研究獲得城大、香港研究資助局、廣東省基礎與應用基礎研究重大項目，和中央研究院的前瞻計劃的資助而進行。

此文收錄於城大《研究故事》。



The team developed three atomic structural models for the same alloy, with different distributions of the element atoms, and compared their properties. Model II and III agreed well with the experimental results. (Credit: Q.F. He, et al. / DOI number: 10.1038/s41586-021-04309-1)

團隊為此合金制作了三種元素原子分布各有不同的原子結構模型，然後比較它們的特性。當中模型 II 及 III 大致與實驗結果吻合。（DOI number: 10.1038/s41586-021-04309-1）

Professor Kaili ZHANG's Group
張開黎教授研究團隊

Au/Pt/Cr microheater and nanoenergetic film based self-destruction microchip

Introduction

Microchip plays a crucial role in the semiconductor and MEMS industry, and is closely related to the development of aerospace, automotive electronics, consumer electronics, biomedicine and other fields. Nowadays, with the improvement of data security awareness, the demand for microchips with controllable lifetime is increasing. Self-destruction chip can lose its function in a way of disappearing or degrading through active or passive trigger mechanism after completing its mission. The self-destruction characteristic can prevent the leakage of chip design information, sensitive information stored on the chip, and personal privacy in electronic products. Self-destruction microchip is especially important in the military, intelligence agencies, finance, and many other government and private organizations. It also has great potential in completely eliminating the information storage modules on discarded mobile phones, computers and other electronic products.

Microchips involve inorganic or organic semiconductors, metals, packaging materials and substrate materials. A lot of research work has been devoted to the use of light, water, temperature, or electric current to trigger physical and chemical changes such as corrosion, dissolution, hydrolysis, and tearing of these materials, so as to achieve the self-destruction of microchips. There is no doubt that good results have been achieved in the previous researches on self-destruction devices, but there are two main problems in most self-destruction mechanisms. First, they are only suitable for microchips with special structures, which is incompatible with the existing complementary metal oxide semiconductor (CMOS) and integrated circuit (IC) manufacturing processes and technology; second, it takes a long time for these self-destruction mechanisms to fail, and some even take several years, which restricts the application of these technologies in secured hardware for protecting sensitive information or data. In order to widely realize information security and reduce the risk of data leakage, simple manufacturing process and rapid self-destruction are very important.

基於 Au/Pt/Cr 微加熱器和納米含能薄膜的自毀微芯片

背景介紹

微芯片在半導體行業和微機電系統（MEMS）中發揮著至關重要的作用，與航空航天、汽車電子、消費電子、生物醫學等領域的發展密切相關。如今，隨著資料安全意識的提高，對具有自毀能力的微芯片的需求也在增加。自毀微芯片在完成任務後會通過主動或被動觸發機制消失或降解，從而失去其功能。自毀特性可防止芯片的設計資訊，芯片上存儲的敏感資訊以及電子產品上個人隱私的洩露。自毀微芯片在軍事、情報機構、金融以及許多其他政府和私人組織中尤其重要。另外，在徹底摧毀報廢的手機和電腦等電子產品上的資訊存儲模組方面，自毀微芯片也具有巨大的應用潛力。

微芯片涉及無機或有機半導體，金屬，封裝材料和基底材料。已有大量研究工作致力於利用光、水、溫度或電流等方式使這些材料發生腐蝕溶解、水解、撕裂等物理化學變化，從而達到毀壞微芯片的目的。毫無疑問，這些工作已經取得了良好的進展。但是，大多數自毀機制中都存在兩個主要問題。首先，它們僅適用於特殊構造的微芯片，這些結構與現有的互補金屬氧化物半導體（CMOS）和積體電路（IC）的製造工藝和技術不相容，很難實際應用；其次，這些自毀機制依賴慢速的物理化學反應，要花很長時間才能起效，有的甚至需要數年，這限制了這些技術在保護敏感資訊或資料安全性上的應用。為了廣泛地實現資訊安全、減少資料洩漏的風險，簡單的製造過程和快速的自毀機制非常重要。

In this scenario, the self-destruction microchip based on energetic materials (EMs) and Au/Pt/Cr microheater has outstanding advantages. On the one hand, EMs, such as explosives, propellants and pyrotechnics, store a large amount of energy in the form of chemical energy, which can be released rapidly under external stimulation. The controllable trigger, rapid energy-release process and strong destructive property of EMs aptly meet the requirements of transient chips. Compared with traditional EMs, nano-energetic materials (nEMs) possess smaller size, faster reaction rate, and easier integration with microchips, so they are more suitable for self-destruction microchips. On the other hand, the Au/Pt/Cr microheater itself is prepared by a MEMS-compatible micromanufacturing process, and a small current can trigger a rapid heating of the Pt resistance, so it is suitable for triggering the combustion or explosive reaction of nEMs. Therefore, we build an independent current-triggered self-destructive module by integrating Au/Pt/Cr microheater and nEMs. It can be used as an add-on module to any CMOS and IC design without requiring any specialized chip design, resorbable solutions, special substrates, or encapsulation.

在這種背景下，基於含能材料（EMs）和 Au/Pt/Cr 微加熱器的自毀微芯片具有突出的優勢。一方面，含能材料以化學能的形式存儲了大量能量，這些能量可以在外部刺激下以光、熱等形式迅速釋放，比如炸藥、推進劑和煙火藥。含能材料的可控觸發性，能量釋放的快速性和強大的破壞性，很好地貼合自毀微芯片的需求。而相比傳統含能材料，納米含能材料具有更小的尺寸、更快的反應速率、更容易與微芯片集成，因此更適合於自毀微芯片。另一方面，Au/Pt/Cr 微加熱器本身使用 MEMS 相容的微製造工藝製備，小電流即可引發 Pt 電阻的快速升溫，因此適合用來觸發納米含能材料的燃燒或爆炸反應。因此，我們通過集成 Au/Pt/Cr 微加熱器和納米含能材料，構建一個電流觸發的自毀獨立模組。該模組可以用作任何 CMOS 和 IC 的附加模組，而無需重新設計專門的芯片，更無需複雜的特殊基底或封裝材料。

Preparation of self-destruction microchip

The structure and geometric dimensions of Au/Pt/Cr microheater are determined by the numerical simulation. Then Au/Pt/Cr microheater is manufactured by MEMS technology combined with the use of photolithography technology and physical vapor deposition method. The Au, Pt and Cr layers with the geometric structure determined by the above simulation are sequentially deposited and patterned on the electrical and thermal insulation layer. A layer of photoresist is first deposited on a high thermal-resistance glass substrate, and then the deposited photoresist is patterned by high-precision photolithography; then electron beam evaporation technology is used to deposit the Au/Pt/Cr three layers; finally, high-precision photolithography technology is used to etch the gold on the specific part with gold etching solution. Figure 1a is a single Au/Pt/Cr microheater on a glass substrate with high thermal resistance. The glass substrate with high thermal resistance ensures the low energy consumption of the microheater, and the high stability of Pt/Au ensures the high reliability of the microheater.

The nEMs are integrated with the functional area of the Au/Pt/Cr microheater in the form of a thin film, and then a silicon wafer is glued on the energetic film, as shown in Figure 1b Silicon wafers are commonly used as substrates for microchips, so they can be used to verify the self-destruct effect. During the test, direct current is applied to the contact pads of the microheater through two micrometer probes, which heats the Pt resistance and triggers the combustion or explosion of the nano-energetic film, and finally destroys the silicon wafer.

Results

By applying a voltage of 20V on both contact pads of the self-destruction microchip, the upper silicon wafer was successfully destroyed. The silicon wafer in the central area that was in direct contact with the energetic film was crushed, and the peripheral area was cracked, as shown in Figure 1c. Figure 2 is an image of the moment that the silicon wafer was crushed captured by a high-speed camera.

自毀微芯片的製備

Au/Pt/Cr 微加熱器是根據數值類比結果所確定的結構與幾何尺寸，利用 MEMS 技術進行加工製作的。通過半導體製備工藝，結合使用光刻技術與物理氣相沉積方法，依次在絕緣絕熱層上沉積並圖形化具有上述類比所確定的幾何結構的 Au、Pt 和 Cr 層，得到新型微加熱器陣列，並對其進行了相關電熱性能測試。先在高熱阻特種玻璃基底上沉積一層光刻膠，然後用高精度光刻技術將沉積的光刻膠圖形化；隨後用電子束蒸鍍技術在圖形化的光刻膠上面沉積鉻 / 鉑金 / 金三層金屬，用 lift-off 技術將沉積的鉻 / 鉑金 / 金三層金屬圖形化；最後用高精度光刻技術配合金蝕刻溶液將鉑金特定部分上面的金蝕刻掉，得到高可靠低能耗薄膜電阻微型加熱器，圖 1a 是高熱阻特種玻璃基底上單個的 Au/Pt/Cr 微型加熱器。高熱阻特種玻璃基底保證微型加熱器的低能耗，鉑金 / 金的高穩定性保證微型加熱器的高可靠性能。

納米含能材料以薄膜的形態與 Au/Pt/Cr 微加熱器的功能區域集成，而後在含能薄膜上面膠封一塊硅片進行測試，如圖 1b。硅片是微芯片的常用基底，因此可以用於驗證自毀效果。測試時，通過微米探針在微加熱器兩端通入直流電，引發 Pt 電阻升溫，觸發納米含能薄膜的燃燒或爆炸，從而破壞硅片。

研究成果

通過在自毀微芯片兩端施加 20V 的電壓，成功毀壞上方的硅片，其中與含能薄膜直接接觸的中心區域的硅片被粉碎，周邊區域裂開，如圖 1c 所示。圖 2 是高速攝影捕捉的硅片被粉碎瞬間的圖像。

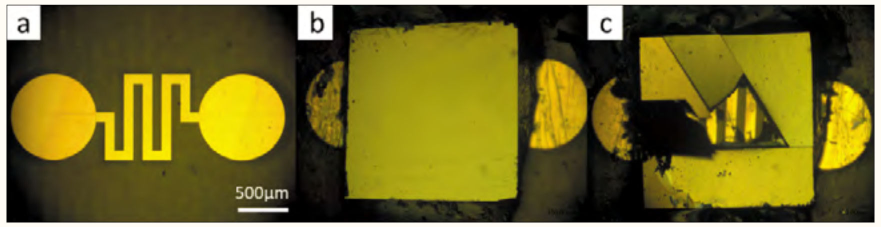
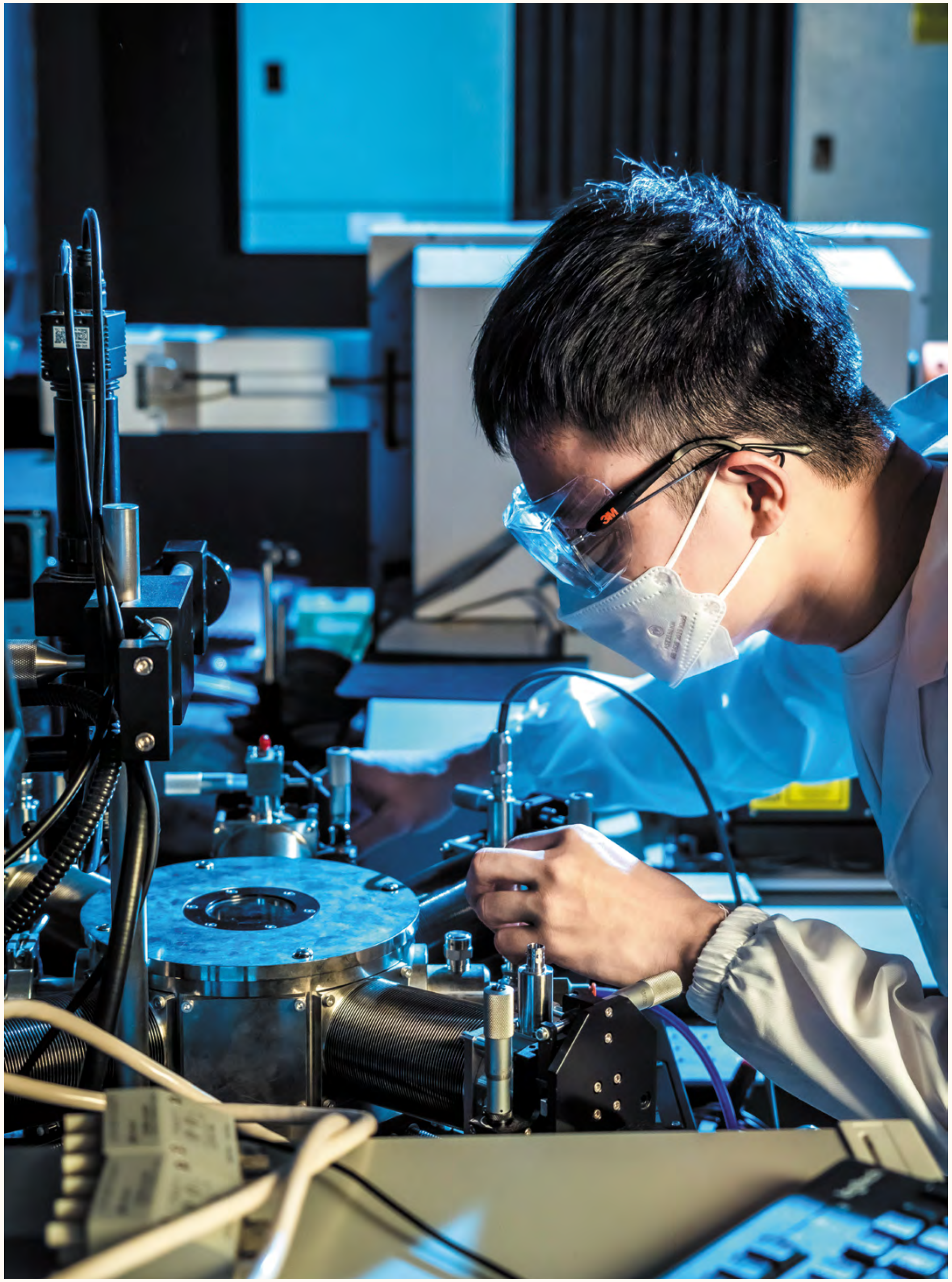


Figure 1 Microscopic images of a single microheater (a), microchip before self-destruction (b), and microchip after self-destruction (c)
圖 1 單個微加熱器 (a)、自毀前微芯片 (b)、自毀後微芯片 (c) 的顯微鏡圖片

Figure 2 The destructing moment of the self-destruction microchip
圖 2 自毀微芯片的毀壞瞬間



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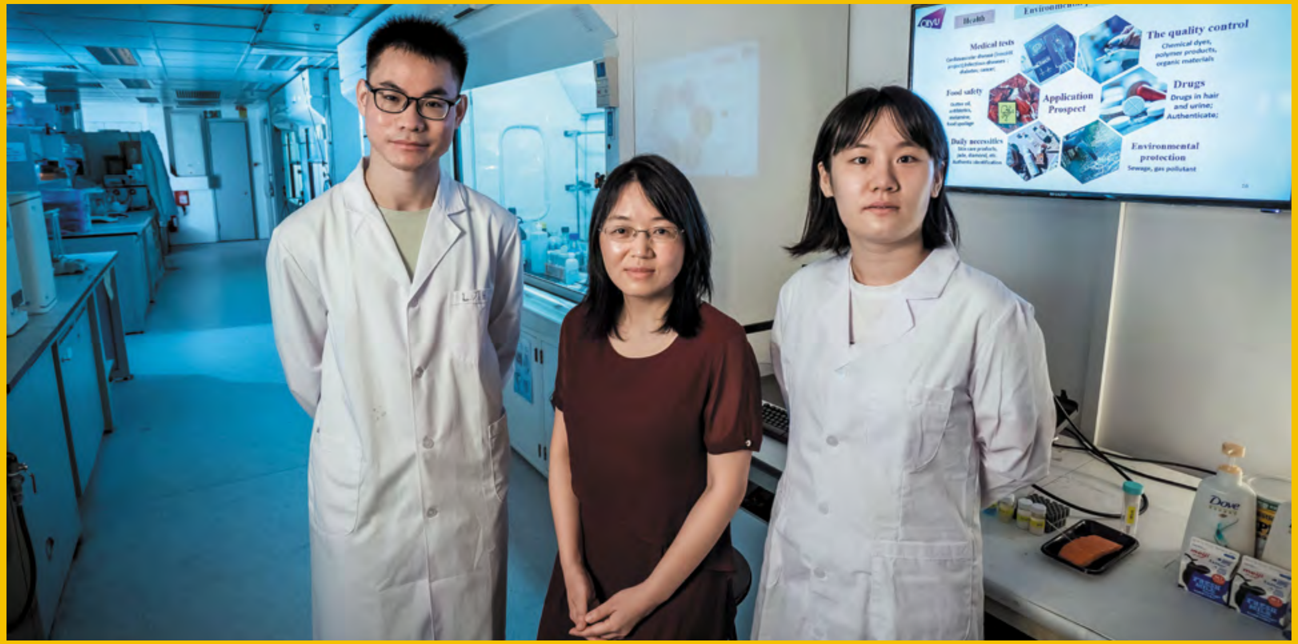
Dr. Yangyang LI's Group
李揚揚博士研究團隊



Based on the excellent laboratory facilities of NPMM, we have developed a convenient, efficient, energy-saving, and environmentally friendly electrochemical processing technique to process the surface of common precious metal materials into nanotopography structures, which shows excellent optical properties and can be used as SERS sensors.[1-3]The sensitivity of the SERS sensor prepared by this method is 100 times higher than that of the current commercial SERS probes, and the cost is tens of times lower than that of the current cheapest commercial SERS sensors(Figure 1). In addition, we have designed an optical adapter (for fixing the SERS sensor) and jointly developed a portable Raman instrument (for acquiring Raman signals) for use with the SERS sensor. The whole set of portable Raman system has the characteristics of good enhancement effect, low cost, easy to use, etc. It has wide application prospects in food safety, major diseases, public safety, environmental protection, etc. The related production technology, process, design and application have been granted seven U.S. patents and four Chinese patents have been granted and won the "Invention Entrepreneurship Award" issued by China Invention Association (National Science Award Social Certificate No. 0123).

依靠國家貴金屬材料工程技術研究中心香港分中心優異的實驗條件，我們發展了簡便、高效、節能、環保的電化學處理工藝，可以將常見的貴金屬材料表面處理為納米拓撲結構，並發現該結構有十分優異的光學性能，可以作為 SERS 探針。[1-3] 本方法製備的 SERS 探針，靈敏度相較目前常見的商用化 SERS 探針提高 100 倍，同時成本比目前最便宜的商用化 SERS 探針還要低幾十倍（圖 1）。此外，我們設計了和 SERS 探針配套使用的光學適配器（用於固定 SERS 探針）以及和企業聯合研發了可携式拉曼儀器（採集拉曼信號）。整套可携式拉曼系統具有增強效果好、成本低廉、使用方便等特點，在食品安全，重大疾病，公共安全，環境保護等方面有廣泛的應用前景。相關生產技術，工藝，設計以及應用已獲七項美國專利，四項中國專利授權，並榮獲中國發明協會頒發的“發明創業獎”（國科獎社證字第 0123 號）。

Inspired by the ancient Chinese practice of "testing poison with a silver needle", we applied our self-developed portable Raman system for food safety and major disease detection (Figure 2). Unlike conventional SERS sensors, our silver needle-based SERS sensors can be used for non-destructive rapid detection of meat products, e.g., detecting malachite green residues in fish,[4] identifying different nutrients in meat products,[1] and detecting heavy metals in meat [5]. In addition, it can also be used for the rapid detection of dairy products, the identification of the authenticity of skin care products and the identification of prohibited additives (Figure 3), and the on-site detection of pesticide residues on the surface of vegetables and fruits.

Since 2020, the novel coronavirus disease (COVID-19) has become a global public health emergency, with more than 500 million people infected worldwide by June 2022, including more than 6.3 million deaths. We have co-opera with Guangzhou Kingmed Ltd. (which has tested more than 170 million people for the new coronavirus), and developed a SERS-based fast screening technology for the new coronavirus. A patent (ZL202111108253.7) based on this technology has been granted. In order to investigate the SERS detection mechanism of novel coronavirus disease more deeply, we collaborated with Professor Zhiwei CHEN's team from HKU to study the detection of different subtypes of the virus based on platform of the State Key Laboratory of Emerging Infectious Diseases. In addition, we have conducted blind testing of clinical samples in collaboration with the BGI group and will continue to conduct rapid bacterial screening experiments based on the portable Raman system.

受到中國古代“銀針試毒”的啟發，我們將自主研發的可携式拉曼系統應用于食品安全的檢測以及重大疾病的檢測（圖 2）。與傳統 SERS 探針不同的是，我們基於銀針開發的 SERS 探針可以用於肉製品的無損快速檢測，例如：檢測魚肉裡面殘留的孔雀石綠；[4] 識別肉製品中的不同營養成分；[1] 探測肉裡面的重金屬 [5]。此外，也可以用於乳製品的快速檢測，護膚品的現場真假鑒別及違禁添加的識別（圖 3），蔬菜水果表面的農藥殘留的現場檢測。

2020 年以來，新型冠狀病毒病（COVID-19）已成為全球突發公共衛生事件，截止 2022 年 6 月，全球有超過 5 億人感染，其中死亡人數超過 630 萬。我們與廣州金域醫學檢驗集團股份有限公司（目前已經測試新冠病毒超過 1.7 億人次）展開合作（已經簽訂三方合作協定），研發基於 SERS 檢測的新冠病毒快篩技術，聯合申請專利“基於拉曼光譜的新型冠狀病毒核酸檢測試劑盒及方法”已獲授權 (ZL202111108253.7)。為了更深入研究新型冠狀病毒病的機制，我們與香港大學陳志偉教授團隊合作，基於新發傳染病國家重點實驗室研究不同亞型的病毒檢測。此外，我們還與華大集團合作進行了臨床樣本的盲測實驗，後續會繼續開展基於可携式拉曼系統的細菌快速篩選實驗。

Cardiovascular disease (CVD) has the highest morbidity and mortality rates in the world, it is one of the costliest diseases in the health care system. One of the critical keys to reducing CVD mortality is the development of more effective detection methods for early prediction and intervention. In collaboration with the Hong Kong Centre for Cardiovascular Health Engineering (COCHE) and with funding from the InnoHK project, we have conducted an exploratory study on early screening methods for cardiovascular diseases based on our in-house developed portable Raman system. It was found to have excellent results in detecting uric acid (one of the markers of cardiovascular disease), which can initially identify urine and blood of cardiovascular patients.

In addition, based on the high-performance, surfactant-free and self-developed SERS sensor, a series of research results on the reaction mechanism have been published. [6-8]

In conclusion, the portable Raman system developed by NPMM has great potential for applications in food safety, rapid screening of major diseases, authentication of daily consumer products, and mechanistic investigation of catalytic reactions.

心血管疾病 (CVD) 是世界上發病率和死亡率最高的一類疾病，也是衛生行業治療成本最高的疾病。降低心血管疾病死亡率的關鍵之一就是研發更有效的檢測方法來進行早期預測和干預。我們與香港心腦血管健康工程中心 (COCHE) 合作，在香港重大研發計畫 InnoHK 專案的資助下，基於自主研發的可携式拉曼系統對心血管疾病的早篩方法進行了探索研究。發現對尿酸（心血管疾病的標誌物之一）有優異的檢測效果，可以初步識別心血管患者的尿液和血液。

此外，由於高性能且無表面活性劑，自主研發 SERS 探針也被用於反應機理研究，並取得了系列成果。[6-8]

總之，基於貴金屬分中心研發的可携式拉曼系統在食品安全，重大疾病快速篩查，日用品真偽鑒別，催化反應的機理探究等領域有著巨大的應用前景。

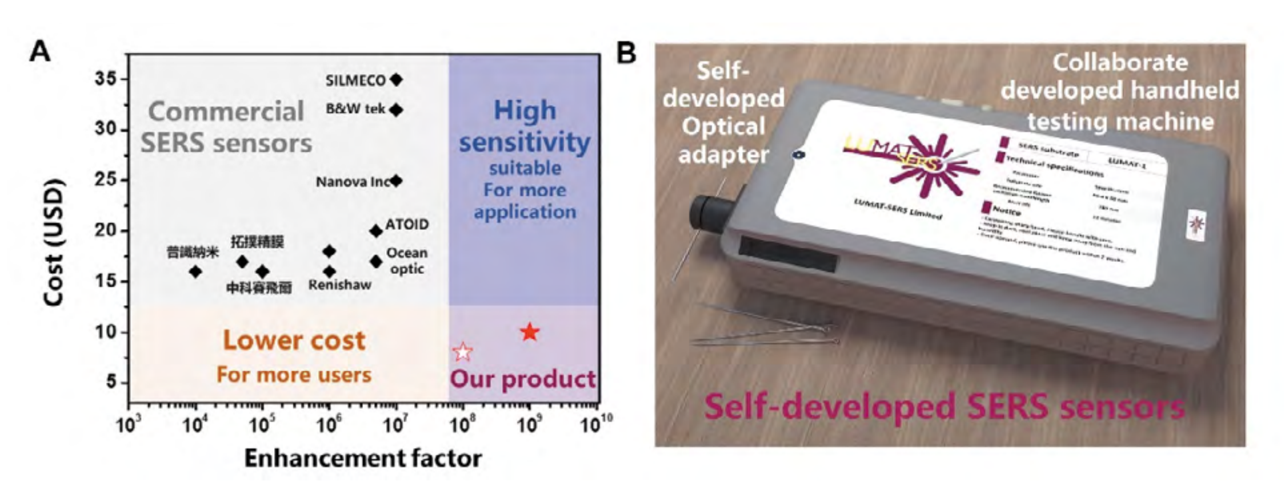


Figure 1 (A) Comparison of self-developed and commercial probes; (B) Portable Raman systems.
圖 1 （A）自研探針和產業化探針的比較；（B）可携式拉曼系統。

Figure 2 Application case of self-developed portable Raman system.
圖 2 自主研發可携式拉曼系統的應用案例。

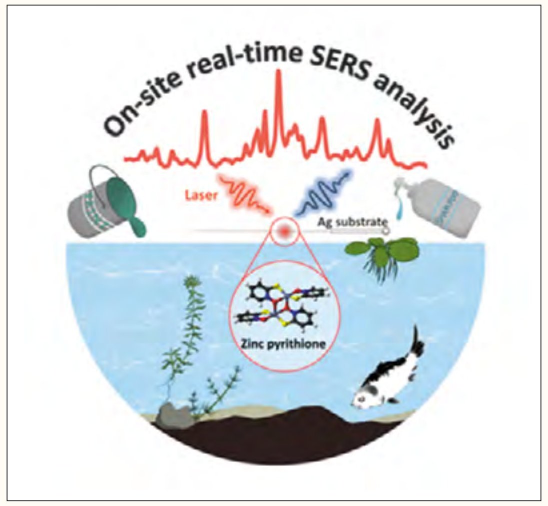


Figure 3 Rapid detection of zinc pyrithione in real samples.
圖 3 實際樣品中吡硫翁鋅嘅快速檢測。

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Dr. Zhanxi FAN's Group
范戰西博士研究團隊

The precious metal-based catalyst is of great significance in the chemistry industry. Compared to non-precious metal-based catalysts, precious metal-based catalysts possess irreplaceable catalytic activity, good selectivity, use safety, and stability, thus making them the most important material in both conventional thermal catalytic reactions and electrochemical catalytic reactions including electrochemical CO$_2$reduction (CO$_2$RR), NO$_3^-$ reduction reaction(NO$_3$RR), and water splitting. In the past few years, we develop several kinds of precious metal-based catalysts for CO$_2$RR and they show very good performance in both aqueous CO$_2$RR and Li-CO$_2$ batteries.

For electrocatalytic CO$_2$RR, precious metals, such as Ag, Au, and Pd are excellent catalysts with acceptable CO activity and selectivity in an aqueous system. And many different methods are used to further improve their performance.[1][2] Unusual phase metal nanomaterials usually possess much higher intrinsic catalytic activity than their conventional phase.[3] By rational design and careful preparation, we prepared a series of metal-based catalysis with an unconventional phase. And for the first time, we report the surface molecular functionalization of unusual phase 4H/face-centered cubic (fcc) Au nanorods with 5-mercapto-1-methyltetrazole (MMT) for high-performance electrochemical CO$_2$RR under industry-relevant current density, as shown in Figure 1. [4] The MMT-modified 4H/fcc Au nanorods (denoted as 4H/fcc Au-MMT) demonstrate significantly enhanced CO$_2$RR performance than the initial oleylamine (OAm)-capped 4H/fcc Au nanorods (denoted as 4H/fcc Au-OAm) in both H-type cell and flow cell under a wide range of potentials and current densities. Significantly, MMT-modified 4H/fcc Au nanorods deliver an excellent carbon monoxide selectivity of 95.6% under the industry-relevant current density of 200 mA cm^{-2}. In addition, surface molecular functionalization of 4H/fcc Au nanorods with a family of MMT derivatives can also remarkably increase the CO$_2$RR performance. And this facile surface molecular functionalization method can also be extended to the conventional fcc Au nanomaterials.

Ru, Ir and Rh are effective catalysts for CO$_2$RR in Li-CO$_2$ batteries. Li-CO$_2$ batteries have been regarded as a promising candidate for the next-generation high-performance energy conversion and storage techniques with carbon-neutral capability. It can not only reduce the CO$_2$ into C but also provide energy for specific applications. By rational design and careful preparation, we developed a versatile method for the controllable synthesis of ultrathin 2D Ru-M (M = Co, Ni, and Cu) nanosheets (NSs) as the cathode catalysts for aprotic Li-CO$_2$ batteries, which effectively decrease the charge voltage and overpotential, as shown in Figure 2.[5] Impressively, the charge voltage and corresponding overpotential for RuCo NSs are 3.74 V and 0.94 V, respectively, which are much lower than those of RuCo nanoparticles and bare carbon nanotubes, and also superior over most of the reported metal and metal-based catalysts for Li-CO$_2$ batteries so far. Ex/in situ experimental studies and theoretical investigations suggest that RuCo NSs can facilitate the round-trip CO$_2$RR and CO$_2$ER kinetics through the promoted adsorption toward Li and CO$_2$ and also the enhanced electron interaction with Li$_2$CO$_3$ by in-plane RuCo alloy active sites, respectively.

貴金屬基催化劑在化學工業中具有重要意義。與非貴金屬基催化劑相比，貴金屬基催化劑具有不可替代的催化活性、良好的選擇性、使用安全性和穩定性，使其成為常規熱催化反應和包括電催化二氧化碳還原 (CO$_2$RR)、NO$_3^-$ 還原反應（NO$_3$RR）以及水分解在內的電化學催化反應中最重要的材料。在過去的幾年裡，我們開發了幾種用於 CO$_2$RR 的貴金屬基催化劑，它們在水系 CO$_2$RR 和 Li-CO$_2$ 電池中都表現出非常好的性能。

對於電催化 CO$_2$RR，貴金屬（如 Ag、Au 和 Pd）是優異的催化劑，在水體系中具有可接受的 CO 活性和選擇性。並且採用了許多不同的方法來進一步提高其性能 [1][2]。非常規性相金屬納米材料通常具有比常規相高得多的內在催化活性 [3]。通過合理設計和精心製備，我們製備了一系列具有非常規相的金屬基催化劑。我們首次報導了具有 5- 巰基 -1- 甲基四唑 (MMT) 表面分子功能化的非常規相 4H/ 面心立方 (fcc) Au 納米棒，用於在工業相關電流密度下實現高性能電化學 CO$_2$RR，如圖 1 所示 [4]。經 MMT 修飾的 4H/fcc Au 納米棒（表示為 4H/fcc Au-MMT）與初始油胺 (OAm) 包覆的 4H/fcc Au 納米棒（表示為 4H/fcc Au-OAm）相比，在各種電位元和電流密度下的 H 型池和流通池系統中表現出顯著增強的 CO$_2$RR 性能。值得注意的是，在工業相關的 200 mA cm^{-2} 電流密度下，MMT 改性的 4H/fcc Au 納米棒表現出 95.6% 的出色一氧化碳選擇性。此外，具有 MMT 衍生物家族的 4H/fcc Au 納米棒的表面分子功能化也可以顯著提高 CO$_2$RR 性能。而且這種簡便的表面分子功能化方法也可以推廣到傳統的面心立方金納米材料。

Ru、Ir 和 Rh 是 Li-CO$_2$ 電池中 CO$_2$RR 的有效催化劑。 Li-CO$_2$ 電池被認為是具有碳中和能力的下一代高性能能量轉換和存儲技術的有希望的候選者。它不僅可以將二氧化碳還原為碳，還可以為特定應用提供能量。通過合理設計和精心準備，我們開發了一種可控合成超薄二維 Ru-M（M = Co、Ni 和 Cu）納米片（NSs）作為非質子 Li-CO$_2$ 電池正極催化劑的通用方法，這些材料可以有效降低充電電壓，如圖 2 所示 [5]。令人印象深刻的是，RuCo NSs 的充電電壓和相應的過電位分別為 3.74 V 和 0.94 V，遠低於 RuCo 納米顆粒和裸碳納米管，也優於迄今為止大多數已報導的用於 Li-CO$_2$ 電池的金屬和金屬基催化劑。外 / 原位實驗研究和理論研究表明，RuCo NSs 可以通過促進對 Li 和 CO$_2$ 的吸附以及通過面內 RuCo 合金活性位點增強與 Li$_2$CO$_3$ 的電子相互作用來促進往返 CO$_2$RR 和 CO$_2$ER 動力學。

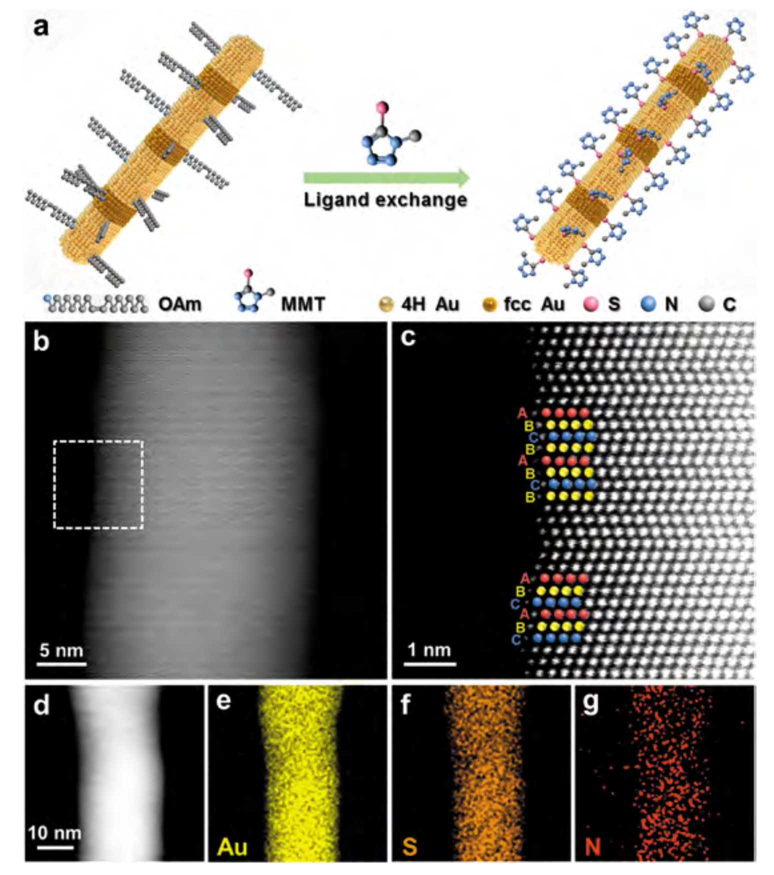

Figure 1 Preparation method and structural characterization of 4H/fcc Au-MMT.
圖 1 4H/fcc Au-MMT 的製備方法和結構表徵。

In addition, these kinds of precious metals can also be used to tune the selectivity of Cu-based catalysts via forming tandem catalysts or heterostructures, especially for the production of value-added multicarbon products (C_{2+}). Generally, Ag, Au, and Pd are CO-selectivity catalysts, and Cu can reduce CO to multi-carbon products more easily. A Tandem catalyst combining precious metals with Cu can decrease the CO_2RR energy barrier and improve the activity and selectivity of C_{2+}. Thus, via the rational control of surfactant and reduction kinetics of Cu precursor, we synthesize three kinds of Ag–Cu Janus nanostructures with {100} facets (JNS-100), as shown in Figure 3.[6]These Ag–Cu JNS-100 are all highly selective tandem catalysts for the electrochemical reduction of CO_2 to C_{2+} products. Impressively, the Cu nanoparticles are grown along one side of the silver nanocubes, which is the first reported cube-to-cube Junus structure. Significantly, Cu(100) facet is beneficial for the production of C_{2+} products, so the novel Janus structure shows very good CO_2RR performance toward C_{2+} products. In particular, Ag65–Cu35 JNS-100 can effectively achieve excellent faradaic efficiency of 54% and 72% for C_2H_4 and C_{2+} products, respectively.

In summary, we realized the controlled synthesis of unconventional phase Au-based catalysts, Ru-M ultrathin nanosheet, and Ag-Cu cube-to-cube Junus structure for CO_2 reduction. Phase engineering of precious metals will not only enrich the catalysts for CO_2RR and beyond but also inspire new theories in material science and catalysis science.[7][8] And the rational design of hetero nanostructures with the integration of two or more materials are one of the most effective ways to improve their performance, which will contribute to the development of structure control and interface engineering. And the innovation in materials will finally contribute to the practical application in chemistry and beyond.

此外，這些貴金屬物質還可用於通過形成串聯催化劑或異質結構來調節銅基催化劑的選擇性，特別是用於生產增值多碳產品（C_{2+}）。一般來説，Ag、Au 和 Pd 是 CO 選擇性催化劑，Cu 可以更容易地將 CO 還原為多碳產物。將貴金屬與 Cu 結合的串聯催化劑可以降低 CO_2RR 能壘，提高 C_{2+} 的活性和選擇性。因此，通過合理控製表面活性劑和 Cu 前驅體的還原動力學，我們合成了三種具有 {100} 晶面的 Ag-Cu Janus 納米結構（JNS-100），如圖 3 所示 [6]。這些 Ag-Cu JNS-100 是所有用於將 CO_2 電化學還原為 C_{2+} 產物的高選擇性串聯催化劑。令人印象深刻的是，Cu 納米顆粒沿著銀納米立方體的一側生長，這是第一個報導的立方體到立方體 Junus 結構。值得注意的是，Cu(100) 晶面有利於 C_{2+} 產物的生產，因此新穎的 Janus 結構對 C_{2+} 產物表現出非常好的 CO_2RR 性能。特別是，Ag65—Cu35 JNS-100 可以有效地實現對 C_2H_4 和 C_{2+} 產品分別達到 54% 和 72% 的優異法拉第效率。

總體來説，我們實現了非常規相 Au 基催化劑、Ru-M 超薄納米片和 Ag-Cu 立方體對立方體 Junus 結構的可控合成，並用於 CO_2 還原。貴金屬相工程不僅豐富了 CO_2RR 及其他領域的催化劑，還將激發材料科學和催化科學的新理論 [7][8]。而將兩種或多種材料整合在一起的異質納米結構的合理設計是提高其性能的最有效途徑之一，這將有助於結構控制和界面工程的發展。材料的創新最終將有助於化學及其他領域的實際應用。

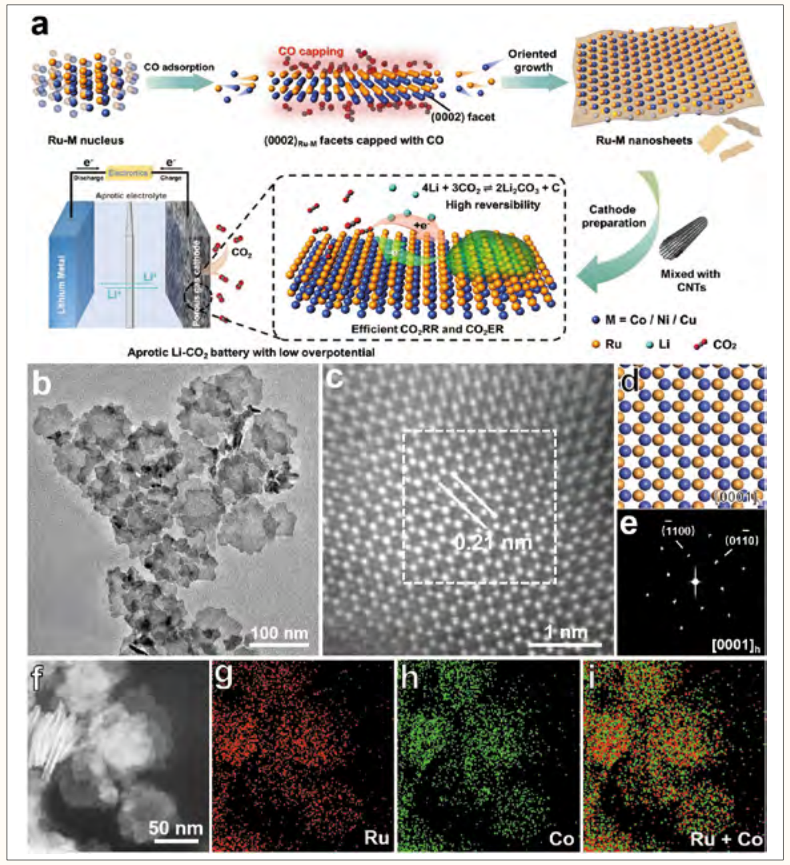

Figure 2 Synthetic route and structural characterization of ultrathin RuCo alloy nanosheets for the aprotic Li-CO_2 battery.
圖 2 用於非質子 Li-CO_2 電池的超薄 RuCo 合金納米片的合成路線和結構表徵。

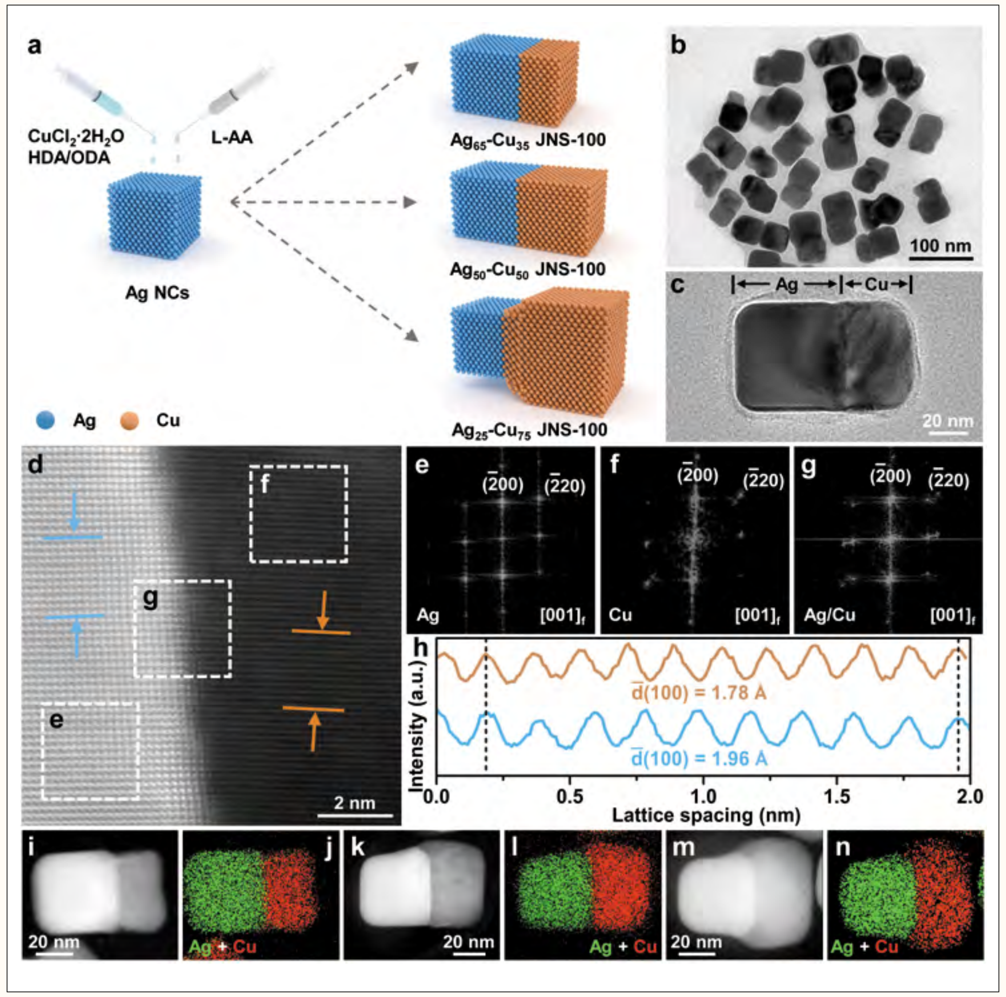

Figure 3 Synthetic protocol and structural characterization of Ag—Cu JNS-100.
圖 3 Ag-Cu JNS-100 的合成方案和結構表徵。

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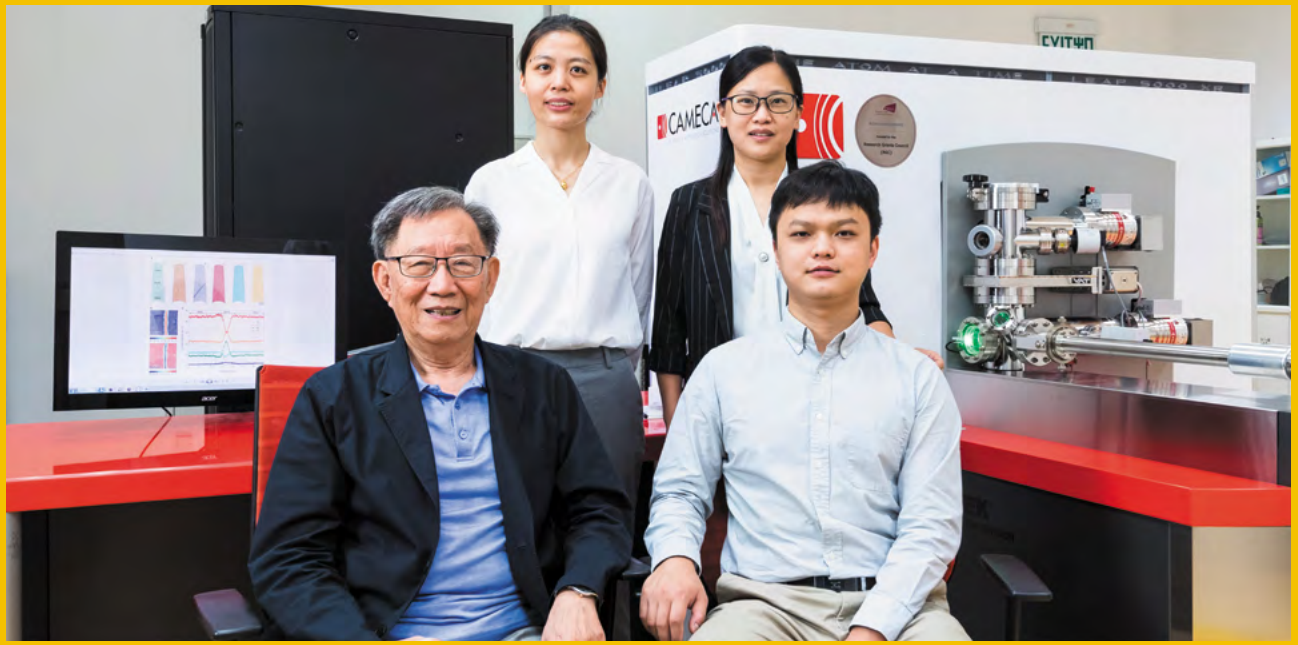
Dr. Yang Tao's Group
楊濤博士研究團隊

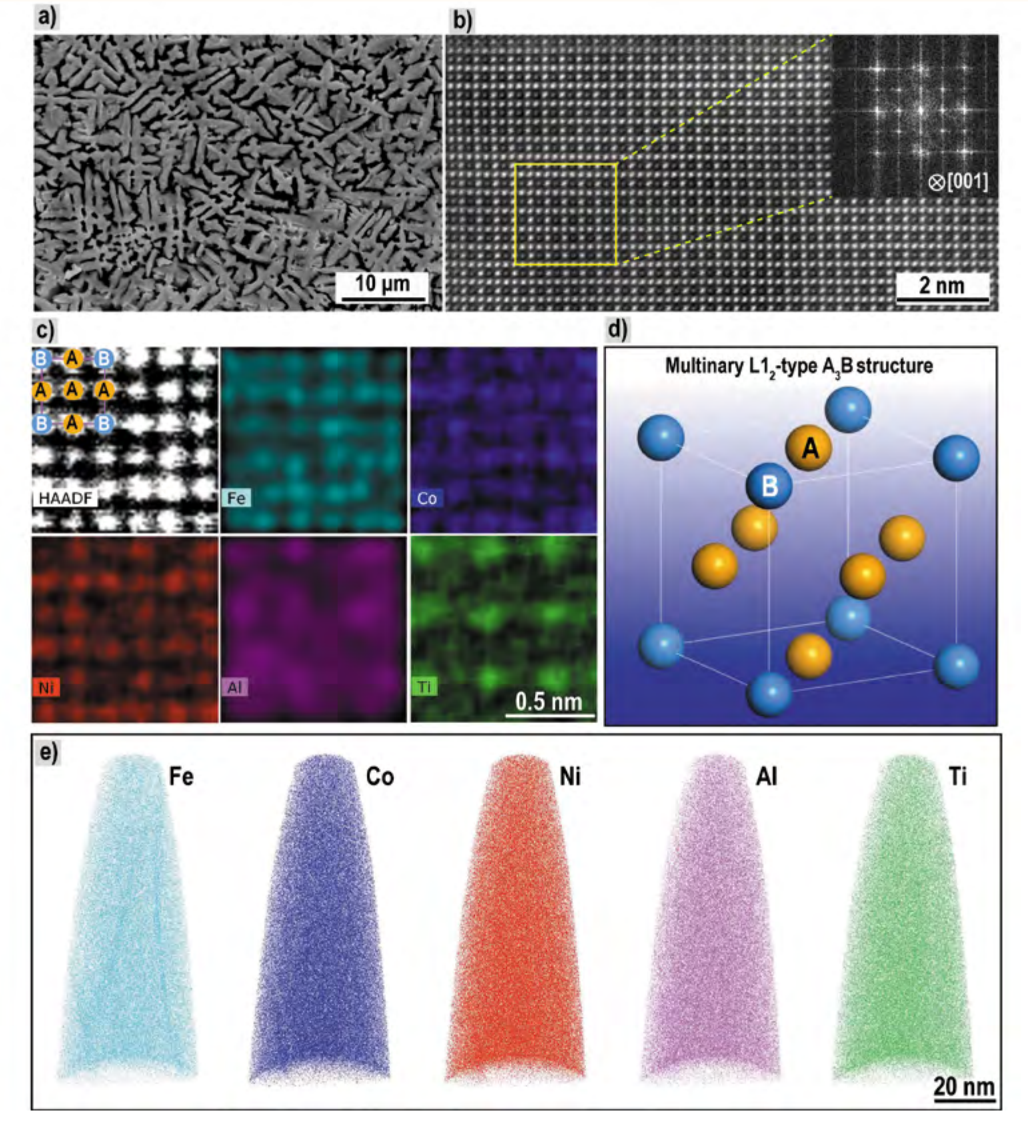


Development of the high-performance noble-metal-free electrocatalyst for hydrogen evolution based on the novel multinary intermetallic

Electrochemical water splitting offers an attractive approach for hydrogen production. However, the lack of high-performance cost-effective electrocatalyst severely hinders its applications. In our work, a multinary high-entropy intermetallic (HEI) that possesses an unusual periodically ordered structure containing multiple non-noble elements is developed, which can serve as a highly efficient electrocatalyst for hydrogen evolution. This HEI exhibits excellent activities in alkalinity with an overpotential of 88.2 mV at a current density of 10 mA cm^{-2} and a Tafel slope of 40.1 mV dec^{-1}, which are comparable to those of noble catalysts. Theoretical calculations reveal that the chemical complexity and surprising atomic configurations provide a strong synergistic function to alter the electronic structure. Furthermore, the unique L1_2-type ordered structure enables a specific site-isolation effect to further stabilize the H_2O/H* adsorption/desorption, which dramatically optimizes the energy barrier of hydrogen evolution. Such an HEI strategy uncovers a new paradigm to develop novel electrocatalyst with superior reaction activities.

基於新型多元金屬間化合物的高性能無貴金屬析氫電催化劑的研製

電化學水裂解為制氫提供了一種非常具有吸引力的方法。然而，高性能、高性價比的電催化劑的缺乏嚴重阻礙了其廣泛應用。在我們的工作中，我們開發了一種多元高熵金屬間化合物（HEI），它具有一種特殊的週期性有序結構，含有多種非貴元素，被證明可以作為一種高效的析氫電催化劑。該 HEI 在鹼性條件下表現出優異的活性，在 10 mA cm^{-2} 的電流密度下，其過電位為 88.2 mV 和 40.1 mV dec^{-1} 的塔菲爾斜率，這一出色的性能可以與貴金屬催化劑相媲美。理論計算表明，化學元素的複雜性及其特殊的原子構型與佔位元為改變電子結構提供了強大的協同作用。此外，獨特的 L1_2 型有序結構使特定的位置隔離效應能夠進一步穩定 H_2O/H* 吸附 / 解吸，從而顯著優化析氫的能量屏障。這種 HEI 策略為開發具有優異反應活性的新型電催化劑提供了新的範例，有望在未來替代傳統的貴金屬催化劑。



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Feature
科研專題故事

CityU's *Strategic Plan 2020-2025: World-class Research and Education* serves as a roadmap for raising CityU's levels of excellence in both research and education and in bringing benefits to the world. Matter is highlighted as one of the five interdisciplinary strategic themes. NPMM members are committed to advancing the frontiers of knowledge by undertaking cutting-edge research. Their top-level research is highly recognized by CityU and featured as CityU Research Story on the CityU website. Some of these research stories are selected in this section.

城大*《2020-2025年策略性發展計劃：世界級研究與教學》*訂立出明確的發展方向，持續提升城大的卓越教研水平，推動人類社會進步，“物質科學”亦是五大主要跨學科研究镇域之一。貴金屬分中心成員孜孜不倦進行尖端研究，推動學科發展，獲得城大高度肯定，他們的研究故事更被收錄到城大網站，得到重點介紹。此章節從中摘錄一些成員的研究故事，以示貴金屬分中心在物質科學上的卓越成就。

2 0 1 8

ADVANCED CATALYST

先進催化劑

Novel “Ink” Gives Birth to 4D Printing for Ceramics

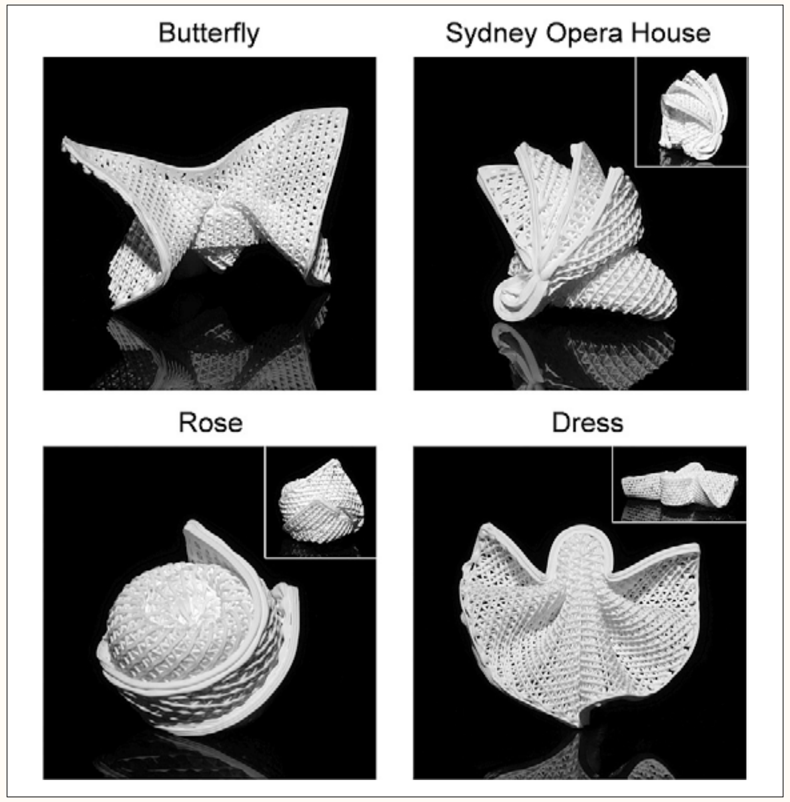
全新「墨水」的誕生帶來陶瓷 4D 打印

Due to its high melting point, ceramic cannot be cast or shaped easily. Hence, it has always been a challenge to produce ceramic with conventional laser printing or existing 3D-printed ceramic precursors. A research team led by Professor Jian LU has achieved groundbreaking results in materials research by developing the world’s first 4D printing for ceramics. The product is mechanically robust and able to form complex shapes, turning a new page in structural applications of ceramics. The innovation was published in the top academic journal Science Advances under the title “Origami and 4D printing of elastomer-derived ceramic structures”.

To overcome the challenge imposed by the intrinsic properties of ceramics, the team has developed a novel “ceramic ink”, which is a mixture of polymers and ceramic nanoparticles. Produced by this new ink, products are soft and can be stretched beyond three times their initial length. The flexibility and stretchability allows the ceramic precursors to form complex shapes.

因為擁有高熔點，陶瓷並不易被鑄造或成型。因此，使用傳統激光打印技術或現有的 3D 打印陶瓷前驅體材料來製備陶瓷一直是個難題。呂堅教授研究團隊開發了全球首套陶瓷 4D 打印技術，並在物料研究方面取得了突破成果。所生產的產品不但堅固，亦能實現複雜形狀，從而為結構陶瓷的應用翻開了新的一頁。相關研究結果以〈Origami and 4D printing of elastomer-derived ceramic structures〉為題發表在頂級學術期刊《*科學進展*》上。

為了克服陶瓷固有特性所帶來的挑戰，本團隊開發了一種新穎的，以聚合物和陶瓷納米顆粒的混合物製成的「陶瓷墨水」。使用此墨水所生產的產品質料柔軟，並可以拉伸至其原本長度的 3 倍。陶瓷前驅體的柔韌性和可拉伸性使其能形成複雜的形狀。



The 3D-printed ceramic precursors printed with the novel “ceramic ink” are soft and stretchable, enabling complex shapes, such as origami folding.
採用「陶瓷墨水」以 3D 打印出來的陶瓷前驅體，既柔軟且可以拉伸，可用於製造複雜的形狀，例如摺紙結構。

Based on the innovative elastic precursors, the team has reached another milestone by developing two methods of 4D printing of ceramics. 4D printing is a technique combining conventional 3D printing with the fourth dimension, where the printed objects can undergo re-shaping or self-assembly over time with external stimuli. The new methods involve the use of elastic energy stored in the stretched precursors for shape morphing. In the first method, a 3D-printed ceramic precursor and substrate are printed with the novel ink. The substrate is stretched and the precursor is placed on it connected by printed joints. The materials are morphed into a designed shape under computer-programmed control of time and release of the stretched substrate. In the second method, the designed pattern is directly printed on the stretched ceramic precursor. It undergoes self-morphing process upon release under computer-programmed control.

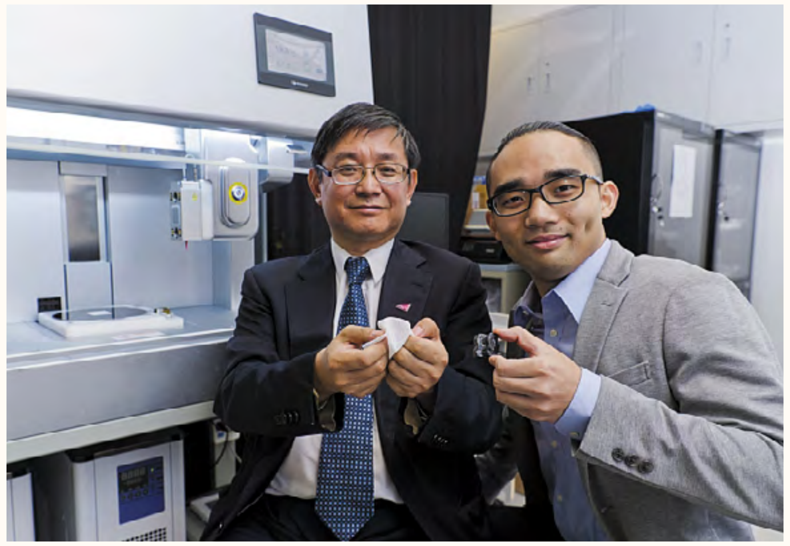
It is believed the shape-morphing capability of the printed ceramic precursors would open door to wide applications of the material. Given the exceptional performance of ceramic materials in transmitting electromagnetic signals, one promising application will be for electronic devices. The team is enthusiastic to witness ceramic products playing a crucial role in the manufacture of electronic products with the arrival of 5G networks. Further, this robustness and tolerance toward high temperatures of the 4D-printed ceramic lay a solid foundation for it to be used as a propulsion component in the aerospace industry and space exploration. With the breakthrough in material and advancement in 4D-printing technique, the team will strive to enhance the mechanical properties of the material.

The research was supported by the Major Program of NSFC, the Hong Kong CRF and TBRS, ITC via the NPMM, the Guangdong Provincial Department of Science and Technology, and the Science and Technology Innovation Commission of Shenzhen Municipality. This 4D printing-based ceramic technology was also listed in the European Commission’s *“100 Radical Innovation Breakthroughs for the Future”* as an example of innovation in 4D printing.

基於新型彈性前驅體材料，本團隊開發了兩種 4D 打印陶瓷的方法，從而實現了另一個重要里程碑。 4D 打印是一種將傳統 3D 打印與第四維相結合的技術，其中打印的物體可在外部刺激下隨時間進行變形或自組裝。此新方法需要使用儲存在拉伸前驅體中的彈性能來改變形狀：第一種方法便是以該新型墨水打印出陶瓷前驅體和基底，然後基底被拉伸，而前驅體則被放置在上，二者之間打印相應的連接點。在程序控制時間和釋放拉伸基底的效果下，這些材料會變化為所設計的形狀。在第二種方法中，設計的圖案則直接打印在拉伸的陶瓷前驅體上。通過程式控制，前驅體會在預應變釋放後會進入自變形的過程。

可打印陶瓷前驅體的變形能力，將為該材料的廣泛應用打開大門。基於陶瓷材料在電磁信號傳輸上的優異性能，電子設備將會是一個有前景的應用。在 5G 網絡時代下，陶瓷材料在電子產品製造領域中亦佔上重要一席。此外，4D 打印陶瓷的堅固性和耐高溫性為其在航空航天工業和太空探索中用作推進部件奠定了堅實的基礎。隨着材料的突破和 4D 打印技術的進步，本團隊將進一步提高該材料的機械性能。

相關研究得到國家自然科學基金會重大項目、香港大學教育資助會的協作研究金和主題研究計劃、香港創新科技署透過貴金屬分中心、廣東省科學技術廳、深圳市科技創新委員會等資助。該 4D 打印陶瓷技術被歐盟委員會列為《*面向未來的 100 項顛覆性技術創新*》中 4D 打印案例之一。



Professor Jian LU (left), Dr. Guo LIU and the research team have developed the world's first-ever 4D printing for ceramics.
呂堅教授（左）、劉果博士以及研究團隊開發全球首套 4D 打印陶瓷技術。

2019

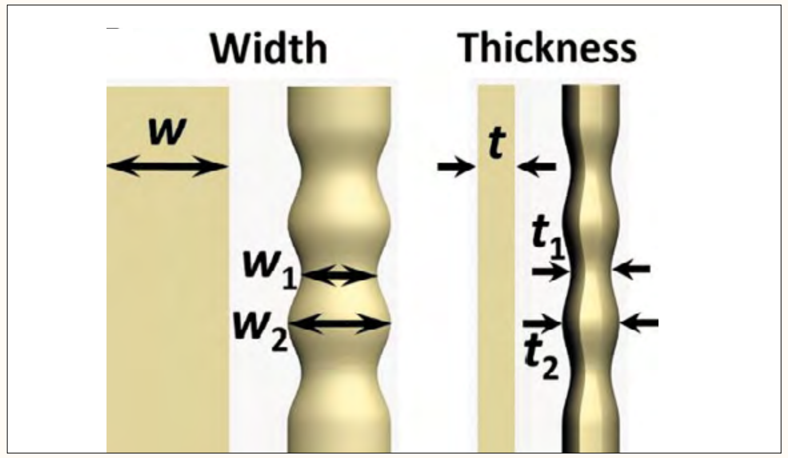
Ultrathin Hexagonal Gold Nanoribbons: Liquid outside and Solid inside
超薄六方結構的金納米帶：外圍液體包含內在固體

A research team co-led by Professor Hua ZHANG and Professor Yang LU, collaborated with researchers of McGill University, revealed an intriguing phenomenon: while the ultrathin gold nanoribbons with unique hexagonal (4H type) crystal phase shows "liquid-like" behavior under heating, its hexagonal crystalline structure remains stable. This groundbreaking observation deepens our understanding of thermal stability of this new metallic nanomaterial and facilitates its practical applications. The research findings were published in the scientific journal *Matter* from Cell Press, titled "Thermal effect and Rayleigh instability of ultrathin 4H hexagonal gold nanoribbons".

Having a size smaller than 10nm, ultrathin metal nanostructures possess favorable properties distinguishing them from bulk metals and regular metallic nanostructures, guaranteeing their role as promising carrier for future nanoelectronics and catalysis. In particular, ultrathin gold nanoribbons with metastable hexagonal phase introduced by Professor Zhang from CityU in 2015 have great potential in plasmonic and catalytic applications. The research revealed the thermal responses and phase stability of the material at elevated temperature by advanced in situ transmission electron microscopy (TEM) techniques.

由張華教授、陸洋教授與麥吉爾大學的學者共同領導的一項研究發現了一個有趣的現象：雖然具有獨特六方 (4H 型) 晶相的超薄金納米帶在加熱下表現出「液體狀」的行為，但其六方晶體結構卻能保持穩定。這一突破性的發現加深了我們對這種新型金屬納米物料熱穩定性的理解，並促進了它的實際應用可能性。研究結果在 Cell Press 旗下的科學期刊《*Matter*》上發表，題為〈Thermal effect and Rayleigh instability of ultrathin 4H hexagonal gold nanoribbons〉。

尺寸小於 10 納米的超薄金屬納米結構具有將它們與塊狀金屬和常規金屬納米結構區分開的特質，若利用它們作未來納米電子學和催化載體，這特性將會帶來非常理想和穩定的作用。當中由張教授於 2015 年推出具亞穩態六方相的超薄金納米帶，在等離子體和催化應用方面具有尤其巨大的潛力，該研究亦透過先進的原位透射電子顯微鏡 (TEM) 技術，揭示了該物料在高溫下的熱響應和相穩定性。



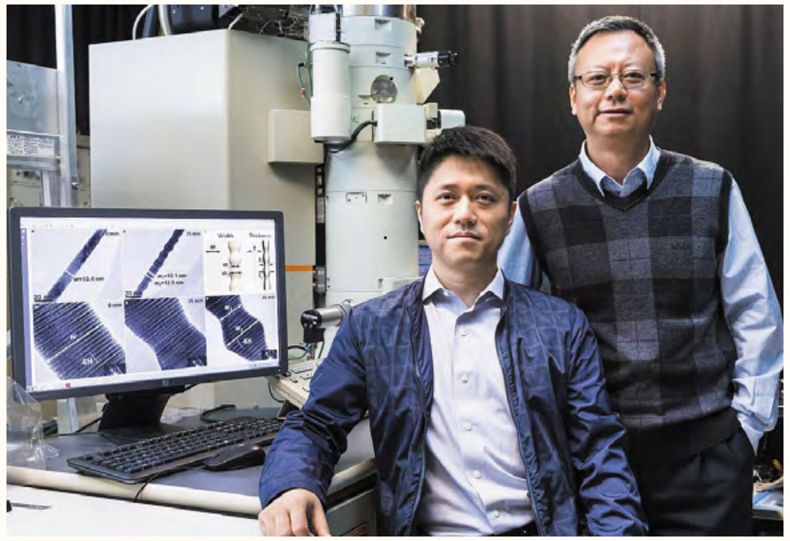
Schematic diagrams of the shape evolution Schematic diagrams of the shape evolution before and after E-beam irradiation. It can be speculated that the surface gold atoms would diffuse and migrate towards the thickness direction to minimize the surface area during the Rayleigh instability process. Therefore, the thicknesses, i.e. both the necking part (t1) and bulging part (t2) increased.
受電子束照射前後的形貌演變示意圖。研究團隊推測在瑞利不穩定發生時，表面的金原子會向厚度方向擴散及遷移，以令表面積變得最小，因此 t1（頸縮）和 t2（凸出）兩部分的厚度都會增加。

Under the team's best endeavor, it was discovered that under moderate heating, the geometric shape of the 4H gold nanoribbons changed but crystalline phase inside remained. Its shape experienced "Plateau-Rayleigh instability" – changing from a smooth shape into a sinusoidal one under low heating temperature. This could be explained by the small size of ultrathin nano-metal which surface atom-to-overall volume ratio is relatively high, such that the diffusion of surface atoms significantly impacts its overall shape, resulting in drastic change of shape when heated. It was also observed that, to reduce surface area while constant total volume matins, the ribbon shape of gold nanoribbons possesses a general tendency to become a cylindrical shape when heated. Yet, the most surprising finding was, despite its liquid-like deformation behavior of Rayleigh instability, the 4H metastable phase of gold nanoribbons was stable, remaining in solid crystalline structure free from phase transition throughout the moderate heating. In other words, the material reached a state of being both solid inside and liquid on the outside at once. The team further studied the phase stability at higher temperature of the 4H gold nanoribbons. It was observed that the material begins to change its phase from 4H to face-centered cubic phase as the temperature rises, and the phase transition was irreversible.

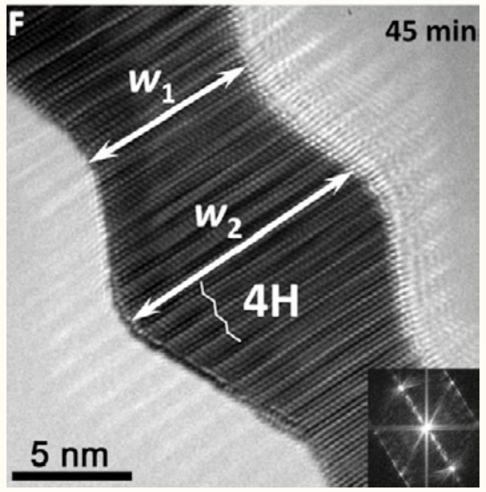
This research strengthens our understanding of the property and thermal stability of ultrathin gold nanoribbons with 4H phase, facilitating future practical applications that involve operation under high temperature. The research was supported by the Start-Up Grant from CityU, RGC of HKSAR, NSFC, Natural Science Foundation of Guangdong Province, China and ITC via NPMM.

團隊發現在適度的加熱下，4H 金納米帶的幾何形狀會產生變化，但內部的晶相則仍然存在。它的形狀經歷了「高原 - 瑞利不穩定性」— 在低幅度的加熱溫度下從光滑的形狀變成正弦形狀。這可解釋為一塊擁有表面原子與總體積比例相對較高的微型尺寸超薄納米金屬，其表面原子的擴散會大幅影響其整體形狀，因而可理解為在受熱的情況下其形狀會產生劇烈的變化。研究亦觀察到為了在整體積不變的情況下減少表面積，金納米帶的帶狀一般傾向在加熱時會變成圓柱形。然而，最令人驚訝的發現是，雖然它具瑞利不穩定性的類液體變形行為，但金納米帶的 4H 亞穩相是穩定的，並能在整個適度加熱過程中保持無相變的固態晶體結構。換句話說，物料同時達到了內部固體和外部液體的狀態。團隊進一步對 4H 金納米帶在較高溫度下的相之穩定性進行了研究，結果發現隨著溫度的升高，物料的相開始從 4H 轉變為面心立方相，而晶相的變化亦是不可逆轉的。

這項研究令我們進一步了解具 4H 相的超薄金納米帶之性質和熱穩定性，並推進了未來涉及高溫操作的實際應用可能性。這項研究得到城大初創資金、香港研究資助局、國家自然科學基金、廣東省自然科學基金，以及貴金屬分中心的支持。



Professor Yang LU (left) and Professor Hua ZHANG (right) collaborated to unveil the thermal stability of ultrathin 4H gold nanoribbons at elevated temperatures.
陸洋教授（左）及張華教授（右）攜手合作，成功解開超薄 4H 金納米帶的熱穩定性之謎。



Under the moderate E-beam irradiation heating for 45 minutes, the "Rayleigh instability" became more significant in an ultrathin gold nanoribbon. However, the 4H crystalline phase still maintains.
以可控電子束中低溫照射 45 分鐘後，超薄金納米帶的「瑞利不穩定性」變得更加明顯，但仍保持 4H 晶相。

2019

Evaluating Thermal and Non-Thermal Effects in Plasmon-Mediated Chemical Reactions

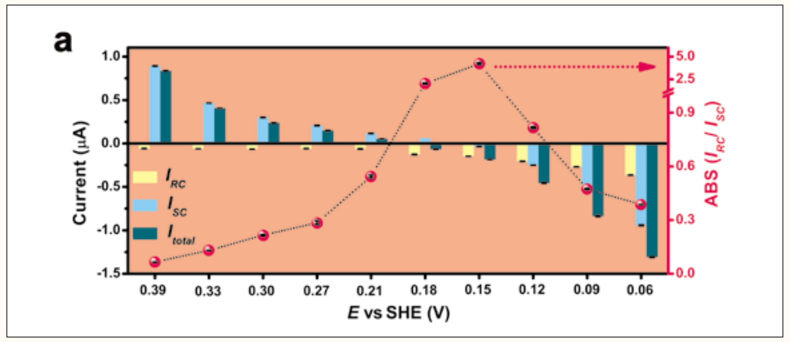
評估等離子體介導化學反應中的熱效應和非熱效應

Owing to its great application potential, plasmonics has long been the center of researchers' attention. A research team led by Professor Jian LU and Dr. Yangyang LI, developed a novel way to decouple, quantify and control precisely the thermal and non-thermal effects shown in plasmon-mediated chemical reactions, substantially contributing to the design and optimization of plasmonic devices and their applications. The research findings were published in the scientific journal *Angewandte Chemie,* titled "Thermal and Nonthermal Effects in Plasmon-Mediated Electrochemistry at Nanostructured Ag Electrodes".

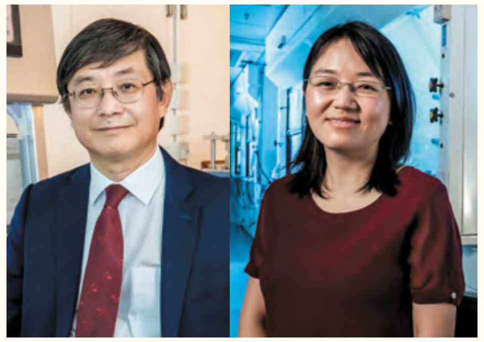
Plasmonics has drawn much attention in both basic and applied researches as it provides a possibility to manipulate the interaction between light and matter in a nanoscale. During plasmonic applications, both hot carrier effect (non-thermal effect) and local heating (thermal effect) occur. To improve the efficiency of plasmonic devices, quantification of both effects is helpful. Following the conventional measure method, thermal effect based on the surface temperature change is firstly measured, the thermal effect from the overall plasmonic effects is then subtracted to deduce the contribution of non-thermal effect. It is challenging to achieve accurate measurement of temperature by this traditional method, and a subtle error may render totally different conclusion. Thus, scientists have never reached a consensus on which effect is the dominant one.

由於其巨大的應用潛力，等離子體學一直是研究人員所關注的領域。由呂堅教授和李揚揚博士領導的研究團隊在2020年開發了一種新方法，可精確地解耦、量化和控制等離子介導的化學反應中所顯示的熱效應和非熱效應，大大地改善了等離子的設計及改良了相關的設備及其應用。同年，研究成果於國際期刊《*德國應用化學*》上發表，題為〈Thermal and Nonthermal Effects in Plasmon-Mediated Electrochemistry at Nanostructured Ag Electrodes〉。

一直以來，等離子體學在基礎研究和應用研究上都引起了大量關注，因為它提供了在納米尺度上控制光與物質之間相互作用的可能性。在應用等離子體時，熱載流子效應(非熱效應)和局部加熱(熱效應)都會發生，而對這兩種效應進行量化，有助提高等離子體裝置的效率。按照常規測量方法，首先會測量根據表面溫度而變化的熱效應，然後從整個等離子體效應中除去熱效應數值，以推斷出非熱效應在整個過程中的影響程度。用這種傳統方法得出準確的溫度測量具相當的挑戰，當中任何細微的誤差都可能會得出完全不同的結論。因此，科學家們從未就哪種效應佔主導地位達成共識。



This graph shows rapid-response currents, slow-response currents, and total photocurrents at different electrode voltage in electrolyte with laser illumination switched on-off for three times. (Photo source: DOI: 10.1002/anie.202001152)
不同電位下激光照射時產生的快響應電流、慢響應電流及總響應電流。（圖片來源：DOI: 10.1002/anie.202001152）



Professor Jian LU and Dr. Yangyang LI are one of the corresponding authors of the paper.
呂堅教授和李揚揚博士也是論文的通訊作者之一。

The team had broken this dilemma by their latest quantification method. Bypassing the difficulty of measuring the surface temperature, the team introduced a novel quantification technique which measured precise contribution of thermal and non-thermal effects. The team designed an experimental setup to observe the photoelectrochemical behaviors of the plasmonic silver electrode. By close examination of rapid-response currents, slow-response currents and the total photocurrents at different electrode voltages, the team quantified the thermal and non-thermal effects exhibited in plasmon-mediated chemical reactions, and it was discovered for the first time that plasmoelectric surface potential contributed to the rapid-response currents. The results also suggested that the ratio between thermal and non-thermal effects could be controlled by adjusting the electrode potential, laser wavelength and intensity. Return to the daunting debate about dominant effect, after deriving actual temperature of reaction sites from the slow-response current data, the team concluded that the contribution of thermal effects was way more significant than anticipation.

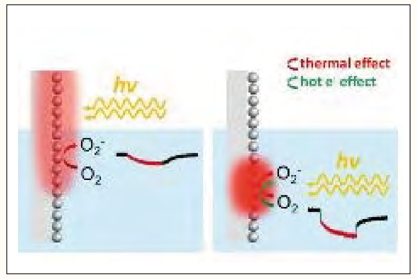
Through bypassing the challenge of precise temperature measurement, the team invented a reliable and convenient method for quantitatively evaluate the contribution of thermal and non-thermal effects in plasmon-mediated electrochemical reactions based on photoelectrochemcial behaviors, deepening our understanding of plasmon-mediated electrochemical reaction and paving way for its wide applications.

The study was supported by the National Key Research and Development Program of China, the Major Program of the NSFC, as well as the ITC of HKSAR.

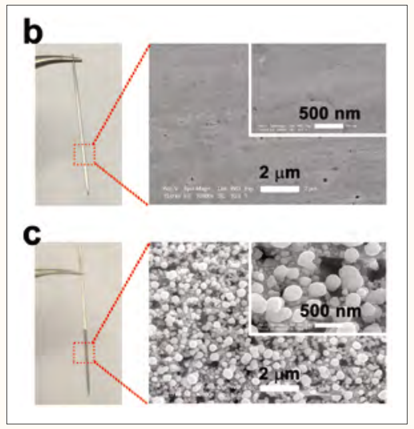
研究團隊最近使用了他們最新的量化方法，在這一困境中得到了突破性的發現。透過引入一種新的量化技術，團隊無須測量表面溫度，就可精確測量出熱效應和非熱效應各自在整個過程中的影響程度。團隊設計了一個實驗裝置，以觀察等離子體銀電極的光電化學行為。透過對不同電極電壓下的快響應電流、慢響應電流及總光電流的仔細研究，團隊除了量化了在等離子介導的化學反應中表現出的熱效應和非熱效應數值外，亦首次發現在等離子電表面電位或可能對快速響應電流產生作用。結果亦顯示可以透過調整電極電位、激光波長及強度來控制熱效應和非熱效應之間的比率。至於過去有關主導效應的激烈爭論，在從慢響應電流數據中得出反應位點的實際溫度後，團隊發現熱效應的影響程度確實比所預期的大得多。

透過繞過精確測量溫度，團隊發明了一種可靠便捷的方法，並根據光電化學的行為，定量評估了熱效應和非熱效應在等離子體介導的電化學反應中所產生的作用，從而加深了我們對等離子體介導電化學反應的理解，並為其更廣泛的實際應用寫下新的一頁。

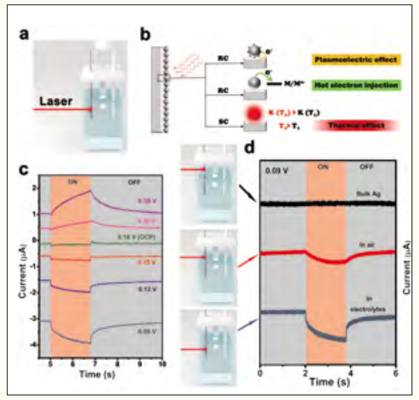
這項研究得到國家重點研發計劃、國家自然科學基金重大項目以及香港創新科技署的支持。



Bypassing the difficulty of measuring the surface temperature at the reaction sites, the research team identifies a novel method to quantify precisely the contribution of thermal and non-thermal effects. (Photo source: DOI: 10.1002/anie.202001152)
呂教授的研究團隊開發出一種新方法，在不用測量溫度的情況下，仍能清晰觀測熱效應及非熱效應的貢獻。（圖片來源：DOI: 10.1002/anie.202001152）



Researchers treat the lower part of silver needles electrochemically before the experiment, so that uniform nanospheres which support plasmonic excitation are formed on the surfaces. Here shows the photographs and scanning electron microscope images of the silver needles before (b) and after (c) the treatment. (Photo source: DOI: 10.1002/anie.202001152)
研究人員先以他們前期發明的獨特電化學方法處理銀電極的下半部分，令其表面生成尺寸可控的納米球結構，從而於此獲得表面等離激元性能。圖為特別處理前（b）和後（c）的電鏡圖片。（圖片來源：DOI: 10.1002/anie.202001152）



(a)Schematic illustrations of the experimental setup for photoelectrochemical measurements ; (b) three proposed plasmonic effects on nanostructured silver electrode under illumination ; (c) Nanostructured silver electrode illuminated in electrolyte generates photocurrents at different voltages ; (d) Photocurrents generated at -0.61 V with laser beam illumination at three different locations. (Photo source: DOI: 10.1002/anie.202001152)
（a）特製裝置的外觀；（b）實驗過程圖示；（c）不同電位下光電流曲線；（d）鐳射光照射在銀電極三個不同位置時的電流曲線。（圖片來源：DOI: 10.1002/anie.202001152）

2020

Novel HEI as Electrocatalyst for Hydrogen Production
以嶄新 HEI 作為製氫的電催化劑

Hydrogen is generally regarded as an ideal clean energy. Hydrogen production is however costly, hindering its wide development and application. A team co-led by Professor Jian LU and Professor Chain Tsuan LIU has developed a low-cost and high-performance electrocatalyst that can be produced at large scale, paving the way for general hydrogen production by electrochemical reaction. The findings were published on the international top academic journal *Advanced Materials* with the title of "A Novel Multinary Intermetallic as an Active Electrocatalyst for Hydrogen Evolution" and featured in the bottom cover of Advanced Materials.

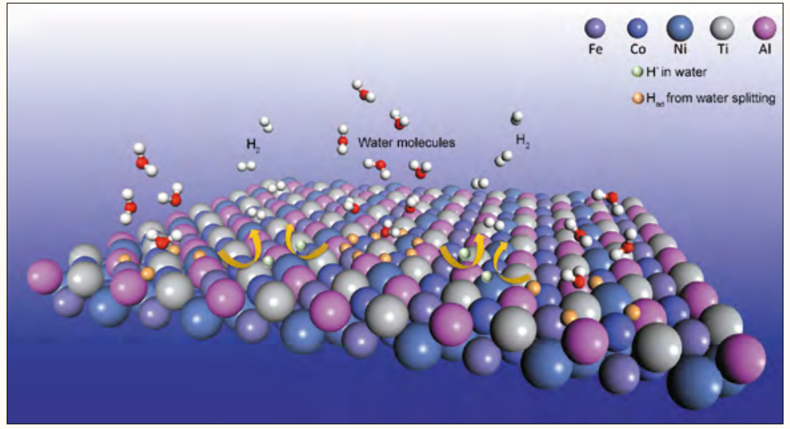
Electrochemical water splitting, the most nature-friendly method of hydrogen production, is expensive since existing electrocatalysts are costly and scarce noble-metal-based. Scientists have been searching ways to develop new electrocatalysts for wider applications of hydrogen production. Professor Liu's team successfully developed an innovative alloy design strategy for manufacturing high-entropy intermetallic compounds, which overcame the trade-off dilemma between strength and ductility in traditional metallic materials by introducing high density of nanoparticles of multi-component intermetallic compounds at nanoscale, laying the foundation for developing novel electrocatalysts.

In this research, Professor Liu's team cooperated with Professor Lu's team which has considerable expertise in noble metal. By adopting the aforementioned alloy design strategy, the team successfully developed a new high-entropy intermetallic (HEI) electrocatalysts comprising of five metal elements with well-ordered atomic structure. The team managed to produce a dendrite-like porous structure that increases the surface area for electrochemical activities, significantly enhancing its electrochemical performance.

氫氣普遍被視為一種理想的清潔能源。然而，製氫的成本高並直接阻礙了其發展和應用。由呂堅教授和劉錦川教授組成的團隊最近開發了一種可大規模生產且成本低、性能高的電催化劑，為電化學反應制氫帶來新的契機。研究結果早前於國際學術期刊《*先進材料*》上，以〈A Novel Multinary Intermetallic as an Active Electrocatalyst for Hydrogen Evolution〉為題發表，該論文獲《*先進材料*》於封底推薦。

電化學水分解是最一種環保的製氫方法，但現有的電催化劑昂貴且稀缺貴金屬基催化劑，故生產成本十分高昂。一直以來，科學家都在尋找方法來開發用於製氫的新電催化劑。來自城大的劉錦川教授成功開發了一種用於製造高熵金屬間化合物的創新合金設計方法，透過在納米尺度上引入多組分金屬間化合物的高密度納米粒子，克服了傳統金屬材料在權衡強度和延展性之間膠著的困局，並為發展新型電催化劑奠定了良好基礎。

研究中，劉教授的團隊與在貴金屬方面具相當專業知識的呂堅教授團隊合作。透過上述合金設計方法，團隊成功開發了一種新型高熵金屬間化合物 (HEI) 電催化劑，其由五種原子結構有序的金屬元素所組成。另外，團隊亦生產了一種枝晶狀的多孔結構，除了增加了電化學活動的表面積外，亦大幅提升了該結構的電化學性能。



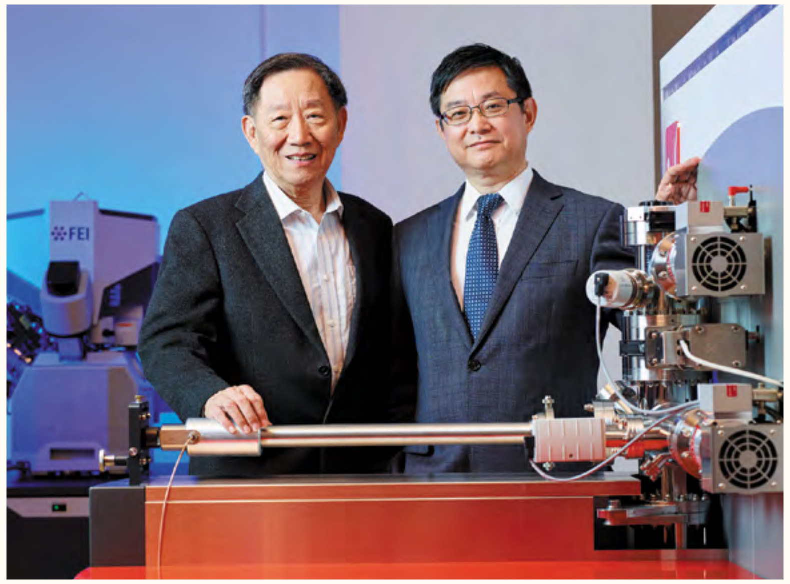
Schematic illustration of the hydrogen evolution reaction process.(Photo source: DOI: 10.1002/adma.202000385)
高熵金屬間化合物催化劑在釋氫反應過程中的示意圖。（圖片來源： DOI: 10.1002/adma.202000385）

The research combined the advantages of high-entropy alloys (HEAs) – synergistic effects among multinary metal elements – and intermetallic compounds – intrinsic structural site-isolation effect and well-tuned electronic structure. By using the atomic-resolution scanning transmission electron microscopy and 3D-atomic probe tomography in experiments, the team characterized the atomic structure of HEI electrocatalyst. Further theoretical calculations even proved that the synergistic effects and the well-ordered atomic structure effectively optimized the electronic structure, and hence promoted the electrochemical water splitting process. Further, the HEI catalyst demonstrated excellent hydrogen evolution reaction in alkaline electrolyte solution due to its unique constituents and structures.

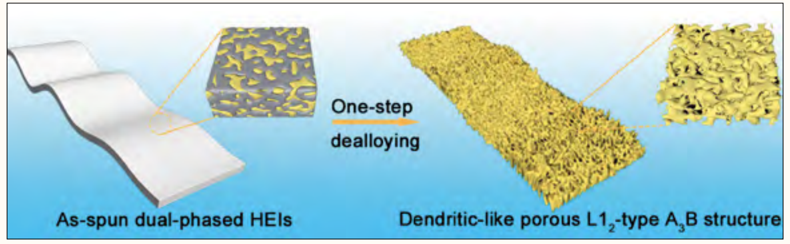
The innovative strategy to produce HEI creates a new paradigm to develop novel electrocatalyst with satisfactory performance in reaction activities for splitting water and producing hydrogen. This technique reduces the cost in electrocatalyst generation and has been widely employed in industrial production. It is believed that this novel electrocatalyst will soon become prime candidate in industrial production of hydrogen.

結合高熵合金 (HEA) 的優勢，亦即是多元金屬元素之間的協同效應、金屬間化合物的固有結構位點隔離效應，以及調整恰到好處的電子結構，該研究得到了驕人的成果。透過在實驗中使用原子分辨率掃描透射電子顯微鏡和 3D 原子探針斷層掃描，團隊對 HEI 電催化劑的原子結構和特性進行了分析。進一步的理論計算甚至證明了該協同效應和有序的原子結構能有效地改良電子結構，從而促進了整個電化學水分解過程。此外，由於其獨特的成分和結構，HEI 催化劑在鹼性電解質溶液中表現出優異的析氫反應。

是次生產 HEI 的創新方法為開發具卓越分解水和製氫反應活性的新型電催化劑揭開新的一頁。 此技術能降低電催化劑的生產成本，並已廣泛應用於工業生產當中。相信在不久將來，這種新型電催化劑將替代傳統方式，成為工業製氫的主要途徑。



Professor Jian LU's and Professor Chain-tsuan LIU's teams join hands together to develop a novel electrocatalyst which can be produced at large scale and at low cost.
香港城大呂堅教授與劉錦川教授的團隊聯手，最近製備了一種廉價、可大規模工業化地生產的高性能合金催化劑，有助推動以電化學製氫的廣泛應用。



Conceptual design of the multinary intermetallic electrocatalyst. This schematic diagram shows the dealloying process from a dual-phase structure to a dendritic-like structure.（Photo Source):DOI: 10.1002/adma.202000385）
多組元高熵金屬間化合物催化劑的概念設計，把具有雙相結構的高熵金屬間化合物（HEI）脫合金到多孔枝晶狀結構的示意圖。（圖片來源： DOI: 10.1002/adma.202000385）

2021

Novel Synthesis Approach for Exploring Secrets Behind TMD Nanomaterials

探索 TMD 納米材料奧秘的嶄新合成方法

Professor Hua ZHANG and Dr. Kedar HIPPALGAONKAR from Nanyang Technological University (NTU) and Institute of Materials Research and Engineering (IMRE), A*STAR (Agency for Science, Technology and Research) in Singapore, used their best endeavor and successfully developed a novel synthesis technique to produce high-quality and pure unconventional metastable transition metal dichalcogenide (TMD) materials in large quantities and solved the single crystal structures of four of them, paving way for further fundamental study and practical application. The findings have been published on *Nature Materials* with the title of "Metastable 1T′-phase group VIB transition metal dichalcogenide crystals".

TMD is one of the most promising novel two-dimensional (2D) nanomaterials, especially the octahedral (1T-phase) and distorted octahedral (1T′-phase) with metastable structures. However, given their complex and diverse crystal structures as well as thermodynamically unstable nature, the unconventional-phase TMDs usually appear in mixtures with different crystal structures which are not sufficiently pure or conducive for conducting study on their intrinsic physical and chemical properties. Attempts have been made all over the world to develop synthesis methods for these TMD materials but the outcomes remain unsatisfactory. The obtained products are of poor quality and inadequate for applications.

The research team overcame the hurdles and developed an innovative synthesis technique by discovering a unique type of precursor, which is crucial in the gas-solid reaction for the synthesis of unconventional 1T′-phase TMD materials. The discovery involves the utilization of vacuum-sealed ampoules as the reaction vessels for the raw materials, which successfully produces a series of significant precursors in a high-temperature environment. These precursors are then used in a gas-solid reaction with a combination of H2 and Ar for large-amount synthesis of six unconventional 1T-phase TMD crystals of high-quality and high-purity. After acquiring these TMD crystals, the team employed "single-crystal X-ray diffraction technique" and successfully solved the single-crystal structures of four unconventional 1T′-phase TMDs for the first time in history, opening the door to further research in material science, crystallography, physics and chemistry. Another breakthrough in the current research is the finding that one of the synthesized unconventional 1T′-phase TMDs is an excellent superconductor which "superconducting transition temperature" is proportional to its thickness, making it one of the best TMD-based superconductors to date.

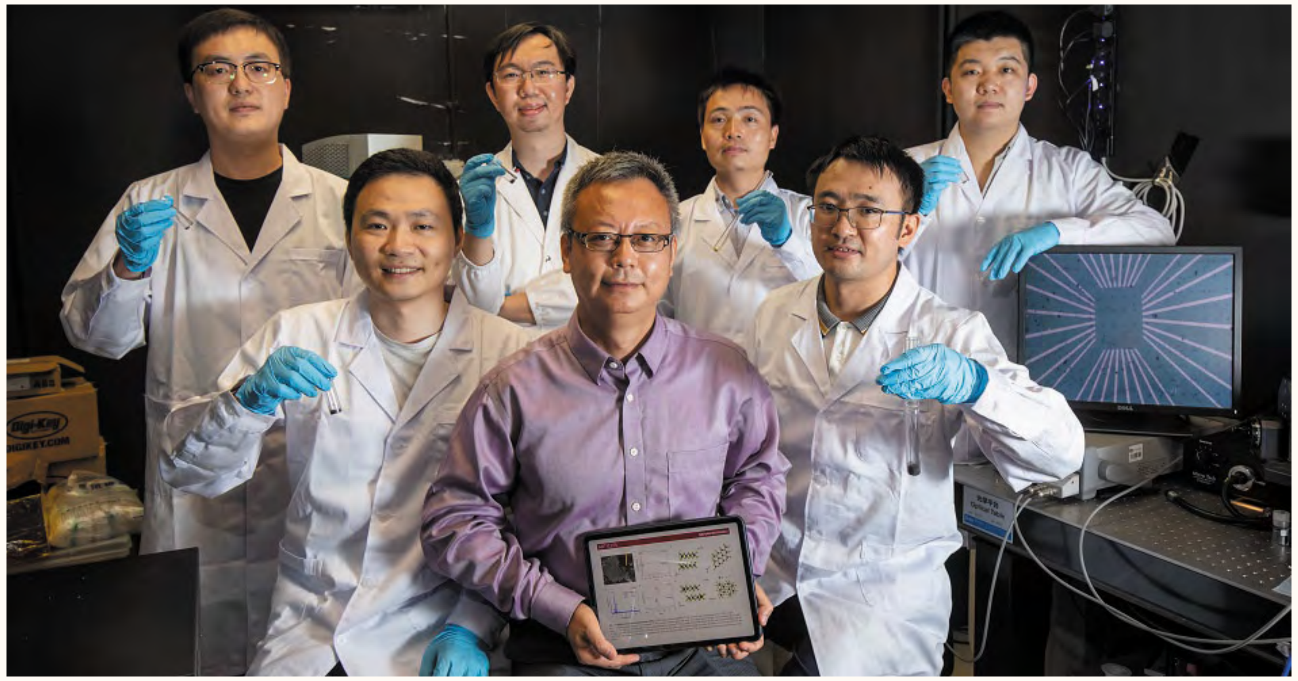
張華教授與新加坡南洋理工大學 / 材料研究與工程研究院的 Kedar HIPPALGAONKAR 博士聯合領導的研究團隊成功開發了一種嶄新的合成技術，以生產大量優質及純度高的非常規亞穩態過渡金屬二硫屬化物（TMD）材料，並解決了其中四個結構單晶問題。這技術為進一步的基礎研究和實際應用帶來突破性的發展。該研究成果已刊載於學術期刊《*Nature Materials*》上，題為〈Metastable 1T′-phase group VIB transition metal dichalcogenide crystals〉。

TMD 是表現最穩定的新型二維（2D）納米材料之一，尤其是具有亞穩態結構的八面體（1T 相）和扭曲八面體（1T' 相）。然而，鑑於其複雜多樣的晶體結構以及在熱力學上不穩定的性質，非常規相 TMD 通常以具有不同晶體結構的混合物形式出現。由於這些混合物的純度不夠，故或不適合用於對其內在物理和化學性質的研究。雖然世界各地多年來都曾嘗試開發這些 TMD 材料的合成方法，但由於所得產品質量差及未能達到使用要求，故效果仍未能令人滿意。

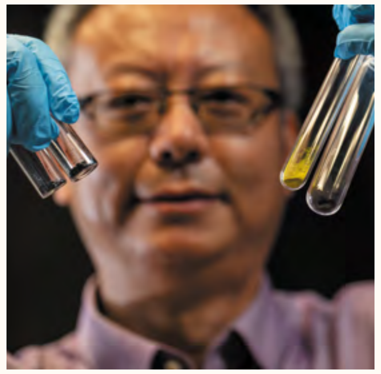
這次研究技術對合成非常規 1T' 相 TMD 材料時的氣固反應至為重要。研究發現在高溫環境下利用真空密封的安瓿作為原材料的反應容器，能成功生產一系列重要的前驅體。其後，將這些前驅體與 H2 和 Ar 的組合加以進行氣固反應，能大量合成 6 種高質量、高純度的非常規 1T 相 TMD 晶體。其後，團隊使用了『單晶 X 射線衍射技術』，破天荒成功解構了四種非常規 1T' 相 TMDs 的單晶結構，為材料科學、晶體學、物理和化學的進一步研究帶來極大啟示。目前研究的另一突破是發現合成的非常規 1T' 相 TMDs 是一種不可多得的超導體。由於其『超導轉變溫度』與其厚度成正比，故亦成為至今基於 TMD 的最優質超導體之一。

In light of the efficiency and better general applicability of this novel TMD synthesis method, it is believed that this method will promote large-scale preparation of more high-purity unconventional-phase TMD materials in the future, generating important source materials for future fundamental and applied research on the intrinsic physiochemical properties of these next-generation novel nanomaterials and opening for the exploration and development of their potential applications. These findings greatly expand the scope of research and application of Phase Engineering of Nanomaterials (PEN), and also pave the way for future exploration of the phase-dependent physicochemical properties of nanomaterials, as well as laying the cornerstone for the development of practical applications based on PEN.

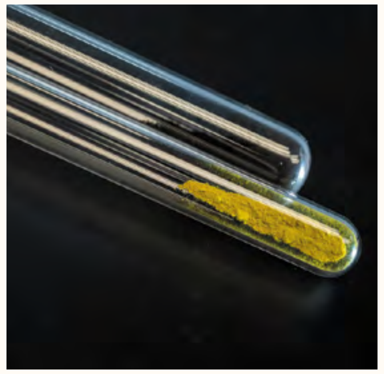
基於其效率和修改的普遍應用程度，團隊深信此新技術最終能大規模生產高純度非常規相 TMD 材料，並於未來為內在理化性質進行應用研究，以繼續探索其潛在應用能力。這項工作極大地擴展了納米材料相工程（Phase Engineering of Nanomaterials, PEN）的研究和應用範圍，同時也為今後探索納米材料的相依賴的物理化學性質，以及探索開發基於相依賴的實際應用鋪下了基石。



Professor Hua ZHANG (front row, centre) and his team and collaborators: (back row, from left) Wei ZHAI, Dr. Bo CHEN, Dr. Chaoliang TAN, Dr. Zhenyu SHI, Dr. Zhuangchai LAI(front row, left) and Dr. Qiyuan HE(front row, right).
張華教授（前排中）與他的研究團隊和合作成員：（後排左起）翟偉、陳博博士、譚超良博士、史振宇博士、賴壯釵博士（前排左一）和何其遠博士（前排右一）。



Professor Hua ZHANG 張華教授



The research team successfully produced the precursors (the yellow and black powders in the photo) by using vacuum-sealed ampoules.
研究人員採用安瓿管製備出前驅體，即圖中黃色和黑色的粉末。

The TMD samples developed by Professor Zhang and his team.
研究團隊製備出的 1T' 相 TMD 材料樣本。

Advanced Metallic Materials
先進金屬材料

2018

Simultaneous Enhancement of Multicomponent Alloys' Strength and Ductility
同時提高多元合金的堅固度及韌性

Strength and ductility are usually mutually exclusive in structural materials. A research team led by Professor Chain Tsuan LIU and Dr. Tao YANG has overcome this dilemma and developed an innovative strategy to develop new alloys that are not only strong but also ductile and flexible, laying the foundation for developing more novel structural materials. This cutting-edge research has just been published in the prestigious journal *Science*, titled "Multicomponent intermetallic nanoparticles and superb mechanical behaviors of complex alloys".

High-entropy alloys (HEAs), a type of novel materials constructed with equal or nearly equal quantities of five or more metals. Attributed to their potentially favorable properties for structural applications, HEAs are now the center of focus in material science and engineering. However, HEAs also share the same detrimental characteristic as most alloys do: the higher the strength, the lower the ductility and toughness.

The team has successfully reached a groundbreaking solution to this daunting dilemma – massive precipitation of nanoscale particles. The team developed a novel HEA namely Al_7Ti_7. Strengthened by nanoparticles, it was five times stronger than that of the iron-cobalt-nickel-based alloy. This is because the additional elements help to form massive precipitates in the alloy, substantially increasing strength and ductility.

在結構物料中，堅固度及延展性通常是互相排斥的。由劉錦川教授和楊濤博士所領導的一個研究小組最近在這方面取得突破，並制定了一項創新方法，開發不僅堅固且具有延展性和柔韌性的新型合金，更為開發更多新穎的結構物料奠定了良好基礎。這項尖端研究在頂尖學術期刊《*科學*》發表，題為〈多組元金屬間納米顆粒和復合合金的優越機械性能〉。

高熵合金 (HEA) 是一種由等量或幾乎等量的五種或更多金屬所構成的新型物料。由於其在結構應用方面有潛在的有利特性，故 HEA 現在已是物料科學及工程領域的焦點。然而，HEA 也具有與大多數合金相同的負面特性，就是當強度越高時，延展性和韌性亦會越低。

團隊成功地以突破性方式，透過納米級顆粒大量沉澱，制造堅固且具有延展性的高熵合金，解答了這個令科學界望而卻步的難題。該團隊開發了一種名為 Al_7Ti_7 的新型 HEA。受納米粒子所強化，這新型 HEA 的強度是鐵鈷鎳基合金的五倍。由於附加元素有助在合金中形成大量沉澱物，從而顯著提高了物料的強度和延展性。

The new alloy Al_7Ti_7 exhibits a superior strength of 1.5 gigapascals and ductility as high as 50% in tension at ambient temperature.
以創新方法制成的新型高熵合金 Al_7Ti_7 解決了強度和延展性不相容這個棘手難題。

Further, the team effectively tackled the "necking problem" by adding "multicomponent intermetallic nanoparticles" to the alloy. Increasing the strength of alloy would usually lead to unstable deformation and necking fracture with very limited uniform elongation. Yet, the team discovered that engineering "multicomponent intermetallic nanoparticles" might be a possible way to strengthen the alloy uniformly by improving the deformation instability. Under their best efforts, the team figured out the ideal formula for these nanoparticles, consisting of nickel, cobalt, iron, titanium and aluminum atoms. The sizes of these nanoparticles range from 30 to 50 nm. To reduce the valence electron density and improve ductility, some of the nickel components were replaced by iron and cobalt atoms. More, to lessen the impact of moisture in air to avoid induced embrittlement in the new alloy, some of the aluminum was replaced by titanium. The formula offers a solution to the necking problem.

The strategy of strengthening complex alloys to achieve superb mechanical properties at room and elevated temperature by means of engineering multicomponent nanoparticles has become a strong basis for future development of superalloys. It is believed that alloys developed with this innovative strategy will demonstrate satisfactory performance in temperatures ranging from -200°C to 1000°C, and hence significantly contribute to wide structural applications.

此外，透過在合金中添加「多組分金屬間化合物納米粒子」，團隊有效地解決了「頸縮問題」。增加合金的強度通常會導致不穩定的變形和頸縮斷裂，而當中的均勻伸長率亦非常有限。然而，研究小組發現，進行「多組分金屬間化合物納米粒子」工程，可能是一種透過改善變形不穩定性來令合金的強化程度變得均勻的可行方法。最終團隊找到了這些納米粒子的理想配方。這些納米粒子由鎳、鈷、鐵、鈦和鋁原子所組成，體積為 30 至 50 納米不等。為了降低價電子密度及提高延展性，當中一些鎳的成份被鐵和鈷原子取代。此外，為減少空氣中水份的影響，以避免誘發新合金脆化，當中一些鋁被鈦所取代。該配方同時亦為頸縮問題提供了解決方案。

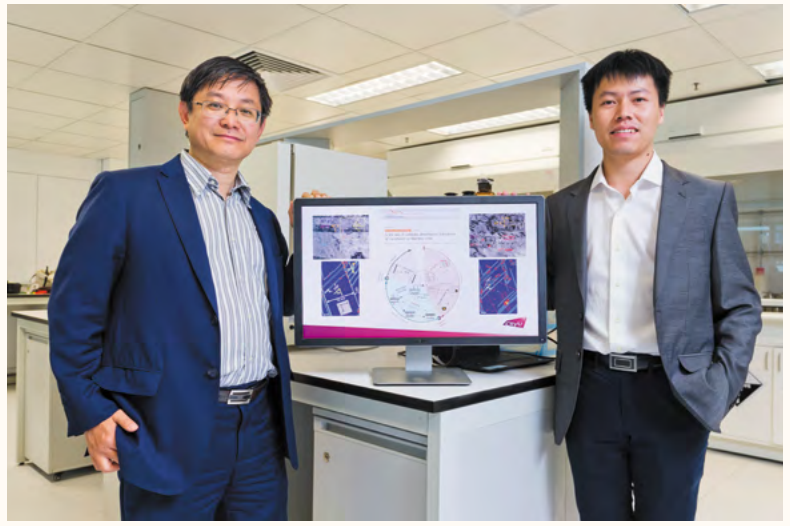
如何令強化複雜合金在室溫下獲得卓越力學性能，以及透過工程多組分納米粒子來提高溫度，已成為了未來高溫合金發展的堅實基礎。相信採用這種創新方法所開發的合金，將會在 -200°C 至 1000°C 的溫度範圍內表現出令人滿意的性能，從而大幅提高廣泛結構性應用的可行性。

From left to right, front row: Professor Jijung KAI, Professor Chain Tsuan LIU, Dr. Zengbao JIAO; back row: Dr. Yilu ZHAO, Dr. Tao YANG and Dr. Junhua LUAN, Senior Research Associate at Inter-University 3D Atom Probe Tomography Unit.
劉錦川教授與團隊合照，前排左起為開執中教授、劉錦川教授、焦增寶博士，後排左起是趙怡潞博士、楊濤博士，和三維原子探針聯合研究實驗室高級副研究員欒軍華博士。

2019

Nanotwin Deformation Mechanism in Stainless Steel: Inaugurating a New Era of Strong-And-Ductile Materials

揭開不鏽鋼納米結構變形的結構方式 開啟高韌性物料的新時代



Professor Jian LU (left) and one of the first authors Dr. Ligang SUN
呂堅教授（左）相信，這次研究成果為下一步研發新型工程材料和新型合金，奠下了理論基礎。
旁為文章的其中一位第一作者孫李剛博士。

Nanotwins (NTs) is a type of nano lamellar structure enabling strength and ductility of materials at once, breaking the dilemma usually faced by materials and alloys: the higher the strength, the lower the ductility and toughness. Proved by a research team led by Prof Jian LU, comprising experts from CityU, University of Shanghai for Science and Technology (USST) and Zhejiang University (ZJU), the hierarchical order of nanotwins is proportional to its density, strength and ductility. Hence, increasing nanotwin density via hierarchical twining becomes an important way to develop novel strong-and-ductile materials. The research results were published in the scientific journal *Nature Communications*, in an article titled “Scale law of complex deformation transitions of nanotwins in stainless steel” and the research project was also supported by the National Key Research and Development Programme of China and the General Programme of NSFC.

The team discovered for the first time the marginal scale of nanotwin deformation transition mechanisms of austenitic stainless steel by combining in situ tensile tests with theoretical modeling and atomistic simulations. It was observed that deformation mechanisms vary as the twin-lamella spacing alters. While primary twinning and detwinning were activated when the spacing was 5nm, secondary twinning and density increase occurred when the spacing was between 6 and 129nm. This discovery fills the current literary gap which focuses mostly on increasing the density of nanotwins from primary twinning. Also, most of the prior research discuss pure materials, such as copper or pure silver, rather than widely used engineering materials like stainless steel in the current research.

納米孿晶（NTs）是一種納米層狀結構，可令物料同時具有強度和延展性，打破了材料和合金通常面臨「強度越高，延展性和韌性就越低」的困境。由呂堅教授帶領、聯同上海理工大學和浙江大學的專家組成的研究團隊證明，納米孿晶的層次順序與其密度、強度及延展性成正比。因此，透過分層孿晶來增加納米孿晶密度，成為了開發新型強韌性物料的一個重要途徑。有關研究成果最近以〈不鏽鋼中納米孿晶變形轉變的尺度規律〉為題，發表於科學期刊《*自然通訊*》上，並獲國家重點研發計劃和國家自然科學基金資助。

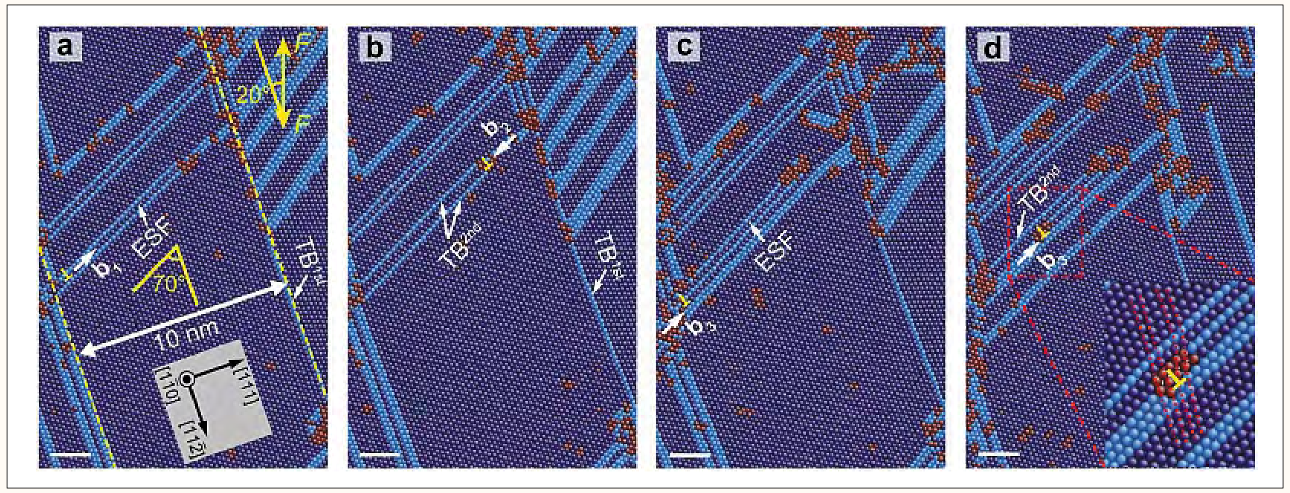
在呂教授的帶領下，該團隊透過結合原位拉伸試驗與理論建模和原子模擬，首次發現了奧氏體不銹鋼納米孿晶變形過渡結構方式的邊際尺度。根據觀察，變形結構方式會隨著雙層間距的變化而有所改變。當間距為 5 納米時，一次孿晶和去孿晶會被激活，而當間距在 6 和 129 納米之間時，二次孿晶和密度亦會隨之而增加。此發現填補了目前文獻上主要有關從一次孿生增加納米孿晶密度的空白。此外，先前的研究大多數都只集中討論一些純物料，例如銅或純銀，而不是是次研究中廣泛使用的工程物料，例如不銹鋼等。

With the team’s best efforts, combined with prior experiments and theoretical studies, a multiscale deformation map of nanotwins has been established. There was also in-depth discussion on the intrinsic mechanisms and transformation process of nanotwins with varying scale effects. All these have become valuable resources for scientists to develop an optimization strategy of nanotwins for new engineering materials and new alloys. This research will serve as a strong basis for future exploration of strengthening mechanism for other conventional metallic materials and development of advanced materials with nanotwins.

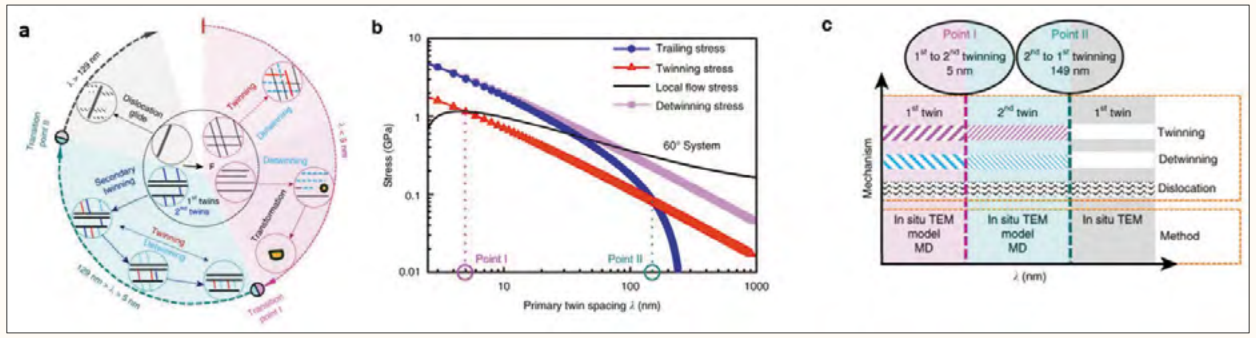
In the future, the team will strive to find ways to realize higher-order hierarchical twinning in stainless steel and other new materials, such as the futuristic high-entropy alloys. Constructed with an equi-atomic or nearly equi-atomic percentage of five or more elements, high-entropy alloys have currently become the center of attention in materials science and engineering for their high potential in structural applications. Motivated by the determination to comply with the future direction of development for materials science, the team will continue to optimize not only the performance of classical metals but also characteristics of new materials, such as high-entropy alloys.

透過結合先前的實驗結果和理論，團隊已經建立了納米孿晶的多尺度變形圖。此外，團隊亦就不同尺度效應納米孿晶的內在結構方式和轉化過程進行了深入討論。這些資料都會成為科學家為新工程物料和新合金制定納米孿晶改良方法的寶貴財產。同時，這次研究將為未來探索其他傳統金屬材料的強化結構方式和開發具納米孿晶的先進物料而奠下了堅實的基礎。

展望將來，團隊將努力尋找在不銹鋼和其他新物料中使用高階分層孿晶的方法，例如具未來概念的高熵合金。由於高熵合金由五種或更多含等原子或接近等原子百分比的元素所建構，其在結構應用上的巨大潛力已成為物料科學和工程領域所關注的焦點。呂教授的團隊決心順應物料科學的發展方向，未來將繼續改善傳統金屬的性能，並同時進一步探索高熵合金等新物料的特性。



Snapshots of secondary twinning in the first nanotwins 在一級孿晶中間產生二級孿晶的過程。



Schematic illustration of the deformation modes of nanotwins 不鏽鋼中納米孿晶的變形圖譜。

2020

Heas’ Multi-stage Deformation Behaviors at Ultra-Low Temperatures

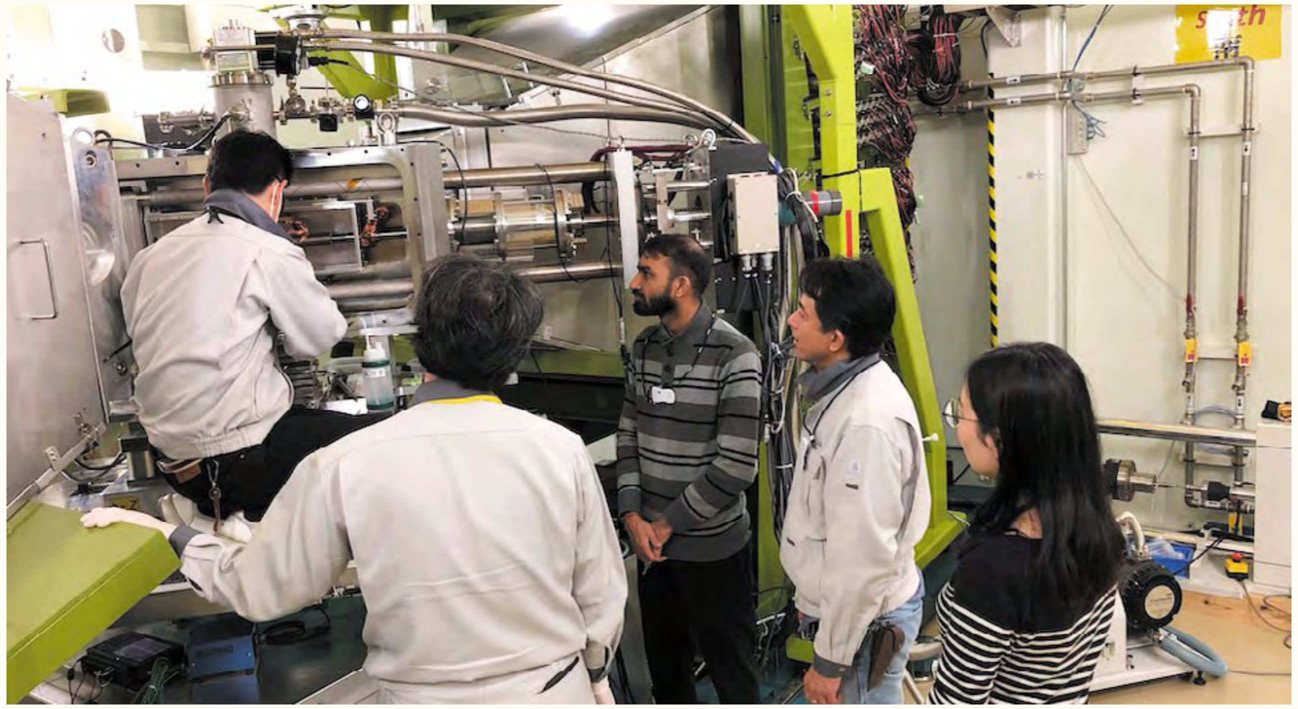
高熵合金 (HEA) 在超低溫下的多階段變形模式

High-entropy alloys (HEAs) are a new class of structural materials. Under the efforts of a Sino-Japanese research team led by Professor Xunli WANG, it is discovered that HEAs demonstrate different favorable mechanical properties at ultra-low temperatures contributing to complex deformation behaviors, opening the gate to design new structural materials for applications under low temperatures. The research findings were published in the scientific journal *Science Advances*, titled “Cooperative deformation in high-entropy alloys at ultralow temperatures”.

Tracing back to 2014, it was discovered that while atoms of most materials were “frozen” and hence immobilized at low temperatures, HEAs demonstrated high ductility and could be stretched to a large deformation under the same conditions. The mechanism behind was however unknown. In 2020, Professor Wang’s team strove to solve this enigma by using in-situ neutron diffraction technique to examine the deformation process of HEAs. This method allows the team to study each step, their order and interactions during the deformation process carefully. More crucially, it conducts measurements at ultra-low temperatures, i.e., near absolute zero, providing detailed microscopic information to help solving the puzzle.

高熵合金（HEA）是一類新型的結構材料。經過多重努力，由王循理教授領導的中日研究團隊成功發現 HEA 在超低溫下能產生不同的複雜演變，有助提升機械性能，並能在低溫環境下為設計新的應用結構材料提供了新發展方向。相關研究結果發表在科學期刊《*科學進展*》上，題為〈Cooperative deformation in high-entropy alloys at ultralow temperatures〉。

早於 2014 年，科學界已發現雖然大多數材料的原子被『凍結』並在低溫下會被固定，但 HEA 具有高延展性，並且可在相同條件下拉伸至大幅度的變形。然而，背後的原因卻始終是一個謎。在 2020 年，王教授及其團隊利用原位中子衍射技術，對高熵體的變形過程進行了研究。這種方法讓團隊能仔細研究變形過程中的每個步驟、當中的順序和相互作用。實驗在超低溫（即接近絕對零）的環境下進行，過程提供了測量所得的詳細微觀資訊，將幫助解決以上難題。



CityU students Muhammad NAEEM (centre) and Haiyan HE (right) discuss the experiment strategy with Japanese collaborators. (Photo Credit: Professor Xunli WANG)
研究團隊成員 Muhammad NAEEM（中）和何海燕（右一）與日本研究人員討論研究策略。（王循理教授提供）

Under the team’s best endeavor over three years, the secrets behind sequence of HEA deformation mechanism were unveiled for the first time – HEA performs a four-stage deformation at 15 Kelvin (K). Beginning with the dislocation slip where the planes of crystal lattice slide over each other. As it continues, stacking faults become active and dominant gradually, where the stacking sequence of crystal lattice planes are altered by the deformation. The next stage is twinning, where mirror image of parent crystal occurs because of misorientation of lattice planes. It eventually transits to serrations where the HEA demonstrates big oscillations of deforming stress. It is observed that HEAs show higher and more stable strain hardening and larger ductility as the temperature falls. The team concluded that stacking faults, twinning and serrations as well as the interaction among these mechanisms were the sources of those extraordinary mechanical properties.

In the future, the team will explore further in the deformation process. For their next step, they will examine when stacking faults will appear in other alloys and their deformation mechanism as temperature varies. It is believed that by deepening our understanding of deformation mechanisms, we will soon be able to design more novel alloys with better mechanical properties for applications at low temperatures.

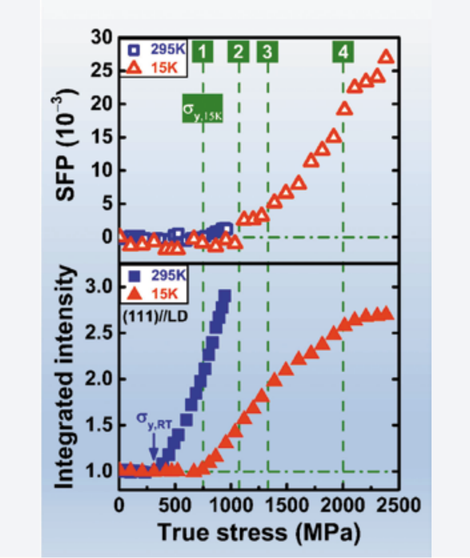
The study was supported by the Croucher Foundation, the RGC of HKSAR, NSFC, the Shenzhen Science and Technology Innovation Committee, and the MOST.

在團隊三年多的努力下，首次揭示了 HEA 變形機制序列背後的秘密，亦即是 HEA 從晶格平面相互滑動的位錯滑移開始，在 15 開爾文 (K) 下所進行的 4 個階段變形過程：隨著過程逐步進展，疊層缺陷逐漸變得活躍並佔領了主導地位，其中晶格平面的堆疊順序因變形而改變；下一階段則是孿晶，由於晶格平面的取向錯誤，出現母晶的鏡像。晶體最終變為鋸齒狀，其中 HEA 表現出變形應力的大幅度振盪。據觀察數據所得，隨著溫度的下降，HEA 表現出更高和更穩定的應變硬化和更大的延展性。團隊得出結論，疊層缺陷、孿晶和鋸齒以及這些機制之間的相互作用是導致這些非凡機械性能背後的動力。

展望未來，團隊將進一步探索整個變形過程，包括研究疊層缺陷在哪種情況下會出現在其他合金中，以及它們隨溫度變化的變形機制。相信透過加深對其理解，很快就能設計出更多具有更高機械性能及能用於低溫環境的新型合金。

這項研究獲得裘槎基金會、香港研究資助局、國家自然科學基金會、深圳市科技創新委員會以及中國科學技術部的資助。

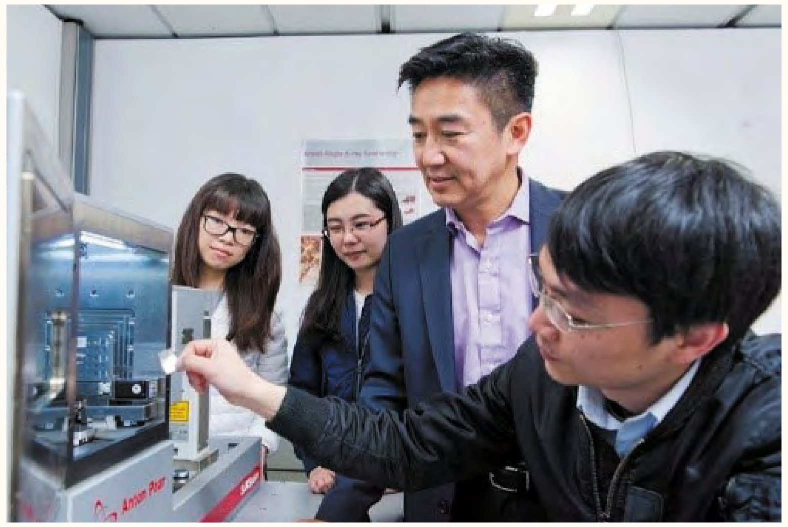
Muhammad NAEEM prepares the experiment at TAKUMI, an engineering materials diffractometer at Japan Proton Accelerator Research Complex (J-PARC) used to perform in-situ neutron diffraction measurements multiple HEA samples, which all showed a multi-stage deformation process.
(Photo Credit: Professor Xunli WANG)
研究團隊成員之一的 Muhammad NAEEM 在日本質子加速器研究中心（J-PARC）內的工程材料譜儀 TAKUMI 上為實驗作準備。研究人員用該設備對多種高熵合金進行原位中子衍射測量，樣本均顯示出多階段的變形過程。（王循理教授提供）



Deformation pathway of CrMnFeCoNi HEA sample at 15 K. Vertical dashed lines are drawn to pinpoint the changes in the deformation behaviour: (1) Start of dislocation slip; (2) start of stacking faults; (3) first sign of serrations; and (4) massive serrations coincided with the saturation of dislocation slip. (Photo source: DOI number: 10.1126/sciadv.aax4002)
CrMnFeCoNi（其中一款高熵合金）的樣本在 15 K 時的變形通路圖解。圖中垂直的虛線標示出變形行為的不同階段：（1）位錯滑移開始；（2）堆垛層錯開始；（3）開始出現鋸齒流變行為；（4）大量的鋸齒流變與位錯滑移的飽和同步。（圖片來源：DOI number: 10.1126 / sciadv.aax4002）

2021

Enigma of Glass Structure
解開玻璃結構之謎



Dr. Si LAN (right), Professor Xunli WANG (second from right), and students examine a Pd-Ni-P metallic glass specimen using the small-angle X-ray instrument.
蘭司博士（最右）、王循理教授（右二）和學生使用小角 X 射線儀器檢查 Pd-Ni-P 金屬玻璃樣本。

In spite of its widespread utilization in daily life, glass remains a mysterious material in the eyes of science. Scientists always want to unveil the secrets behind the detailed structure of this non-metallic and non-liquid material. The research team co-led by Professor Xunli WANG has recently shed light on the understanding of glass structure by close examination of the structural building blocks of the amorphous (non-crystalline) and crystalline metallic materials. The work was published in *Nature Materials*, titled "A medium-range structure motif linking amorphous and crystalline state".

雖然玻璃被廣泛應用於日常生活中，但在科學界裡，這晶瑩剔透、既非金屬亦非液體的物質仍然是一種神秘物料。是次王循理教授領導的研究團隊透過仔細研究這種無定形（非晶體）和晶態金屬物料的結構構件，闡述了對玻璃結構的獨特理解。有關研究成果已經在科學期刊《*Nature Materials*》上發表，題目是〈A medium-range structure motif linking amorphous and crystalline states〉。

As a non-crystalline amorphous solid, glass phase material is mysterious and special: the material appears as a solid on the outside, while it is as disorderly and unorganized as liquid inside. This peculiar structure has long been the center of attention – and grand challenge – of scientific research. This is because, unlike ordinary crystalline solid consisting of periodic stacking (long-range order) of fundamental building blocks known as unit cells, a glass material has no long-range order. It, however, has ordered structures at short-range (2-5 Å) and medium-range (5-20 Å), and even longer length scales. Yet, it is difficult to determine the nature of medium-range order due to the absence of contrast resulting from the amorphous nature of the material, rendering the existence of structural link at medium range or longer length scales between the amorphous material and its crystalline counterpart a scientific mystery. Further complicating the issue is that the crystallization of amorphous material usually results in a phase of different composition with disparate underlying structural building blocks.

作為一種非晶態的無定形固體，玻璃相材料具有神秘而獨有的特點：材料表面呈固體，而內裡則像液體一般雜亂無章。這種奇特的結構除了一直是科學研究的關注焦點，亦是科學家們的重大挑戰。與由稱為單位晶胞的周期性堆疊（長程序）基本構件組成的普通結晶固體不同，玻璃物料雖然沒有長程序，卻具有短程（2-5 Å）和中程（5-20Å）甚至更長尺度的程序結構。但由於缺乏以物料無定形性質所做的對比結果，故一直很難確定玻璃的中程序性質。就此，科學界一直就「無定形物料與其結晶對應物之間是否存在中等或更長尺度的結構鏈接」這難題作出研究；同時，無定形物料的結晶通常會出現具有不同成份和不同底層結構構件的相亦令問題進一步複雜化。

With their best endeavor, the team has successfully discovered a structure link between a glass solid and its crystalline counterpart, paving way for unveiling the secrets behind the structure of glass. They successfully captured an intermediate crystalline phase through precise control of the heating of a metallic glass (a palladium-nickel-phosphorus (Pd-Ni-P) alloy) at high temperature. By employing different advanced structure analysis techniques and comparing the structures of metallic glass (alloy) in its amorphous and intermediate crystalline states, the team discovered that both states share the same structural building blocks and that the connectivity between these structural building blocks distinguishes the crystalline and amorphous states of the materials.

經過不懈努力，研究團隊成功發現了玻璃固體與其晶體對應物之間的結構聯繫。透過精確控制金屬玻璃 [鈀 - 鎳 - 磷 (Pd-Ni-P) 合金] 在高溫下的加熱，團隊成功得到中間結晶相。透過採用不同先進結構分析技術及比較金屬玻璃 (合金) 在其非晶態和中間結晶態的結構，研究小組發現這兩種狀態正共享相同的結構構件，而這些結構構件之間的連通性亦區分了材料的結晶和無定形狀態。

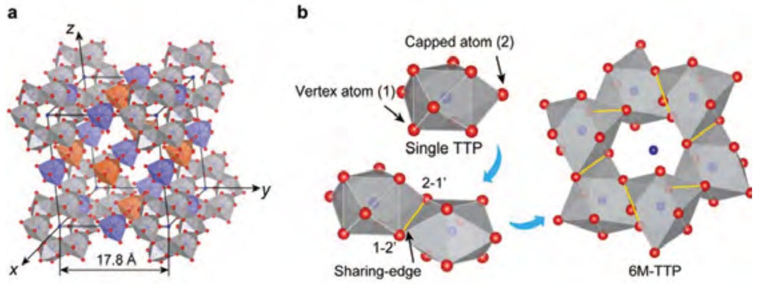
Since it is now proved that the structure determines the properties, it is hopeful that understanding the molecular structure of amorphous materials would open the door to further understanding of the structure of glass and designing of new materials.

由於研究結果已肯定了「結構決定性能」這理論，團隊希望對非晶材料分子結構的了解有助科學界進一步了解玻璃結構，並啟發嶄新物料的設計。

This work was supported by NSFC, the Natural Science Foundation of Jiangsu Province, the Fundamental Research Funds for the Central Universities, Guangdong-Hong Kong-Macao Joint Laboratory for Neutron Scattering Science and Technology, the Croucher Foundation, and the RGC of HKSAR.

這項工作得到了國家自然科學基金、江蘇省自然科學基金、粵港澳中子散射科學技術聯合實驗室、裘槎基金會、香港特別行政區研究資助局以及中央高校基礎研究基金的支持。

Dr. Si LAN (right) and Zhenduo WU (middle), co-first authors of the paper, make final adjustments in a synchrotron X-ray diffraction experiment at Advanced Photon Source, Argonne National Laboratory. Credit: Photo courtesy of Professor Xunli WANG
本論文的共同第一作者蘭司博士（右）和吳楨舵博士（中）在美國阿貢國家實驗室“先進光子源”的同步輻射 X 射線衍射實驗中作出最後的調整。（王循理教授提供）



A structure model illustrating the unit cell of the intermediate cubic crystalline phase. (a) Red balls are Pd and Ni atoms, whereas the blue balls represent P atoms. The orange-coloured polyhedron represents the Pd-enriched small cluster, and the blue-coloured polyhedron represents the Ni-enriched small cluster. Only part of the small clusters is displayed for clarification. (b). Schematic diagrams showing the construction of the 6M-TTP cluster by the edge-sharing scheme. (Photo source: Lan, S., Zhu, L., Wu, Z. et al. / DOI number:10.1038/s41563-021-01011-5)
上述分子結構模型解釋了中間立方結晶相（intermediate cubic crystalline phase）的結構單元。(a) 紅球是 Pd 和 Ni 原子，藍球則代表 P 原子。圖中橙色的多面體代表富含 Pd 的小團簇，藍色的多面體代表富含 Ni 的小團簇。為了清楚起見，圖中只顯示了小團簇的一部分。(b) 顯示通過邊緣共享而構建的 6M-TTP 團簇示意圖。（圖片來源：DOI number: 10.1038/s41563-021-01011-5）

Novel Nanostructured Aluminium Alloy Balancing Strength and Ductility
同時平衡強度和延展性的新型納米結構鋁合金

Strength and ductility are usually incompatible structural metallic materials' properties. However, Professor Jian LU's team developed a new aluminum alloy with high strength and high ductility by molecular dynamics simulations in 2019. The new alloy can be applied to micro-electromechanical systems (MEMS) for flexible wearable devices in the future. Supported by CityU, RGC of HKSAR, the National Key R&D Program of China, and the Major Program of the NSFC, the research findings were published in the scientific journal *Nature Communications,* titled "Hierarchical nanostructured aluminum alloy with ultrahigh strength and large plasticity".

強度和延展性通常是金屬物料不能相容的結構特性。然而，呂堅教授研究團隊在 2019 年成功透過分子動力學，模擬開發了一種具有高強度和高延展性的新型鋁合金。這種新合金未來可應用於柔性可穿戴設備的微機電系統 (MEMS)。這項研究得到城大、香港研究資助局、國家重點研發計劃和國家自然科學基金的支持，更於學術期刊《*自然通訊*》上發表，題為〈Hierarchical nanostructured aluminum alloy with ultrahigh strength and large plasticity〉。

Back to 2017, Professor Lu led a research team and developed the first supra-nano-dual-phase magnesium alloy of excellent strength and deformation capacity that could be developed into implantable biodegradable materials. The success did not bar the team from going further. Rather, they targeted at developing materials with both high strength and high ductility. Usually, approaches strengthening crystalline alloys decrease ductility as compromise, rendering these two properties mutually exclusive.

早於 2017 年，呂教授便開始帶領研究團隊，研發出首個具優異強度和變形能力的超納米雙相鎂合金，並可開發及用於成可植入生物降解物料。他們的目標是開發兼具高強度和高延展性的物料。製造強化結晶合金的方法一般會降低其延展性，從而令這兩種特性相互排斥。

However, the team overcame the obstacle and reaped their harvest when they successfully fabricated a "hierarchical nanostructured aluminium alloy" composed of amorphous-nanocrystalline structures by using advanced nanostructure control technology. That major research breakthrough became the cover story of *Nature*, an international top academic journal, and published on May 4, 2017.

隨著團隊成員利用先進的納米結構控制技術，成功製造出由非晶 - 納米晶結構組成的「分層納米結構鋁合金」後，此障礙便慢慢被克服，並在研究領域更上一層樓。尖端新型材料的強度較當時現有超強鎂合金晶態材料高出十倍，變形能力則較鎂基金屬玻璃高兩倍，並可發展成可生物降解植入材料。

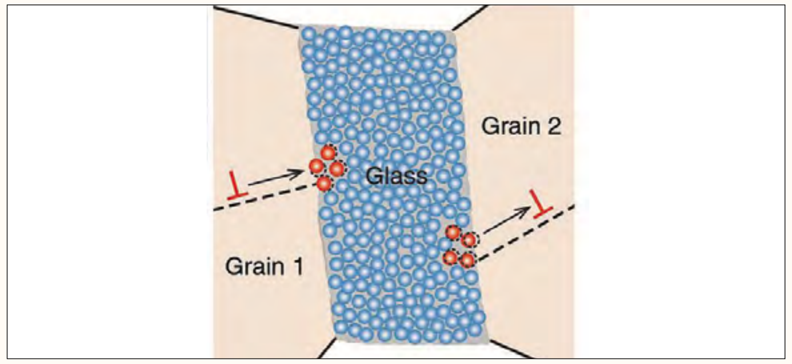
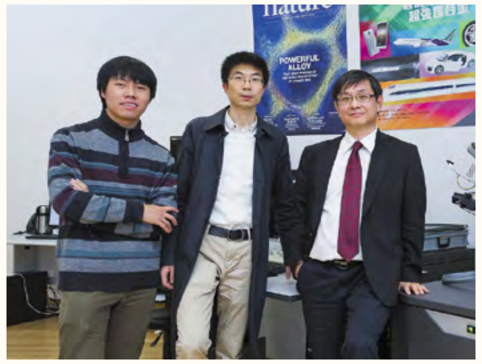


Illustration of dislocations' activities interacted with the nano-sized metallic glass phase. A dislocation ('⊥') is generated on the glass-grain 2 interface and then moves inside grain 2. Another dislocation ('⊥') moves inside grain 1 and then annihilates on the edge of the nano-sized metallic glass phase. The red and blue spheres represent mobile and less mobile atoms, respectively. The dashed lines represent the original positions of the mobile atoms. The black arrows denote the motion directions of the dislocations.
(photo source: Nat Commun 10, 5099 (2019) doi:10.1038/s41467-019-13087-4)
圖為位錯與納米金屬玻璃間相互作用的示意圖。一個位錯（'⊥'）在玻璃 - 晶粒 2 的界面產生，之後在晶粒 2 中移動。另外一個位錯（'⊥'）在晶粒 1 內移動，之後於納米金屬玻璃相邊界湮滅。紅色和藍色的圓形分別代表高活動性和較低活動性的原子。虛線代表高活動性原子的運動「軌跡」。黑色箭頭指示位錯的運動方向。（圖片來源：Nat Commun 10, 5099 (2019) doi:10.1038/s41467-019-13087-4）



(From left) Dr. Ligang SUN, Dr. Ge WU, and Professor Jian LU. The team has already achieved groundbreaking advancement by successfully developing the first-ever supra-nano magnesium alloy. That innovation became the cover story of *Nature*.
（左起）孫李剛博士、吳戈博士及呂堅教授。他們上一個重大研究成果，超納鎂合金雙相材料之前榮登《*自然*》的封面

The key to success lies in combining nanometer-sized amorphous metallic glass with crystalline nanomaterials. Metallic glass demonstrates higher yield strength than crystalline alloys in the absence of dislocation-mediated crystallographic slip. At room temperature, plastic deformation of metallic glass occurs mainly in nano-scale shear bands, softening the material and leading to fracture. To avoid this, theoretically, the metallic glass should be smaller than 100nm such that the material's strength can be significant improved while retaining its plastic deformation. Follow this direction, the team developed a hierarchical nanostructured aluminum alloy which structure enables both the plastic flow of the nano-sized metallic glass phase and the strain hardening of the crystalline phase.

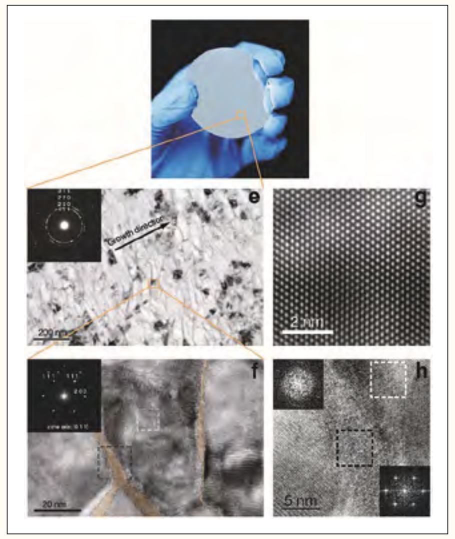
團隊發現，成功的關鍵在於將納米大小的無定形金屬玻璃與晶體納米物料相結合。在沒有位錯介導的晶體滑移情況下，金屬玻璃表現出比晶體合金更高的屈服強度。在室溫下，金屬玻璃的塑性變形主要出現在納米級剪切帶中，令物料軟化並導致斷裂。為避免這種情況出現，理論上金屬玻璃應該小於 100nm，才能令物料的強度顯著提升，並同時保持其塑性變形。按照這個方向，團隊開發了一種分層納米結構鋁合金，其結構既能具備納米金屬玻璃相的塑性流動，亦能帶來結晶相應變硬化的效果。

The novel aluminum alloy shows that strength and plasticity of a material are indeed compatible. Due to the extremely small size of nano-scale metallic glass in the hierarchical nanostructured aluminum alloy, the new material has ultra-high compressive yield strength and tensile yield strength. The continuous generation-movement-annihilation of transitory-dislocations in the nanograins and the intrinsic plastic flow of the nano-sized metallic glass phase contribute to the aluminum alloy's large plasticity. The data also shows that under compression, the new alloy displays homogeneous deformation, confirming the hypothesis about suppressing the formation of shear bands.

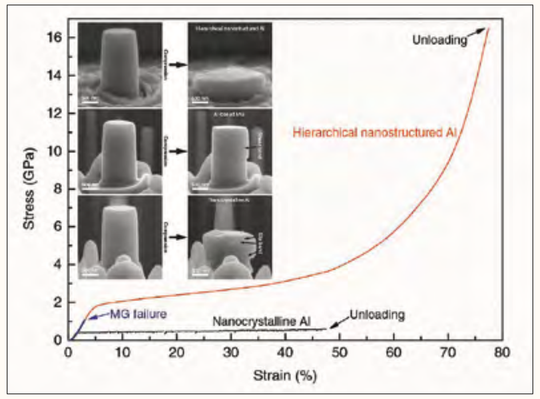
此嶄新的鋁合金顯示了物料的強度和塑性確實是相容的。由於分級納米結構鋁合金中納米級金屬玻璃的體積極小，這種新物料具有超高的抗壓屈服及抗拉屈服強度。納米晶粒中瞬態位錯的連續產生 - 運動 - 湮滅和納米級金屬玻璃相的固有塑性流動有助鋁合金大幅度提高可塑性。此外，數據亦顯示在壓縮情況下，新合金表現出均勻變形，並證實了抑制形成剪切帶的假設。

The research opens the door to a new hierarchical nanostructure approach in material engineering. It is believed that this means of developing aluminum alloy would pave the way for developing tough, lightweight alloys for the MEMS applications in flexible wearable devices in the foreseeable future.

此研究為物料工程中帶來一種突破性的分層納米結構方法。在可預見的將來，相信這種開發鋁合金的方式將有助為柔性可穿戴設備中的 MEMS 應用研究出堅韌而輕質的合金物料。



The top middle picture is the optical image of the hierarchical nanostructured aluminium alloy. Fig f is the high resolution transmission electron microscope (HRTEM) image of the alloy, showing a crystalline aluminium nanograin surrounded by amorphous phase (post-colored by light yellow). The white dashed rectangle region in fig f shows the fcc structure with zone axis of [0 1 1].
(Photo source: Nat Commun 10, 5099 (2019) doi:10.1038/s41467-019-13087-4)
最高的小圖是多級納米結構鋁合金的光學影像。圖 f 的高分辨透射電子顯微（HRTEM）照片顯示出一個鋁納米晶粒被非晶相（即金屬玻璃，後處理為淺黃色部分）所包裹。圖中的白色虛線方形區域，顯示了[0 1 1]晶帶軸下的面心立方（fcc）結構。（圖片來源：*Nature Communication* 10, 5099 (2019) doi:10.1038/s41467-019-13087-4）

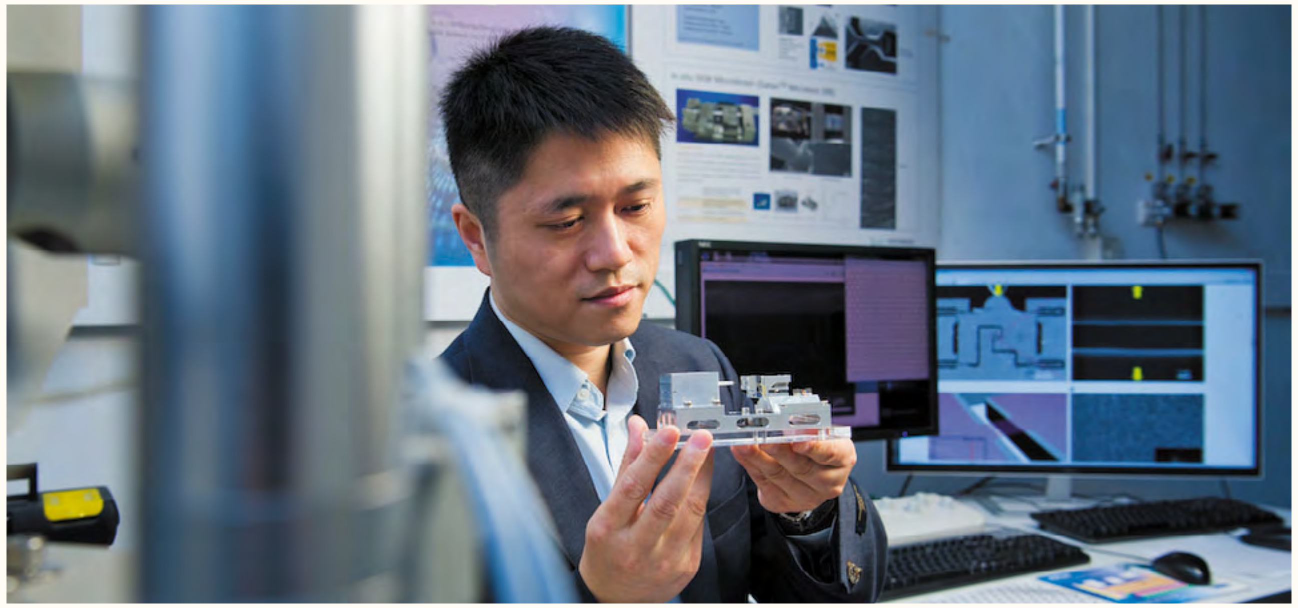


Compressive engineering stress-strain curves of the hierarchical nanostructured aluminium alloy, aluminium-based metallic glass, and nanocrystalline aluminum pillar samples with the same diameter of 1 μm, comparing their mechanical property. The hierarchical nanostructured aluminium alloy is proven to have better plasticity, did not show any shear bands or slip bands.
(photo source: Nat Commun 10, 5099 (2019) doi:10.1038/s41467-019-13087-4)
多級納米結構鋁合金」（上）、鋁基金屬玻璃（中）、納米晶鋁（下）微米柱樣品（1 μm 直徑）的壓縮工程應力 - 應變曲綫，反映樣品的力學性能的對比。可見「多級納米結構鋁合金」能被壓縮，沒有出現裂痕，非常強韌。相反，其他兩者均出現斷裂的情況，塑性不佳。（圖片來源：*Nature Communication* 10, 5099 (2019) doi:10.1038/s41467-019-13087-4）

2020

Revelation of Graphene's Stretchability and Engineering Strength

石墨烯的拉伸性和工程強度所帶來的啟示



Professor Yang LU is holding his nanomechanical platform that reveals the actual stretchability and strength of graphene.
陸教授手上拿的是納米力學測試平台，能測試出石墨烯的實際拉伸強度和彈性極限。

As the thinnest material on earth, the actual mechanical properties of free-standing graphene are difficult to be tested. A joint research team led by Professor Yang LU and scientists from Tsinghua University overcame this challenge and revealed the actual strength and stretchability of monolayer graphene by developing a unique nanomechanical testing platform, substantially contributing to the wide application of graphene in flexible electronics and engineering. Their findings were published in the international journal *Nature Communications*, titled "Elastic straining of free-standing monolayer graphene". The paper was later highlighted by "Editors' Choice" in *Science*.

Prior to this study, it was established that graphene was the strongest material with ultimate strength up to 130 GPa. However, Professor Lu pointed out that this conclusion was based on the local maximum stress that could be withstood at a certain point on a sheet of graphene. He reckoned that the boundaries and edge defects of a large-area graphene monolayer should also be considered for actual engineering application. Hence, he proposed that tensile stretching a large piece of free-standing monolayer graphene was a more suitable measurement method of graphene's practical mechanical properties, as it resembled actual loading conditions more.

作為地球上最薄的物料，獨立石墨烯的實際力學性能在過去一直難以測試。由陸洋教授及清華大學學者領導的研究團隊則克服了這一挑戰，透過開發獨特的納米力學測試平台，揭示了單層石墨烯的實際強度和可拉伸性，這突破性發現為石墨烯在柔性電子和工程中的廣泛應用作出重大貢獻。團隊研究結果早前於國際期刊《*自然通訊*》上發表，題為〈Elastic straining of free-standing monolayer graphene〉，及後更獲《*科學*》雜誌的〈Editors' Choice〉專欄介紹。

在這項研究之前，科學界已肯定了石墨烯是世上最強的物料，其極限強度可高達 130 GPa。然而，陸教授認為這結論是基於一塊石墨烯在某一點所能承受的局部最大應力。他認為大面積石墨烯單層的邊界和邊緣缺陷亦應考慮到實際環境當中。陸教授認為因為拉伸一大塊獨立單層石墨烯更能接近實際的負載條件，因此這方法會更適合用以測量石墨烯的實際力學性能。

The team designed and performed in situ tensile tests on free-standing graphene. After three-year trial and error, the team carried out tensile tests on the suspended graphene monolayers inside a scanning electron microscope, revealing the realistic mechanical properties of graphene in situ. The experiment showed that chemical vapor deposition (CVD)-grown monolayer graphene demonstrates outstanding elasticity, and the measured Young's modulus was very close to the theoretical value. More, the sample-wide tensile strength reached about half of the theoretical value, suggesting that large-area monolayer graphene was indeed an extremely strong material. Professor Lu explained that the results implied a potential of high-quality CVD graphene reaching not only the level of "ultra-strength" but also "deep ultra-strength". When a material can overall achieve such state of deep ultra-strength, it may possess unexpected new physical properties.

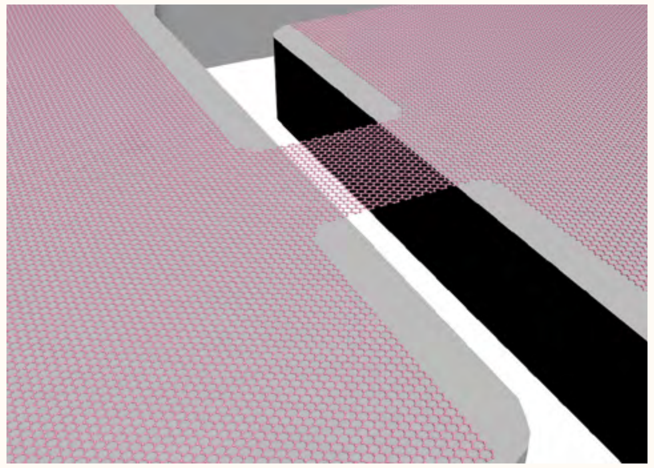
This research revealed actual mechanical properties, as opposed to theoretical value, of graphene, which are essential when designing the application of graphene in the future. As it is now known that graphene can withstand extremely large lattice deformation, scientists can therefore control the lattice strain precisely through the concept of elastic strain engineering for the novel application of graphene or other two-dimensional materials in future electronic or optoelectronic devices. It is hopeful that practical applications of graphene would be more common in the coming future.

The research was supported by CityU, RGC of HKSAR, and NSFC.

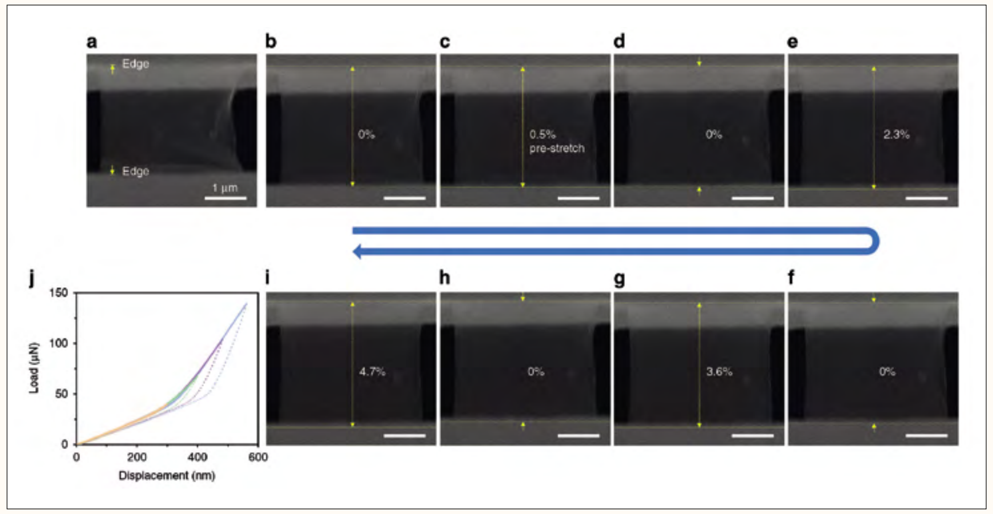
經過三年的反覆試驗，團隊在掃描電子顯微鏡內對懸浮的石墨烯單層進行了拉伸測試，並發現經過化學氣相沉積（CVD）生長的單層石墨烯表現出超凡的彈性，而所測得的楊氏模量亦與理論值非常接近。此外，整個樣本的拉伸強度亦達到理論值的一半左右，顯示大面積單層石墨烯確實是一種極強的物料。根據陸教授解釋，該結果暗示了高質量 CVD 石墨烯的潛力，當中除了可達到「超強」的水平，更可以達致「深度超強」的水平。當一種物料能整體達到這種深度超強狀態時，便可能擁有意想不到的新物理特性。

此項研究顯示了石墨烯的實際機械性能，而不僅僅限於理論值。這對未來石墨烯的應用提供了極重要的數據。因為石墨烯可承受極大的晶格變形，因此科學家可透過彈性應變工程的概念，精確控制晶格應變，從而將石墨烯或其他二維材料應用於未來電子或光電器件中。在未來，石墨烯的實際應用有望更加普及。

這項研究得到香港城大、香港研究資助局和國家自然科學基金的支持。



Monolayer graphene suspends between the device gap in the testing platform. With this platform, the team would further investigate the relationship between graphene's lattice and different properties for future strain engineering devices. (DOI: 10.1038/s41467-019-14130-0)
研究團隊成功將單層石墨烯轉移至特製的納米力學平台上作拉伸測試。透過這個平台還有望找出石墨烯的晶格設定與不同物理特性的關係，製成新的應變工程器件。（DOI : 10.1038/s41467-019-14130-0）



Fully recoverable elastic deformation of monolayer graphene reaches 5%, with maximum strain up to 6%. (DOI: 10.1038/s41467-019-14130-0)
單層石墨烯可實現高達 5% 的可完全回復的彈性變形，其最大拉伸應變達到約 6%。（DOI : 10.1038/s41467-019-14130-0）

2021

Stretching Diamond Inaugurates a New Era in Microelectronics
彈性拉伸金剛石 為微電子新世代揭開序幕

Well known for its hardness, one may overlook diamond's potential as an excellent electronic material. A joint research team led by co-led by Professor Yang LU and researchers from Massachusetts Institute of Technology (MIT) and Harbin Institute of Technology (HIT), demonstrated the potential of developing electronic devices through "deep elastic strain engineering" of microfabricated diamond structures, inaugurating a new era in the field of microelectronics. Their findings have been recently published in the prestigious scientific journal *Science*, titled "Achieving large uniform tensile elasticity in microfabricated diamond".

While industrial applications of diamonds are common due to its hardness, its applications in electronic and optoelectronic devices are less usual. In fact, diamond is a high-performance electronic and photonic material. This can partly be attributed to its ultra-wide bandgap, which enables operation of high-power or high-frequency devices. However, this, along with tight crystal structure, makes a diamond "dope", hampering the modulation of semi-conductors' electronic properties and the applications of diamonds in other fields. A potential alternative, changing the electronic band structure and associated functional properties by "strain engineering", is off the table due to the extreme hardness of diamond.

This alternative is now made possible under the efforts of Professor Yang LU and his research team. The team discovered that nanoscale diamond could be elastically bent with unexpected large local strain, suggesting a possibility to alter physical properties in diamond through elastic strain engineering. In the latest research, the team microfabricated single-crystalline bridge-like diamond samples from solid diamond single crystals, which were then uniaxially stretched in a well-controlled manner within an electron microscope. After a series of loading-unloading of quantitative tensile tests, the diamond bridges performed a highly uniform, large elastic deformation across the whole gauge section of the specimen, and was able to recover their original shape after unloading. Not only did the team reach the theoretical elastic limit of diamond, but it also realized elastic straining of microfabricated diamond arrays to, demonstrating the strained diamond device concept.

鑽石（又名金剛石）的硬度人所共知，但大眾往往忽略了這寶石之王作為一種優質電子物料的潛力。陸洋教授聯同來自美國麻省理工學院和哈爾濱工業大學（哈工大）的研究人員展示了如何透過利用『深彈性應變工程』，為金剛石進行結構微加工以開發電子儀器，並為微電子領域開創了新紀元。研究成果已於權威學術期刊《*科學*》上發表，題為〈Achieving large uniform tensile elasticity in microfabricated diamond〉。

雖然金剛石的堅硬程令其成為工業界經常應用的物料，但金剛石在電子和光電設備中的應用卻不太常見。事實上，金剛石是一種高性能的電子和光子物料。這特點可部分歸因於其超寬帶隙，令高功率或高頻設備能正常運作。然而，這特點及其緊密的晶體結構卻同時窒礙了金剛石半導體電子特性的調製及在其他範疇的應用。由於金剛石的極高硬度，以『應變工程』改變電子能帶結構和相關功能特性的潛在替代方案在過去一直不在考慮之列。

然而，陸教授及其研究團隊發現，納米級金剛石可以在意料之外的大局部應變情況下進行具彈性的彎曲。這證明了透過彈性應變工程，有可能改變金剛石的物理特性。在最新研究中，團隊從固體金剛石單晶中進行了微加工，得出單晶橋狀金剛石樣本，其後在電子顯微鏡內以可控的方式進行單軸拉伸。經過一系列定量拉伸試驗的裝卸後，金剛石橋在整個樣本的標距截面上出現極均勻且大幅度的彈性變形，而在卸載後亦能恢復原狀。此實驗不但達到了金剛石的理論彈性極限，更證明了微加工金剛石陣列的彈性應變能力，及展示了應變金剛石儀器的概念。

The team then estimated the impact of elastic straining from 0 to 12% on the diamond's electronic properties by density functional theory calculations. The results indicated that the diamond's bandgap is inversely proportional to the tensile strain. An electron energy-loss spectroscopy analysis on a pre-strained diamond sample was performed to verify the trend. The calculations also showed that the bandgap change from indirect to direct with tensile strains larger than 9% along another crystalline orientation, allowing many high-efficiency optoelectronic applications.

The nanomechanical approach adopted has demonstrated continuous and reversible changes of diamond's band structure, welcoming a new era of general applications of diamond. The research was funded by the RGC of HKSAR and NSFC.

其後，透過密度泛函理論的計算，團隊對 0% 到 12% 的彈性應變對金剛石電子特性影響進行了估算。結果顯示，金剛石的帶隙與拉伸應變成反比。其後又對預應變金剛石樣本進行了電子能量損失光譜分析，計算結果亦顯示帶隙從間接變為直接，沿另一個晶體取向的拉伸應變亦大於 9%，讓許多高效光電能得以應用。

是次研究採用了納米力學方法，證明了金剛石能帶結構的連續和可逆變化，同時亦為其廣泛應用於一般儀器揭開了序幕。這項研究獲得香港研究資助局和國家自然科學基金會的資助進行。

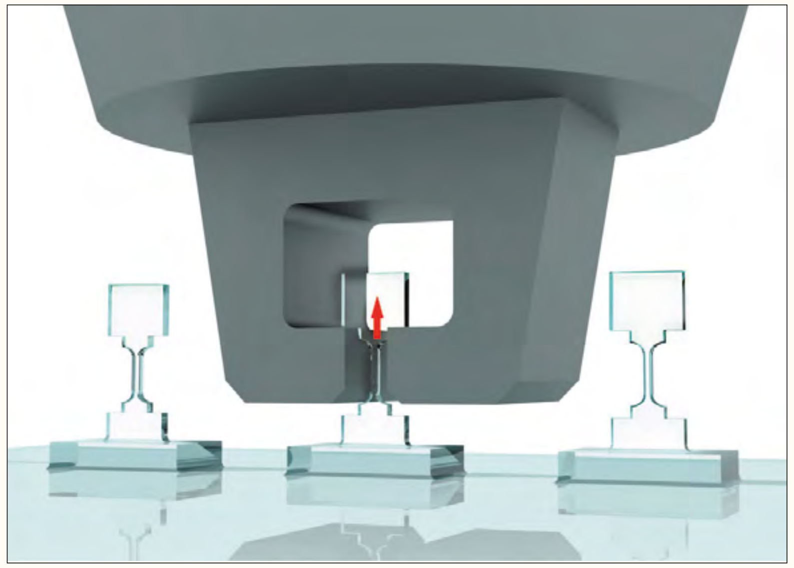
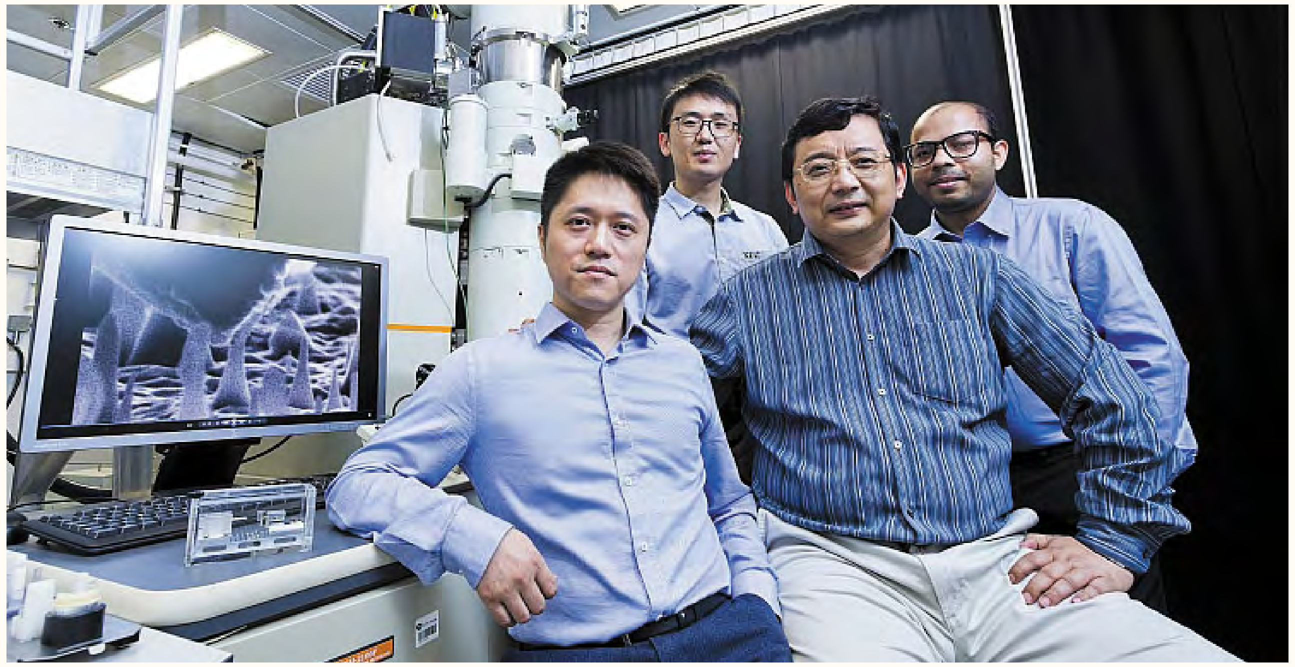


Illustration of tensile straining of microfabricated diamond bridge samples. (Credit: Chaoqun DANG / CityU) 對金剛石微橋樣品進行拉伸應變測試的示意圖。(圖片來源：Dang Chaoqun / CityU)

Stretching of microfabricated diamonds pave ways for applications in next-generation microelectronics. (credit: Dang Chaoqun / CityU) 拉伸金剛石應用於微電子技術 (圖片來源：Chaoqun DANG / CityU)

Nano Diamond Demonstrates Surprising Elasticity
納米鑽石表現出驚人彈性



The CityU team has discovered that nanoscale diamond can experience a significant amount of elastic deformation. (From left: Professor Yang LU, Dr. Hongti ZHANG, Professor Wenjun ZHANG and Amit BANERJEE)
陸洋教授（前排左）研究團隊運用香港城大材料科學與工程系張文軍教授（前排右）課題組制備的納米金剛石樣品來進行納米力學研究。

Diamond is the hardest material in nature. Out of many expectations, it also has excellent elasticity. An international research team led by Professor Yang LU has achieved a significant breakthrough in nanomechanics as it discovered that diamonds at nanoscale could undergo ultra-large, fully reversible elastic deformation, greatly contributing to the nanotechnology and biomedical fields, and even quantum information technologies. Supported by the RGC of HKSAR and NSFC, this ground discovery was published in the prestigious journal *Science* under the title “Ultralarge elastic deformation of nanoscale diamond”.

Despite its hardness, diamond fractures easily when subjected to relatively small amount of deformation. The team showed another facet of diamond’s properties – elasticity. When diamond is downsized to nearly 100nm in diameter, up to around 9% of tensile elastic strain is recorded for single crystalline sample, which is close to the maximum theoretically achievable strain for an ideal diamond crystal. The team also revealed that the deformation of the nanoscale diamond was fully-reversible in nature, implying that the elastic nature of nanoscale diamond.

鑽石是大自然界中最堅硬的物料。但鮮為人知的是，這珍貴寶石其實亦具有非常出色的彈性。由陸洋教授領導的國際研究團隊在納米力學方面取得了重大突破，當中發現了納米級鑽石可出現超大及完全可逆轉的彈性變形。此發現為納米技術和生物醫學領域乃至量子信息技術作出了重大貢獻。該項目主要由香港研究資助局以及國家自然科學基金的資助，研究成果更以〈Ultralarge elastic deformation of nanoscale diamond〉為題被刊登在世界頂級學術期刊《*科學*》雜志上，宣布了這項金剛石在納米尺度下力學行為的重大發現。

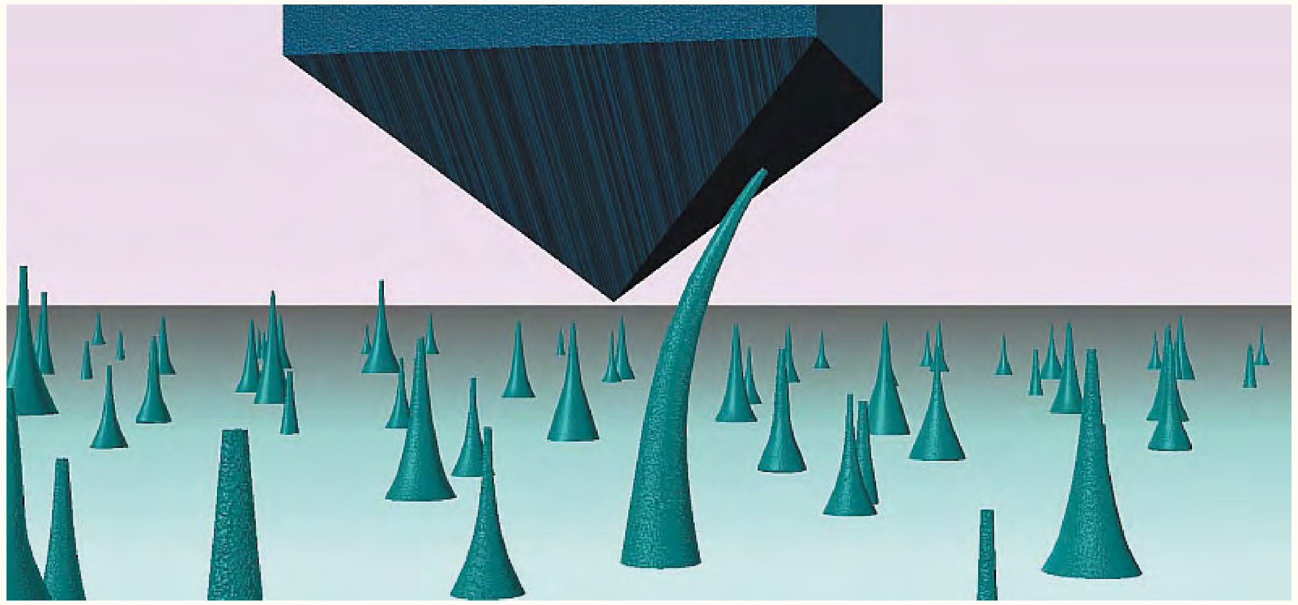
雖然具有相當硬度，但鑽石在受到相對較小的變形時亦很容易斷裂。由陸洋教授領導的研究小組展示了鑽石的另一個特性，亦即是其彈性。當鑽石的直徑縮至接近 100 納米大小時，單晶樣本記錄的拉伸彈性應變高達 9% 左右，接近理論上理想鑽石晶體可達到的最大變化。研究小組亦透露了納米級鑽石的變形本質是完全可逆的，這發現代表了納米級鑽石的彈性。

This project aimed at characterizing the mechanical properties of diamonds at nanoscale. Being the hardest natural material, diamond is often used to test other material’s mechanical properties. To avoid the predicament of “diamond against diamond”, the team employed the innovative “push to bend” test – observe the bending of diamond nanoneedles under the exertion of force onto nanoneedles from the slant surface of a nanoindenter diamond tip. Later, the team combined finite element method analysis with these real-time bending experiment videos, and evaluated the local stress, strain and displacement of the nanoneedle structures. The results showed that both “single-crystalline” and “poly-crystalline” needles of diamond were able to reach unexpectedly high elastic strain, while the former performed better. The nano diamond samples were fabricated by Professor Wenjun ZHANG.

These innovative findings would inaugurate a new nanomechanics era that puts great emphasis on the practical applications of nano diamonds in different fields. As diamond is compatible with human body, one of the possible exploration directions is diamond needle-based drug delivery to human cells. The exceptional ductility of nano diamond can enhance the durability of intracellular delivery and lower the cost. Further, diamond may also be widely applied in the next-generation information technology. When it comes to quantum computing and quantum information processing, the diamond’s nano-sized characteristics discussed in the research enable manufacturers to produce highly reliable and efficient diamond resonators and sensors for faster data storage and transfer.

此研究的目的是為了指出納米級鑽石的機械性能特徵。作為最堅硬的天然物料，鑽石通常用於測試其他物料的機械性能。為避免出現以「鑽石測試鑽石」的難題，團隊採用了嶄新的「壓縮 - 彎曲」測試法，從納米壓痕儀尖端的側面向鑽石納米針施加壓力時，觀察鑽石納米針的彎曲情況。隨後，團隊結合了有限元法分析及從實時彎曲實驗所得的影片資料，對納米針結構的局部壓力、應變和移位情況作出了評估。結果顯示鑽石的「單晶」和「多晶」針都能達到意想不到的高彈性應變，當中前者的表現較好。這次研究運用張文軍教授團隊特別制備的研究用納米金剛石錐樣品來進行測試。

這些創新發現將為科學界開啟一個全新的納米力學時代，當中會非常著重納米鑽石在不同領域的實際應用方式。由於鑽石與人體相容，因此這項研究極有發展前景。未來有可能進一步探索以納米鑽石針把藥物傳輸至人體細胞：納米鑽石卓越的延展性可增強細胞內遞送的耐久性，並降低成本。此外，鑽石亦可廣泛應用於下一代資訊科技。在量子計算及量子資料處理方面，研究當中的鑽石納米尺寸特性能讓製造商生產極具可靠性及高效的鑽石共鳴器和傳感器，以更快捷地儲存及傳送數據。



A schematic diagram showing the “push to bend” nanomechanical test on a diamond nanoneedle.
團隊採用「壓縮 - 彎曲」測試法，觀察鑽石納米針的彎曲情況。

2021

Uncovering Nanolayers Intermetallic Alloys' Grain Boundary
探索納米層金屬間合金的晶界


Professor Chain Tsuan LIU leads the research. The advanced three-dimension atom probe tomography (3D APT) at CityU is being used in the research.
研究由香港城大傑出教授兼香港高等研究院資深院士劉錦川教授領導，並使用了圖中所示、華南地區唯一一部的三維原子探針斷層攝影儀。
(圖片來源：香港城市大學)

Strength and ductility within material are usually irreconcilable. A research team led by Professor Chain Tsuan LIU and Dr. Tao YANG, has developed an innovative alloy design strategy to overcome the challenge in intermetallic alloys, which will greatly promote the wide applications of materials that could operate under extreme temperatures in the future. Supported by CityU, RGC of HKSAR, and the NSFC, the findings were published in the prestigious scientific journal *Science*, titled "Ultrahigh-strength and ductile superlattice alloys with nanoscale disordered interfaces".

物料內的強度和延展性通常是不相容的。最近，由劉錦川教授及楊濤博士領導的研究團隊開發了一種創新的合金設計方法，以克服這個一直存在於金屬間合金的挑戰，並大大提高了未來於極端溫度下產生作用的物料之廣泛應用。這項研究獲得城大、香港研究資助局及國家自然科學基金委員會等資助進行。研究結果在頂尖學術期刊《*科學*》上發表，題為〈Ultrahigh-strength and ductile superlattice alloys with nanoscale disordered interfaces〉。

The inner structure of intermetallic alloys, same as metals, is formed with individual crystalline areas known as "grains". During tensile deformation, these grain boundaries crack along each other, rendering the intermetallic alloys fragile. To overcome this brittleness, the conventional approach is to add trace amount (0.1 to 0.5 atomic percent (at.%)) of boron to the intermetallic alloys, which can enhance the grain boundary cohesion and overall ductility. When excessive amounts of boron are added, this traditional means would not work. Studied this approach 30 years ago, Professor Liu achieved another breakthrough by developing the novel "interfacial nanoscale disordering" strategy in multi-element intermetallic alloys, realizing both high strength and large ductility of a material at once.

與金屬一樣，金屬間合金的內部結構由稱為「晶粒」的單個結晶區域所組成。在拉伸變形過程中，這些晶界會互相破裂，令金屬間合金變得脆弱。為了克服這種脆弱的特質，常規方法是在金屬間合金中加入微量【0.1 至 0.5 原子百分比 (at.%)】的硼，以增強晶界凝聚力和整體延展性。然而，當添加過量的硼時，這種傳統方法便不能奏效。近年，遠在 30 年已開始研究此方法的劉錦川教授在多元素金屬間合金中開發出嶄新的「界面納米無序化」方法，能令物料同時擁有高強度和大延展性，並在科學研究上取得一大突破。

Aimed at enhancing the grain boundary cohesion, Professor Liu and his team were originally optimizing the amount of boron added. To everyone's surprise, distinctive nanoscale layers were formed between the orderly packed grains in the alloy when the team added 1.5 to 2.5 at. % of boron to the intermetallic alloys. These nanolayers serve as buffer zones between adjacent grains that enable plastic-deformation at grain boundaries, and thus rendering the intermetallic alloys not only very strong but also extremely ductile. Experiment results further showed that the alloys with 2.5 at. % of boron demonstrated an ultra-high yield strength of 1.6 gigapascals, with tensile ductility of 25% at ambient temperature.

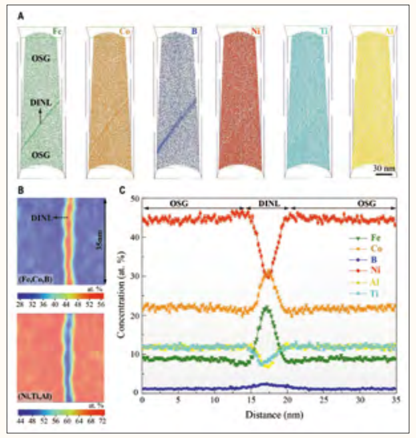
為提高晶界的黏聚力，劉教授和他的團隊原先的目標是改良硼的添加份量。然而，當團隊在硼對金屬間合金的百分比添加 1.5 至 2.5 at 時，他們發現合金中有序堆積的晶粒之間形成了獨特的納米級層，其充當了相鄰晶粒之間的緩衝區，使晶界處發生塑性變形，令金屬間合金不但變得非常堅固，亦同時具有極強的延展性。實驗結果進一步顯示在添加了 2.5 at % 硼的合金在室溫下表現出 1.6 吉帕的超高屈服強度，以及 25% 的拉伸延展性。

The team also found that by adding more boron to the alloys, the "multi-element co-segregation" would be enhanced – while a high concentration of boron, iron and cobalt atoms was observed within the nanolayers, the nickel, aluminum and titanium were substantially depleted there. This element partitioning induced the nanoscale disordering and promoted ductility by suppressing the fractures along grain boundaries. More, suppressed by the nanolayer, the grain size remained stable even under high temperature for 120 hours. Hence, the strength of the alloys maintained.

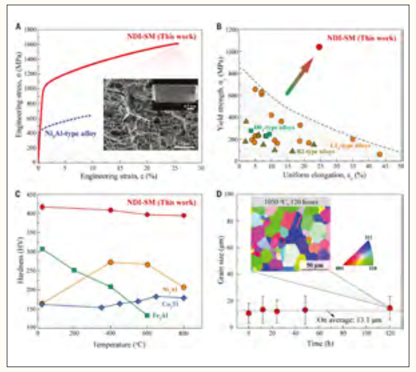
研究團隊亦發現，在合金中進一步添加更多的硼後，會顯著增強「多元素共同偏析」－雖然在納米層內部含有高濃度的硼、鐵和鈷原子，但在當中的鎳、鋁和鈦則大幅減少。透過抑制沿晶界的斷裂，這種元素分配能導致納米級無序化，並為物料帶來延展性。此外，受到納米層的抑制，即使在高溫下 120 小時，晶粒尺寸仍保持穩定，令合金的強度得以保留。

It is believed that the discovery of this nanolayer will lay a solid foundation for the development of high-strength and high-ductility materials that can apply to high-temperature settings like aerospace, automotive, etc., soon.

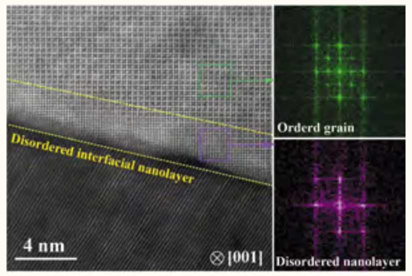
團隊深信這一納米層的發現將為高強度、高延展性物料的開發奠定了堅實的基礎，且在不久將來被應用於航空航天、汽車等高溫環境中。



Atom maps reconstructed using 3D-APT show the distribution of each element. Iron (Fe), cobalt (Co), and boron (B)are enriched (darker in colour) at the nanolayer, whereas nickel (Ni), aluminum (Al), and titanium (Ti) are depleted (lighter in colour) correspondingly. (B) and (C) also show the same results. (photo source: DOI number: 10.1126/science.abb6830)
3D-APT 可以檢測出每種元素的分佈。無序納米層（disordered interfacial nanolayer, DINL） 中聚集了鐵（Fe）、鈷（Co）和硼（B）（可見顏色較深），而鎳（Ni）、鋁（Al）和鈦（Ti）的分佈相應較少（可見顏色較淺） 。圖 B 和圖 C 也顯示相同的結果。（圖片來源：DOI number: 10.1126/science.abb6830）



These pictures suggest that the alloy (NDI-SM) has achieved a superior strength-ductility synergy at ambient temperature and extraordinary heat resistance at elevated temperatures. (photo source: DOI number: 10.1126/science.abb6830)
這些圖片表明研究團隊實驗所測試的合金（NDI-SM）在室溫下展示優異的強度 - 延展性協同作用，並在高溫下具備出色的耐熱度。（圖片來源：DOI number: 10.1126/science.abb6830）



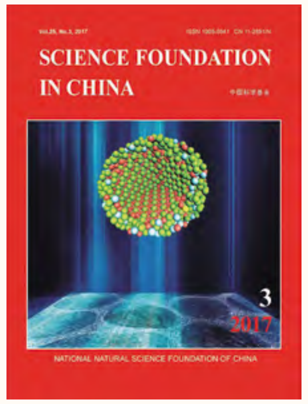
HAADF-STEM image reveals the ultrathin disordered layer at the grain boundaries with a thickness of about 5 nm. (photo source: DOI number: 10.1126/science.abb6830) HAADF-STEM
HAADF-STEM 圖片顯示了於晶界出現的超薄無序納米層，其厚度約為 5 nm。（圖片來源：DOI number: 10.1126/science.abb6830）


The new high-entropy alloy is extremely strong but ductile.
新型高熵合金強度與延展性兼得。

2021

Development of Bioimplants by 2D/3D/4D Additive Manufacturing
透過 2D/3D/4D 增材製造開發生物植入物

The SERS biosensing technology can be used to test contaminants in food and cosmetics.
表面增強拉曼光譜（SERS）的生物傳感技術可用於檢測食品和化妝品中的污染物。



The findings were reported in the prestigious scientific journal *Nature* and *Science Foundation in China* as the cover story.
有關研究成果被國際頂尖科學學術期刊《*自然*》及中國國家自然基金委員會主辦的綜合指導性學術期刊《*中國科學基金*》獲選為表封面文章。

The fabrication of novel materials with complex shapes and desirable properties is the heart of materials science and engineering. After developing two bleeding-edge technologies that has changed the landscape in materials science, Professor Jian LU has been working on the integration of them to fabricate lightweight, high-stretch metallic materials for biomedical applications. The findings were reported in the prestigious scientific journal *Nature* as the cover story, as well as the cover story in *Science Foundation in China.*

In 2017, Professor Lu and his team developed the world's first-ever supra-nano-dual-phase magnesium alloy. By employing dual-phase nanostructuring technology, the novel material developed is 10 times stronger than conventional crystalline magnesium alloy and has ultra-deformation capacity two times higher than that of magnesium-based metallic glass. This novel material successfully breaks the strength-ductility trade-off dilemma. The high excellent resistance of the new alloy makes it possible to be used as a novel prototype for biodegradable implants or coating material for artificial joints. The second technology developed by the team was 4D ceramic printing. Unlike conventional 3D-printed metallic materials that are generally of insufficient fatigue and wear resistance, the 3D-printed ceramic precursors printed by Professor Lu's latest technology can undergo self-reshaping by themselves over time with the elastic energy stored in the stretched precursors, making the fabricated ceramics exceptionally strong and mechanically robust.

製造形狀複雜和性能理想的嶄新物料是物料科學與工程的核心研究範疇。在成功開發兩項改變物料的尖端技術後，呂堅教授正致力研究將它們整合，以製造出輕盈同時擁有高拉伸度的金屬物料，以應用於生物醫學領域。有關研究成果在國際頂尖科學學術期刊《*自然*》上發表封面文章，是中國科學家首次在該刊就結構材料領域研究發表的封面文章，並獲中國國家自然基金委員會主辦的綜合指導性學術期刊《*中國科學基金*》選為的封面成果。

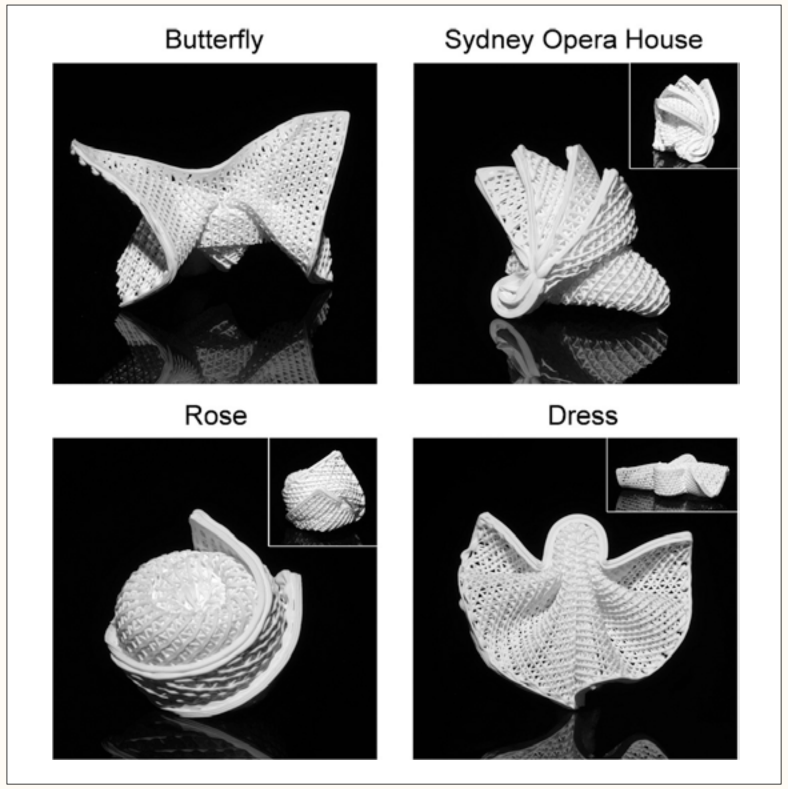
2017 年，呂教授和他的團隊開發出世上獨一無二的超納米雙相鎂合金。透過採用雙相納米結構技術，所開發的新型物料比傳統的結晶鎂合金強度高 10 倍，而超變形能力亦是鎂基金屬玻璃的 2 倍，成功打破了強度和延展性之間一直存在的矛盾，其高抗性更使其有機會被用作可生物降解植入物的全新原型或人工關節的塗層物料。另外，團隊亦開發了 4D 陶瓷打印技術。有別於傳統 3D 打印金屬物料所面對的抗疲勞性和耐磨性不足，其 3D 打印陶瓷前驅體可利用拉伸前驅體中所儲存的彈性能量，隨時間自行重塑，令製造的陶瓷變得異常堅固及擁有如機械般的牢固特質。

With the foundation laid, the team attempts to fabricate metallic-based materials with complex shapes, particularly those used in biomedical and lightweight structure applications, through a 2D/3D/4D manufacturing system. The team will begin with producing supra-nano 3D-printed titanium-based alloy as titanium-based alloys are considered the ideal implant material for clinical use. The next step of the team will be focusing on the post-treatment effects on the mechanical properties of the printed materials. For instance, using SMAT to enhance fatigue resistance. The ultimate goal of the team is to set up a database of 3D-printed metallic materials, with detailed information about their mechanical properties, microstructure, treatment process and potential applications. The database will be a valuable asset and assistance to materials researchers and engineers for their future research and explorations.

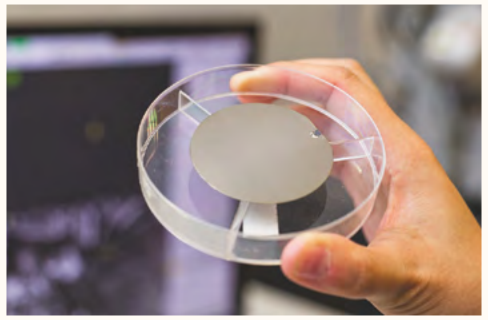
In addition to the printing technology, the team also use their best endeavor to contribute to the biomedical field. The team has worked on functional metallic materials, particularly their newly developed biosensing technology based on ultrasensitive SERS. They are currently testing the feasibility of its application in fast detection of COVID-19, cancer, etc.

奠定基礎後，團隊試圖透過 2D/3D/4D 製作系統製造形狀複雜的金屬基物料，尤其是用於生物醫學和輕質結構應用的物料。因為鈦基合金被認為是最適用於臨床的植入物料，團隊將從生產超納米 3D 打印鈦基合金開始。下一步，團隊將會專注於後處理對印刷物料機械性能的影響。例如，使用表面機械研磨處理 (SMAT) 來增強抗疲勞性。團隊的最終目標是建立一個 3D 打印金屬物料數據庫，其中包含有關其機械特點、微觀結構、處理過程及潛在應用的詳細資料，並有望為物料研究人員和工程師帶來極大幫助。

除了打印技術外，團隊亦新開發了基於超靈敏表面增強拉曼光譜（SERS）的生物傳感技術，並正研究使用 3D 打印在快速檢測新冠病毒、癌症等方面應用的可行性。



The 3D-printed ceramic precursors are soft and stretchable, enabling ceramics with complex shapes, such as origami folding mimicking the Sydney Opera House.
以 3D 打印出來的陶瓷前驅體，既柔軟兼可拉伸，能製備出複雜的形狀，例如仿悉尼歌劇院的折紙結構。



Supra-nano-dual-phase magnesium alloy
超納雙相鎂合金材料

2021

Revealing Potential of 3D Printing for Material Design
揭示 3D 打印技術在合金材料設計上的潛力


Professor Chain Tsuan LIU (left) and Dr. Tianlong ZHANG discuss the new pathway to design alloys by a 3D printing technique.
劉錦川教授（左）和張天隆博士（右）討論如何以 3D 打印技術設計合金。

The belief that 3D printing has great potential beyond designing geometries has brought Professor Chain Tsuan LIU and Dr. Tianlong ZHANG to develop a super-strong, highly ductile and super-light titanium-based alloy, opening the door to design alloys with unprecedented structures and properties.

The inhomogeneity in alloy components has always been considered as undesirable as it leads to unfavorable properties such as brittleness. It is therefore important to eliminate this inhomogeneity during fast cooling. However, Dr. Zhang's earlier study has revealed that a certain degree of heterogeneity in the component would produce unique and heterogeneous microstructures, and they could improve the alloy's properties. Based on these findings, the research team conducted further experiments by using the additive manufacturing.

With the aid of 3D printing, the team has developed a partial homogenization method to produce alloys with micrometer-scale concentration gradient, overcoming the challenge of inhomogeneity and greatly enhancing the alloy's properties. The method involved the melting and mixing of two alloys (titanium alloy powders and stainless steel powders) using a focused laser beam. With more controllable parameters, the team successfully developed the non-uniform composition of the elements in the new alloy in a controllable way.

劉錦川教授和張天隆博士利用 3D 打印技術，開發和設計出一種超強、高韌性和超輕的鈦基合金材料。

研究人員認為，由於合金成份屬非均質性，令合金材料易脆，因此必須在快速冷卻的過程中消除這種非均質性。張博士早期的研究已經發現，合金成份中一定程度的異質性會產生獨特且異質的微型結構，最終可以改良合金材料的特性。基於以上發現，研究小組再次利用 3D 增材技術以作進一步實驗。

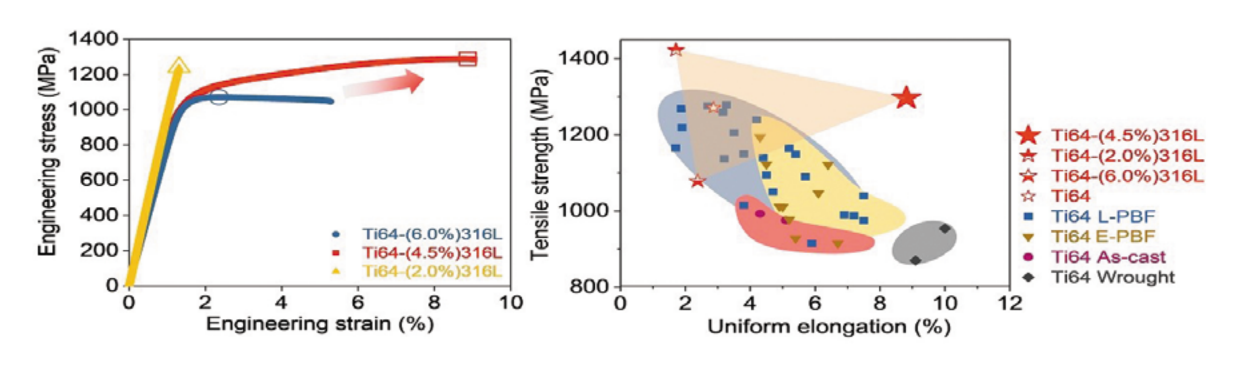
團隊利用 3D 打印技術，加入了更多具穩定性的參數，研發出一個局部均質化方法：利用聚焦雷射光束，將兩種合金材料（鈦合金粉末和不銹鋼粉末）熔化和混合，消除當中的非均質性，成功生產出具有微米級濃度梯度的合金材料，同時大幅增強合金材料的特性，以及提高了生產的穩定性。

The unprecedented lava-like microstructures created brings about supreme mechanical properties, realizing exceptional strength, ductility and light-weight of the alloy. Compare to stainless steel that is generally 7.9 g/cm³, the new alloy is only 4.5 g/cm³, resulting in a 40% reduction in weight. The titanium alloy also demonstrates high tensile strength of around 1.3 gigapascals with a uniform elongation of about 9% and excellent work-hardening capacity of over 300 megapascals, guaranteeing a large safety margin prior to fracture. These excellent properties are rather useful in structural applications in a variety of fields, such as aerospace, automotive, chemical .

Supported by CityU, HKIAS, the National Key Research and Development Program of China, NSFC, Guangdong Academy of Sciences, and the US National Science Foundation, this research has achieved remarkable results and was published in the prestigious scientific journal *Science*, titled "In situ design of advanced titanium alloy with concentration modulations by additive manufacturing". As the pioneer of developing innovative alloys with distinctive microstructures and properties by using 3D printing, the team will strive to apply this concept on different alloy systems and discover other properties of new alloys for wider applications.

全新的熔岩狀微型結構具有良好的機械特性，令合金材料更加強硬、更加柔韌和更加輕巧，同時具有較大安全系數。相比一般重量為 7.9 g/cm³ 的不銹鋼，新合金材料的每平方厘米克數僅為 4.5 g/cm³，重量減輕了 40%。新合金材料還具有約 1.3 吉帕斯卡的高抗拉強度、約 9% 的均勻伸長比率以及超過 300 兆帕斯卡的超卓加工硬化特性，能承受極大的壓力以防止斷裂。因此，新合金材料能廣泛應用於航天、汽車、化學和醫療等多個領域。

有關研究已獲得城大、香港城市大學高等研究院、國家重點研發計劃、國家自然科學基金委員會、廣東省科學院和美國國家科學基金的贊助並取得傑出成果。研究成果亦已經在科學期刊《*科學*》上發表，標題為 < 利用增材技術製作具微型結構的先進鈦合金的原位設計 >。作為利用 3D 打印技術進行研發的先驅，並創造出具獨特微型結構和優異性能的新合金材料，團隊將會努力將這技術應用到不同的合金材料上，希望能研發出其他新合金性能以達至更廣闊的應用層面。



The experimental results show that the new titanium alloy has supreme mechanical properties. (Credit: Dr. Tianlong ZHANG /DOI number: 10.1126/science.abj3770)
3D 打印鈦合金經實驗測試，證明具有優異的力學性能。（張天隆博士提供 / DOI number: 10.1126/science.abj3770）


The new titanium alloy using 3D printing has lava-like microstructures that give rise to its excellent mechanical properties.
研究團隊創造出一種前所未見、具有熔岩狀微觀組織的新合金，這種微觀組織令合金衍生出優異的力學性能。


Grain orientation map of the 3D-printed titanium alloy developed by the CityU research team.
Credit: Dr. Tianlong ZHANG /DOI number: 10.1126/science.abj3770e.abj3770）
3D 打印鈦合金內的晶粒取向和形貌。（張天隆博士提供 / DOI number: 10.1126/science.abj3770）

Future Research Plan
未來研究計劃

Professor Jian LU
呂堅教授

1. Surface mechanical attrition treatment (SMAT)

We will further extend our study on integration of SMAT and micro-alloyed technologies on high pure gold and other precious metals, and the optimization of the process parameters.

In recent years, our research group has been mainly engaged in research on thin-film physics and thin-film fabrication. We have used these techniques to prepare various high-strength, high-ductility nanostructured metal and metal-alloy thin films. This has given us a comprehensive understanding and practical mastery of core disciplines in this and related areas. Consequently, we have achieved a range of excellent research results related to thin-film growth theory, amorphous alloy theory, and optical thin-film properties. In 2017, our group developed a magnesium-based ultrathin-nanofilm with a dual-phase nanostructure, and showed that this ultrathin-nanofilm exhibits high strength that is close to its theoretical value. This work was published in *Nature* (DOI: 10.1038/nature21691). In 2019, we applied film-growth theory to study a new type of aluminum-based nanostructured alloy film, which exhibits ultrahigh yield strength and substantial tensile and compressive plasticity. The main results from this work were published in *Nature Communications* (DOI: 10.1038/s41467-019-13087-4).

Recently, we used the magnesium-based supra-nano dual-phase film to develop a novel magnesium-based reflective filter (Figure 1). This filter has extremely high color saturation and excellent mechanical properties, which are realized by simultaneously adjusting the composition and fabrication of the magnesium-based thin film. Hence, this filter will be useful in various applications, such as in optical display equipment, structural color printers, home electronics, photodetectors, solar cells, and large-scale automotive components. This filter also overcomes the complex problems associated with multilayer dielectric filters formed by multiple depositions of conventional reflective metal-based films. Moreover, as this filter does not use materials with different thermal expansion coefficients, it avoids the problems (such as a limited color range and poor mechanical properties) that are exhibited by other types of filters. This work was published in 2019 in *Advanced Optical Materials* (DOI: 10.1002/adom.201901626). We also applied for a US patent, which has been granted.

1. 表面機械研磨處理（SMAT）

我們將進一步拓展表面機械研磨處理技術與微合金化技術在高純金等貴金屬上的研究，以及優化工藝參數。

近年來，我們主要從事薄膜物理和薄膜製造的研究，已經成功地製備了多種具有高強度和高延展性的納米結構金屬和金屬合金薄膜（圖 1），對相關學科領域已有較全面的理解和掌握。在薄膜生長理論、非晶合金理論以及光學薄膜特性等方面取得了很好的研究成果。鎂基金屬玻璃納米薄膜材料以其高強度重量比、輕質低密度以及出色的生物相容性等特點，在改善機械性能和新型的功能性應用上得到越來越多的關注。2017 年，我們成功研發了具有雙相納米結構的鎂基超納薄膜，這材料表現出近乎理論值的高強度。這成果作為封面文章發表於*《自然》*（DOI:10.1038/nature21691）。2019 年，我們應用薄膜生長理論研究了新型的鋁基納米結構合金薄膜，該合金具有超高的屈服強度，並且在拉伸和壓縮時都具有非常顯著的塑性，其主要結果發表在國際權威刊物*《自然通訊》*（DOI: 10.1038/s41467-019-13087-4）。

及後，基於鎂基超納雙相薄膜的基礎上研發了一種新型鎂基反射型濾光薄膜，該鎂基反射型濾光薄膜具有極高的色彩飽和度和優異的機械性能，打破了常規的反射型金屬基濾光膜片多層介電膜多次沈積的複雜工藝，解決了材料膜層之間由於熱膨脹系數的差異所導致的應用面積和機械性能受到限制的問題。並且通過調控鎂基薄膜的成分和工藝使其同時擁有極高的色彩飽和度以及良好的機械性能，可以在光學顯示設備、結構彩色印刷、家用電子產品、光電探測器、太陽能電池、汽車部件等領域大面積應用。該成果發表在國際權威刊物*《Advanced Optical Materials》*（2019 年 ,DOI: 10.1002/adom.201901626），並申請相關美國專利一項，已獲授權（專利號：US011168401B2）。

In the coming future, we will start exploring the feasibility of employing an environmentally friendly and efficient magnetron sputtering coating technology to prepare multi-level color coatings with high hardness and wear resistance to bring stylish colors and novel color change concept to the traditional 18K or higher Carat gold or platinum. As an advanced technology for film preparation, magnetron sputtering coating allows film materials densely growing on various materials, including materials with complex shapes such as rings, necklaces or even "dragon-phoenix" bracelets. The interference color film through material design and parameters control of magnetron sputtering will be realized. The existence of the transparent oxide film and the concentration of the reaction gas of the reactive magnetron sputtering will change the color significantly, so that a range of colors can be generated. The controlled optical film can then be deposited on the surface of the 18K or higher Carat precious metal alloy substrate with the desired colors added as well as the hardness and scratch resistance of the substrate enhanced. This method is simple in process, can realize automatic control, large-scale production, green environmental protection, energy saving and low carbon, and has wide applicability. Thus, we target at putting this concept forward to realization in the near future.

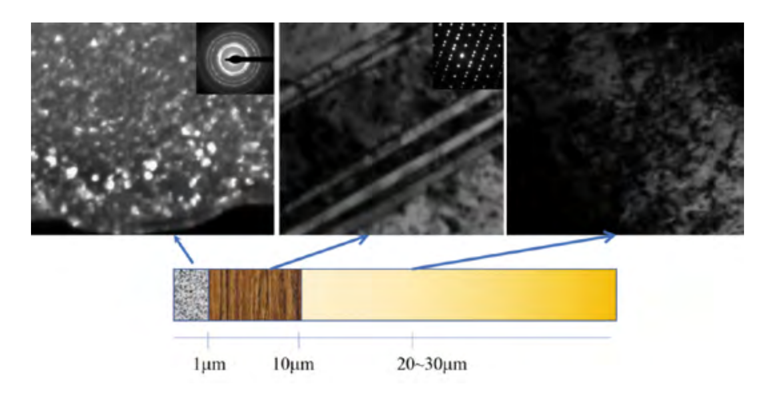


Figure 1 The nanocrystallized (a), nanotwinned (b) and plastically deformed (c) microstructure characteristics along depth in the treated surface layer of the 24K SMATed gold.
圖 1 經表面機械研磨處理技術加工過的 24K 黃金的表面納米化 (a) 納米孿晶 (b) 塑性變形 (c) 微結構特征。

在未來的日子，我們還將探索採用環保高效的磁控濺射鍍膜技術製備高硬度和耐磨的多層次彩色塗層的可行性，為傳統的 18K 或以上純度的金或鉑金帶來時尚的色彩和新穎的變色理念。磁控濺射鍍膜作為一種先進的薄膜製備技術，可以使薄膜材料密集生長在各種材料上，包括戒指、項鍊甚至龍鳳手鐲等形狀複雜的材料。通過材料設計和磁控濺射參數控制實現彩色薄膜。透明氧化膜的存在和反應磁控濺射反應氣體的濃度會顯著改變顏色，從而產生一系列不同顏色的薄膜，並將受控光學薄膜沉積在 18K 或以上純度的貴金屬合金基板的表面上，添加所需的顏色以及增強基材的硬度和抗劃傷性。這方法工藝簡單，可實現自動化控制、規模化生產、綠色環保、節能低碳，具有廣泛的適用性。因此，我們的目標是在不久的將來把這概念實現出來。

2. Supra-nano-dual-phase Nanostructured Materials

The unique size effects and dual-phase synergistic effects of SNDP nanostructuring contribute to gratifying properties that can hardly be achieved by conventional phase- and defect-engineering, making SNDP a new class of basic structural motif beyond ordered crystal and disordered glass. The interactions between the dual phases at the nanoscale below 10 nm are an unlimited source for diverse functions but are far from being fully comprehended. Future research should focus on the function exploitation of SNDP materials, especially the electrocatalysis dominated by interfaces and sophisticated nanostructure.

1) A series of SNDP precious metals (Pt, Ir, Ru, Ag, and Pd are prior) will be synthesized, via an economical and scalable strategy, as a kind of fire-new catalysts for highly efficient hydrogen evolution. The intrinsically advanced nanostructure of these novel SNDP catalysts can provide substantial active sites for desirable HER performance with super electrocatalytic stability that cannot be achieved by any reported catalysts. These SNDP precious metals are the ideal paradigms for the design of high-performance electrocatalysts.

2) Developing SNDP base metals with precious-metal doping for efficient and low-cost electrocatalyst for HER. Base metals provide a rich material library to develop SNDP materials with specific functions and structures. Micro-doping of precious metals into SNDP base metals, inspired by the structure design of single-atom catalysis and single-cluster catalysis, is expected to significantly improve catalytic performance. The SNDP nanostructure with dual-phase interfaces could provide fertile sites and ideal coordination environments for the incorporation of precious metals, resulting in substantial catalytic active sites and high utilization efficiency of precious metals.

3) Due to lower resistance losses and less gas crossover, hydrogen generation through proton exchange membrane water electrolysis in an acidic electrolyte may reach substantially greater current densities than standard alkaline electrolyzers. However, the water splitting is limited by oxygen evolution reactions owing to the sluggish four-electron transfer process. The SNDP Ir- and Ru-based films show great potential to optimize the binding energy of oxygen intermediates owing to the phase interfaces and lattice strain. Therefore, the application of SNDP Ir- and Ru-based catalysts may promote the application of proton exchange membrane and create significant economic benefits.

2. 超納雙相納米材料

超納雙相納米結構獨特的尺寸效應和雙相協同效應有助於實現常規相和缺陷工程難以實現的性能，使超納雙相納米結構成為超越有序晶體和無序玻璃的新型基礎結構基序。目前對納米雙相之間的相互作用還未完全理解。未來的研究應該集中在超納雙相納米結構材料的功能性應用和開發，特別是受到界面和複雜納米結構影響的電催化領域。

1）開發低成本、可大規模生產的工藝用以製備超納雙相納米結構的貴金屬催化劑（優先採用 Pt、Ir、Ru、Ag 和 Pd）。這些新型催化劑所具有的豐富納米結構可以為 HER 催化反應提供大量的活性位點，並具有任何已報導的催化劑都無法實現的優異穩定性。

2）開發具有貴金屬摻雜的超納雙相納米結構常規金屬催化劑。常規金屬（如 Ni 和 Co）可提供豐富的材料庫來開發具有特定功能和結構的超納雙相納米材料。受單原子催化和單團簇催化結構的啟發，將貴金屬摻雜到超納雙相常規金屬中，有望顯著提高其催化性能。具有雙相界面的超納雙相納米結構可以為貴金屬的摻入提供豐富的位點和理想的配位環境，從而產生大量的催化活性位點並有效提高貴金屬的利用效率。

3）通過質子交換膜在酸性電解質中電解水產生氫氣的工藝可以達到比標準鹼性電解槽大得多的電流密度。然而，由於受到緩慢的四電子轉移過程的影響，水分解過程受到析氧反應的限制。由於具有豐富的相界面和晶格應變，超納雙相的 Ir 和 Ru 基薄膜有望顯著優化催化劑表面與氧中間體的結合能。因此，超納雙相 Ir 和 Ru 基催化劑的開發可能會促進質子交換膜的應用並創造顯著的經濟效益。

Professor Chain Tsuan LIU

劉錦川教授

The research team led by Professor Chain Tsuan LIU has innovatively discovered the superlattice alloys, nanoparticle-strengthened high-entropy alloys, and additively manufactured Ti-based alloys that exhibit extraordinary mechanical properties. However, the intrinsic correlations between the alloying effects, structural evolutions and associated mechanical properties of these novel structural materials have not been well understood. Moreover, their thermal stability, mechanical responses and oxidations behaviors at elevated temperatures are still largely unknown. Therefore, in the future, the research team will mainly focus on three crucial scientific and technological issues of the advanced structural materials: (1) To quantitatively determine the thermal stability of structural materials, in particular, the thermal stability, phase transformation, and critical ordering temperature. (2) To investigate the alloying effects of additional elements on the electronic structure, phase stability, and energy state of metallic materials through the systematic thermodynamic evaluations combined with the first-principal calculations. (3) To comprehensively evaluate the mechanical responses of the newly developed metallic materials, especially the yielding anomaly behavior, environmental effects, and creep resistance at elevated temperatures. These results will provide technological and scientific knowledge helpful in developing new-generation structural materials.

由劉錦川教授領導的研究團隊創新性地開發了具有非凡機械性能的超晶格合金、納米粒子強化高熵合金和增材製造的鈦合金。然而，這些新型結構材料的合金化效果、結構演變和相關機械性能之間的內在相關性尚未得到很好的理解。此外，它們在高溫下的熱穩定性、機械響應和氧化行為仍然未知。因此，未來研究團隊將主要關注先進結構材料的三個關鍵問題：（1）定量確定結構材料的熱穩定性、相變和臨界溫度。 (2) 通過系統熱力學評價結合第一性原理計算，研究添加元素對金屬材料電子結構、相穩定性和能態的合金化影響。 (3) 綜合評價新開發金屬材料的力學響應行為，特別是高溫下的屈服異常行為、環境影響和抗蠕變性。這些結果將為開發新一代結構材料提供技術和科學指導。

Professor Hua ZHANG
張華教授

Based on the research progress achieved, in the future we will conduct research in the following directions:

1. Systematic studies on the phase-dependent physicochemical properties of noble metal nanomaterials. Currently, we mainly focus on investigating the catalytic properties of the noble metal nanomaterials with unconventional phases. In the future, we will study the effect of phase on other properties of noble metal nanomaterials, including optical property, electrical property, magnetic property, mechanical property.

2. Preparation of noble metal-semiconductor heterostructures using noble metal nanomaterials with unconventional phases as seeds. Currently, we realize the epitaxial growth of a series of transition metals on the noble metal nanomaterials with unconventional phases via the templated/seeded growth method. In the future, we will extend this strategy to grow semiconductors, including metal oxides, metal sulfides, on these noble metal seeds to achieve noble metal-semiconductor heterostructures. Besides the conventional roles on improvement of the charge separation and transport at the metal-semiconductor interface, the noble metal seeds with unconventional phases are expected to induce new growth behaviors of semiconductors, thus resulting in unique properties.

在目前取得的研究進展的基礎上，未來我們將在以下幾個方向開展研究工作：

1. 系統研究貴金屬納米材料相依賴的物化性質。目前，我們主要研究了非常規相的貴金屬納米材料的催化性質。接下來，我們將研究相對貴金屬納米材料其他性質的影響，如光學性質、電學性質、磁學性質和力學性質等。

2. 以非常規相的貴金屬納米材料為晶種製備貴金屬 - 半導體異質結構。目前，我們通過範本法實現了一系列過渡金屬在非常規相的貴金屬納米材料上的外延生長。接下來，我們將擴展該合成策略，實現金屬氧化物、金屬硫化物等半導體在這些貴金屬晶種上的生長，以製備新型貴金屬 - 半導體異質結構。在該異質結構中，金屬 - 半導體界面可以有效促進載流子分離和輸運，而非常規相的貴金屬晶種則有望誘導半導體產生全新的生長行為，從而賦予其獨特的性質。

Professor Wenjun ZHANG
張文軍教授

1. Water electrolysis has been recognized as a promising alternative to produce hydrogen in an eco-friendly and sustainable way. In water electrolysis, however, the efficiency of hydrogen evolution reaction (HER) on cathode is mainly restricted by the sluggish kinetics of oxygen evolution reaction (OER) on anode, and meanwhile, the anode product, i.e., oxygen, has a low economic value. We propose to utilize methanol oxidation reaction (MOR) with faster kinetics to replace OER to realize an energy-saving hydrogen production and simultaneous a high-value upgrade conversion of methanol to formate. In this study, we will develop plasma chemical vapor deposition and electrodeposition technologies to directly grow nickel-based layered double hydroxide/vertical graphene array (LDH/VGA) composites on carbon cloths as integrated three-dimensional (3D) electrodes for MOR. The prototypes of 3D integrated LDH/VGA electrodes will be prepared. This research will provide a new solution for the development of high-efficiency electrocatalysts for energy-saving and high value-added water electrolysis.

2. The sp^3-configurated diamond has a unique combination of physical and chemical properties, and particularly its extreme stability and large electrochemical window in comparison with other sp^2 carbon phases enable it to be used as an electrode material to achieve a high selectivity in electrocatalytic CO_2 and N_2 reduction reactions. We propose to develop a new type of diamond-based electrocatalytic electrode through anchoring metal clusters (MCs, M=Fe, Co, and Ni) on one-dimensional diamond nanostructure arrays (1D-DiaNAs). The basic idea is to increase both the yield rate and Faraday efficiency of diamond electrodes in CO_2 and N_2 electroreductions, taking the synergistic advantages of the enhanced activity through engineering the diamond/MCs interface, and the broad electrochemical window and tip effect of 1D-DiaNAs. The effects of the factors such as the surface nanostructures of diamond, the type of metals, and the loading amount, distribution, and coordination of metal clusters, on the electroreduction performance will be investigated. Through comprehensive characterization and theoretical simulation, the electrocatalytic mechanisms of CO_2 and N_2 reductions on 1D-DiaNA/MCs electrodes, and the synergistic enhancement effects between metals and 1D diamond nanostructures will be elucidated. This project will provide further understanding for the design and development of new high-efficiency electrodes for CO_2 and N_2 electroreductions.

1. 電解水作為一種環保、可持續的制氫方法，具有較高應用前景。然而，電解水過程中，陰極析氫反應 (HER) 的效率受到陽極析氧反應 (OER) 效率的制約，同時陽極產生的氧氣經濟價值較低。我們擬利用動力學更快的甲醇氧化反應 (MOR) 來取代陽極 OER，以實現高效節能制氫和甲醇向甲酸鹽的升級轉化。研究中將利用等離子體化學氣相沉積和電沉積等技術，在碳布上直接生長鎳基層狀雙氫氧化物 / 石墨烯陣列 (LDH/VGA) 複合材料，製備用於 MOR 的三維集成 LDH/VGA 電極。本研究將為開發高效節能的電解水技術提供新的解決方案。

2. 與 sp^2 碳相比，sp^3 構型的金剛石具有獨特的理化性質，尤其是穩定性和較寬的電化學窗口，使其在 CO_2 和 N_2 電催化還原反應中表現出較高的選擇性。我們將通過在一維金剛石納米陣列 (1D-DiaNAs) 上錨定金屬納米簇 (MCs, M=Fe, Co 和 Ni) 的方式來開發新型的金剛石基電極。通過調控金剛石 /MCs 界面結構，綜合金剛石較寬的電化學視窗和尖端效應，提高 CO_2 和 N_2 還原的產率和法拉第效率；考察金剛石表面結構、金屬類型、負載量、團簇分佈和配位元等因素對催化性能的影響；結合實驗表徵和理論模擬，闡明 CO_2 和 N_2 在 1D-DiaNA/MCs 電極上的催化還原機理，以及金屬與金剛石的協同增強效應。本研究將為新型高效的 CO_2 和 N_2 電催化還原電極的設計和開發提供進一步的認識。

Professor Xiaoqiao HE

何小橋教授

The proposed project will theoretically study the mechanical behavior of helical carbon nanotubes (HCNTs). HCNTs with different coil pitches can be generated by incorporating pentagon and heptagon pairs into the predominantly hexagonal framework of the carbon nanotubes (CNTs). Due to their special helical structure, HCNTs possess super-elasticity and unique mechanical, chemical, and electric properties, which makes them promising materials for use in HCNTs-reinforced precious metals.

In the proposed project we will conduct a comprehensive study of the mechanical properties of HCNT structures in three stages. First, a modified atomic-based cellular automata algorithm (MACAA) based on the shape of a helix with various helical pitches and angles will be established for the analysis of single-walled HCNTs, in which the HCNT structures will be treated as a discrete system at the atomic scale. Tersoff-Brenner's many-body potential will be used to describe the interaction between the atoms, while the solution framework will be based on the conventional continuum mechanics. By linking the atomistic and continuum methods, the proposed MACAA will be as accurate as the molecular dynamic (MD) method and allow much faster simulation. Second, an explicit expression will be established to describe the van der Waals (vdW) forces between any two layers of a multi-walled HCNT. With the developed expression for vdW forces, the established MACAA for a single-walled HCNT will be extended to the analysis of multi-walled HCNTs, which can deal with large atomic systems for the numerical simulation. Finally, an effective parallel MACAA algorithm will be developed for the mechanical analysis of HCNTs reinforced precious metals. The influence of different geometric parameters such as coil diameter, helical pitch, helical angle, size and chirality of nanotubes, etc. on the tensile strength, stretchability, stability, damage mechanism, etc. of HCNTs reinforced precious metals will be studied in detail.

本項目將從理論上研究螺旋碳納米管 (HCNTs) 的力學行為。 通過將一組五邊形和七邊形結合到碳納米管的框架中，可以生成不同線圈間距的螺旋碳管。 由於其特殊的螺旋結構，螺旋碳管具有超彈性和獨特的力學、化學和電學性能，這使其在貴金屬增強納米材料中具有廣闊的應用前景。

在本項目中，我們將分三個階段對螺旋碳管結構的力學性能進行綜合研究。 首先，將建立一種改進的基於不同螺旋形狀的元胞自動機演算法 (MACAA)，用於分析單壁螺旋碳管，其中螺旋碳管結構將在原子尺度上被視為一個離散系統。 Tersoff-Brenner 的多體勢將用於描述原子間的相互作用，而解決框架將基於傳統的連續介質力學。 通過連接原子尺度上的模擬和連續力學類比，改進的 MACAA 演算法將與分子動力學方法一樣準確，且計算速度更快。 其次，建立描述任意兩層螺旋碳管間的范德華力顯式表達式。 隨著范德華力表達式的建立，單壁螺旋碳管的力學分析模型將擴展到多壁螺旋碳管的力學分析中，可以用於數值模擬大原子系統。 最後，將開發一種有效的並行 MACAA 演算法用於螺旋碳管增強貴金屬的力學分析。螺旋直徑、螺旋間距、螺旋角、納米管尺寸和手性等不同幾何參數對螺旋碳管增強貴金屬材料的抗拉強度、拉伸性能、穩定性、損傷機理等的影響將會得到系統性的研究。

Professor Kaili ZHANG

張開黎教授

Development of microthruster based on Au/Pt/Cr microheater and energetic coordination polymer propellant

Micro/nano satellites are receiving more and more attention because of their reduced launch and mission costs, and improved reliability. With the development of micro/nano satellite technology and the expansion of its application fields, the functions of micro/nano satellites such as attitude control, resistance compensation, station positioning, and orbit adjustment have put forward more urgent needs for micropropulsion systems. Micro electro mechanical system (MEMS) technology plays a very important role in the development of micropropulsion systems. The microthruster is the combination product of the micropropulsion system and MEMS technology, which provides maneuverability for in-orbit micro/nano satellites. There are still many challenges in the development of microthruster. One of the key challenges is finding a suitable propellant.

We will develop a non-toxic and pollution-free green solid propellant with high gas yield and will integrate it into a microthruster. A nanoscale energetic coordination polymer (ECP) constructed from transition metal ions, nitrogen-rich bis-tetrazole ligands and graphene oxide (GO) will be prepared as a solid propellant. The composition design of the proposed new propellant is expected to bring many advantages. We will design a microthruster that is more suitable for high level integration. The microthruster will be fabricated by standard MEMS technology. The microchamber will be fabricated by etching a silicon substrate via deep reactive ion etching (DRIE) to create a microscale hole. The intermediate layer will also be fabricated by etching through a silicon substrate via DRIE. Highly reliable Cr/Pt/Au microheater will be fabricated on a silicon substrate. Both aqueous KOH etching and DRIE will be employed to generate anisotropic and isotropic etching of the other side of the silicon substrate to create the micronozzle with different divergence angles that will affect the micropropulsion performance of the microthruster. After the ECP-GO based propellant is filled into the microchamber, the microchamber layer, intermediate layer, and micronozzle layer with the microheater on the backside will be bonded together by appropriate technique to form the three-dimensional microthruster. Specific impulse and thrust are important indexes of propulsion performance of microthruster and important reference for thruster selection during space mission. Therefore, after the successful fabrication of microthruster based on the new solid propellant, the specific impulse and thrust measurement need to be carried out. The change of propulsion performance under different solid propellant formulations is also worth studying, so as to provide reference for customizing special propellant formulations according to the propulsion requirements of specific space missions in the future.

基於 Au/Pt/Cr 微加熱器和高能配位聚合物推進劑的微推進器的研發

微型 / 納米衛星因其發射和任務成本降低以及可靠性提高而受到越來越多的關注。隨著微納衛星技術的發展及其應用領域的擴大，微納衛星的姿態控制、阻力補償、空間定位、軌道調整等功能對微推進系統提出了更加迫切的需求。微機電系統（MEMS）技術在微推進系統的發展中發揮著非常重要的作用。微型推進器是微推進系統和 MEMS 技術的結合產品，為在軌微型 / 納米衛星提供了機動性。微型推進器的發展仍存在許多挑戰，其中一個關鍵挑戰是找到合適的推進劑。

我們將研發一種無毒、無污染、氣體產量高的綠色固體推進劑，並將其集成到微型推進器中。由過渡金屬離子、富氮雙四氮配體和氧化石墨烯（GO）構成的納米級高能配位聚合物（ECP）將作為固體推進劑製備，所提出的新型推進劑的組成設計具有許多優點。我們將設計一個更適合高度集成的微推進器，微推進器將通過標準 MEMS 技術製造。微室將通過深度反應離子蝕刻（DRIE）蝕刻矽襯底來製造，以產生微尺度的空穴，中間層也將通過 DRIE 通過矽襯底蝕刻來製造，高度可靠的 Cr/Pt/Au 微加熱器將在矽襯底上製造。將採用水性 KOH 蝕刻和 DRIE 來生成矽襯底另一側的各向異性和各向同性蝕刻，以產生具有不同發散角的微噴嘴，來測試不同發散角微推進器的微推進性能。將基於 ECP-GO 的推進劑填充到微室後，微室層、中間層和微噴嘴層與背面的微加熱器將通過適當的技術粘合在一起，形成三維微推進器。比沖和推力是微型推進性能的重要指標，也是空間飛行中推進器選型的重要參考。因此，在基於新型固體推進劑的微型推進器成功製備後，需要進行比沖和推力測量。不同固體推進劑配方下推進性能的變化也值得研究，可為今後根據特定空間飛行任務的推進要求定制特殊推進劑配方提供參考。

Dr. Yangyang LI
李揚揚博士

SERS detection technology has gained a significant place in the field of on-site, real-time detection with its unique advantages. First, SERS detection technology is non-destructive to the sample and has a short detection time (in seconds). Secondly, SERS spectroscopy provides information on the vibration of molecules, which can be used to identify unknowns through fingerprint spectroscopy data base, thus achieving qualitative detection. Finally, single-molecule detection using SERS technology has been achieved and is expected to provide on-site highly sensitive and rapid analysis of ultra-trace substances. SERS can be used to in-situ monitor the molecular information of the reactants, intermediates, and products, gaining insight into the mechanisms of catalytic reactions.

Based on the portable Raman system developed by the NPMM, we hope we will be able to promote the industrialization of SERS technology in various fields. Our future plan is to cooperate with third-party testing organizations to jointly promote the research of the portable Raman system in food safety and major diseases, take the lead or participate in the development of some industry standards, complete clinical experimental verification and medical device registration and approval, and eventually promote our portable Raman system in scientific research institutions, medical institutions, and third-party testing organizations to better serve the community. We will provide our technical solutions for the "Healthy China 2030".

SERS 檢測技術以其獨特的優勢在現場及時檢測領域佔有了重要的地位。首先， SERS 檢測技術不破壞樣品，檢測用時短(以秒計)。其次， SERS 光譜可以提供分子的振動資訊，通過這些振動資訊對應的指紋光譜來辨別未知物，從而達到定性檢測的效果。然後，SERS 技術已經實現單分子檢測，有望為超痕量的待測物提供現場高靈敏的快速分析。SERS 技術可以用作原味檢測催化反應中反應物、中間態、產物的分子狀態，揭示催化反應的機理。

基於貴金屬分中心研發的可携式拉曼系統可以有效推動 SERS 技術在多領域的產業化進程。我們的未來計畫是與協力廠商檢測結構合作，共同推動可携式拉曼系統在食品安全和重大疾病領域的快檢研究，牽頭或者參與制定一些列的行業標準，完成臨床實驗驗證和醫療器械的註冊審批，最終在科研機構，醫療機構，協力廠商檢測機構，推廣我們的可携式拉曼系統，使之更好的服務社會，為構建“健康中國2030”提供我們的技術方案。

Dr. Zhanxi FAN
范戰西博士

In the future, we will still focus on the methodology of the design and preparation of unusually phase metals, advanced functional metal-based hetero nanostructures, and their application in small molecule conversion. We will continue to explore the synthesis method of novel metal nanomaterials with unusual or unprecedented crystal phases, characterize their fine structures, interpret their formation mechanism, and expand their synthesis method to other kinds of methods. Detailly, we will pay special attention to the preparation of Ru, Ir, Rh, and Pt with pure phase and/or heterophase structure. Exploring the methodology using wet chemical synthesis method, electrochemical synthesis method, and epitaxial synthesis method. We will delicately characterize the atomic structure, and try to expand the method to non-precious metals.

We will keep researching the rational design and preparation of advanced functional metal-based hetero nanostructures, especially focusing on the composition, structure, and interface based on the properties of applications. Detailly, We will dedicate ourselves to the preparation of novel precious-metal-based hetero nanostructures with different compositions, such as AgCu, AuCu, RuCu, RuNi, IrNi, RuIr, AuRu, AuIr, and so on. We will try to modulate their spacial structure forming a desired structure such as the Janus structure, core-shell structure, and so on. We will try to tune the interface of the two parts via modulating their position, boundaries, and contents.

We will focus on the application of these novel materials for catalysis, and pay more attention to the area of carbon neutrality. We will carefully evaluate the electrocatalytic CO_2 reduction performance of the prepared novel materials in both the aqueous CO_2RR system and Li-CO_2 battery system. Based on the rational design of the material, we will try to improve the activity, selectivity, and longevity aiming at the production of C_{2+} products in aqueous CO_2RR system; and boost the kinetics in the Li-CO_2 battery. We will also expand the application of these materials to other catalytic reactions such as NO_3 reduction reaction.

未來，我們仍將重點關注異相金屬、先進功能金屬基異質納米結構的設計和製備方法及其在小分子轉化中的應用。我們將繼續探索具有不尋常或前所未有的晶相的新型金屬納米材料的合成方法，表徵其精細結構，解釋其形成機制，並將其合成方法擴展到其他種類的方法。具體而言，我們將特別關注具有純相和 / 或異相結構的 Ru、Ir、Rh 和 Pt 的製備。探索濕化學合成法、電化學合成法和外延合成法的方法學。我們將精細地表徵原子結構，並嘗試將合成方法擴展到非貴金屬。

我們將繼續研究先進功能金屬基異質納米結構的合理設計和製備，特別是基於應用特性的成分、結構和界面。具體而言，我們將致力於製備具有不同成分的新型貴金屬基異質納米結構，如 AgCu、AuCu、RuCu、RuNi、IrNi、RuIr、AuRu、AuIr 等。我們將嘗試調整它們的空間結構，形成所需的結構，例如 Janus 結構、核殼結構等。我們將嘗試通過調整它們的位置、邊界和含量來調整這兩個部分的界面。

我們將重點關注這些新型催化材料的應用，更加注重碳中和領域。我們將仔細評估所製備的新型材料在水電催化二氧化碳還原（CO_2RR）系統和 Li-CO_2 電池系統中的 CO_2RR 性能。在材料合理設計的基礎上，針對 CO_2RR 水溶液體系中 C_{2+} 產物的生產，我們將努力提高活性、選擇性和壽命；並提高 Li-CO_2 電池系統的動力學。我們還將把這些材料的應用擴展到其他催化反應，如硝酸根還原。

Dr. Tao YANG
楊濤博士

As a newly emerged field in materials science, the chemically complex intermetallic alloys (CCIMAs) offer a rich playground for designing novel materials for structural applications because of their tunable superlattice structures, huge compositional ranges, and promising mechanical properties. Along with the deepened studies gradually, the application prospect of CCIMAs would become more brilliant and broader, and meanwhile, new challenges arise accordingly, especially upon the innovative alloy design and manufacturing techniques. Therefore, more fundamental and comprehensive studies should be carried out systematically to further accelerate the discovery of novel high-performance CCIMAs, and ultimately, facilitate their wide applications in different industrial fields. Here, we will focus on several critical issues and possible key directions for future research on advanced structural CCIMAs, including:

1. High-throughput design of ordered superlattice structure

2. Microstructural control and mechanical properties at elevated temperatures

3. Designing high-performance CCIMAs for ultra-high temperature structural applications based on the noble metallic systems

作為材料科學的一個新興領域，化學複雜型金屬間化合物合金（CCIMAs）具有可調的超晶格結構、巨大的成分範圍和良好的力學性能等獨特優點，為設計新型結構材料的開發提供了廣闊的空間。隨著研究的逐步深入，化學複雜型金屬間化合物合金的應用前景將更加廣闊，同時也帶來了新的機遇與挑戰，尤其是在合金設計和製造技術等方面。因此，在未來我們將系統地開展更基礎、更全面的研究工作，以期進一步加速新型高性能化學複雜型金屬間化合物合金的發現，最終促進其在不同工業領域的廣泛應用。為此，我們將重點關注一下幾個關鍵的技術問題和研究方向，主要包括：

1. 有序超晶格結構的高通量設計

2. 微觀結構控制和高溫力學性能

3. 基於貴金屬合金體系開發新型超高溫金屬間化合物材料

Professor Minhua SHAO
邵敏華教授

Electrochemical conversion of CO_2 into value-added fuels via using renewable electricity is a promising technology in both atmospheric CO_2 concentration reduction and clean energy generation. However, the wide adaption of CO_2 electrochemical reduction (CO_2RR) technology has been hindered by the unsatisfactory performance of catalysts due to their low catalytic activity, poor selectivity on a single product and limited lifetime. Among all the products that can be generated via CO_2RR, CO has received considerable attention since it can be readily used as the feedstock in the well-established Fischer–Tropsch process to generate various chemicals. Pd is an excellent candidate due to its ability to generate CO at low overpotentials with an acceptable reaction rate. However, the suppression of hydrogen evolution and CO poisoning issue on Pd-based catalysts has not been well achieved. This proposal aims to adopt catalysts surface structure and composition design to develop advanced Pd-M (M=Au, Ag and Cu) bimetallic nanocatalysts with novel structures for selective CO generation in CO_2RR.

In this research, we will investigate the synthesis, characterization and evaluation of *"Pd-based Bimetallic Nanocatalysts"* with novel techniques and approaches. Two categories of Pd-based nanocatalysts will be the target systems: 1) *"nanowire structure"* Pd-M (M=Au, Ag and Cu) catalysts with a varied nanowire diameter and shape (jagged, smooth and dendrite); 2) a *"core-shell structure"* consisting of a Pd (and Pd-based alloy) shell with a varied thickness, shape and a foreign metal core. We will develop novel protocols to synthesize the target catalysts with well-controlled composition and structure, which will be the key for the intended high CO_2RR catalytic performance. The activity and stability of these shape-controlled catalysts will be evaluated in both liquid cells and electrolyzers to demonstrate their feasibility in practical CO_2RR applications. Combined experimental studies and theoretical approaches will be utilized to investigate the reaction mechanisms, and build up the relationship between the catalytic performance and the catalyst composition & structure. Besides, we will also explore the structural and compositional evolution of developed catalysts under reaction conditions, which will shed light on the development of long-lifetime catalysts.

通過使用可再生電力將二氧化碳轉化為增值燃料是降低大氣二氧化碳濃度和產生清潔能源的一項有前途的技術。然而，CO_2 電化學還原（CO_2RR）技術的廣泛應用受到催化劑催化活性低、對單一產物選擇性差和壽命有限的限制。在所有 CO_2RR 生成的產物中，CO 受到了極大的關注，因為它可以很容易地用作成熟的費 - 托工藝的原料來生產各種化學品。 Pd 能夠在低過電位下以比較高的反應速率生成 CO。然而，在 Pd 基催化劑上抑制析氫和 CO 中毒問題尚未得到很好的實現。該研究旨在採用催化劑表面結構和成分設計，開發具有新穎結構的先進 Pd-M（M=Au、Ag 和 Cu）雙金屬納米催化劑，用於選擇性生成 CO。

在這項研究中，我們將利用新技術和方法研究“基於 Pd 的雙金屬納米催化劑”的合成、表徵和評估。主要基於兩類 Pd 基納米催化劑系統：1）“納米線結構”Pd-M（M=Au、Ag 和 Cu）催化劑，具有不同的納米線直徑和形狀（鋸齒狀、光滑和樹枝狀等）；2）由厚度、形狀各異的 Pd（和 Pd 基合金）殼和外來金屬核組成的“核殼結構”。我們將開發新的合成方法來合成形貌和成分可控的目標催化劑，這是實現高 CO_2RR 催化性能的關鍵。這些形貌可控的催化劑的活性和穩定性將在液體電池和電解槽中進行評估，以證明它們在實際 CO_2RR 應用中的可行性。結合實驗研究和理論方法來研究反應機理，並建立催化性能與催化劑組成和結構之間的關係。此外，我們還將探索開發的催化劑在反應條件下的結構和組成演變，這將為長壽命催化劑的開發提供啟示。

Professor Zijian ZHENG
鄭子劍教授

The recent development in health monitoring, sports tracking, Internet of Things (IoT), and electronic skins highly requires flexible and wearable electronic sensor systems with high breathability. The breathability of wearable sensors to gas and liquid can ensure high wearable comfort for end-users, and more importantly, provide an effective solution for non-invasive, accurate, and long-term monitoring of important physiological signals of the human body. In the past twenty years, while research efforts have been greatly focused on the development of highly sensitive, stable, reliable, and multifunctional wearable sensor systems, the wearing properties, particularly the breathability of such device system, has been largely overlooked. The fundamental obstacle is that these devices are built on the basis of non-permeable plastic thin film and bulky packages, which hardly provide conformable and comfortable contacts between devices and skins with soft and dynamic surfaces. This has largely limited their applications in simultaneous, continuous and long-term health monitoring.

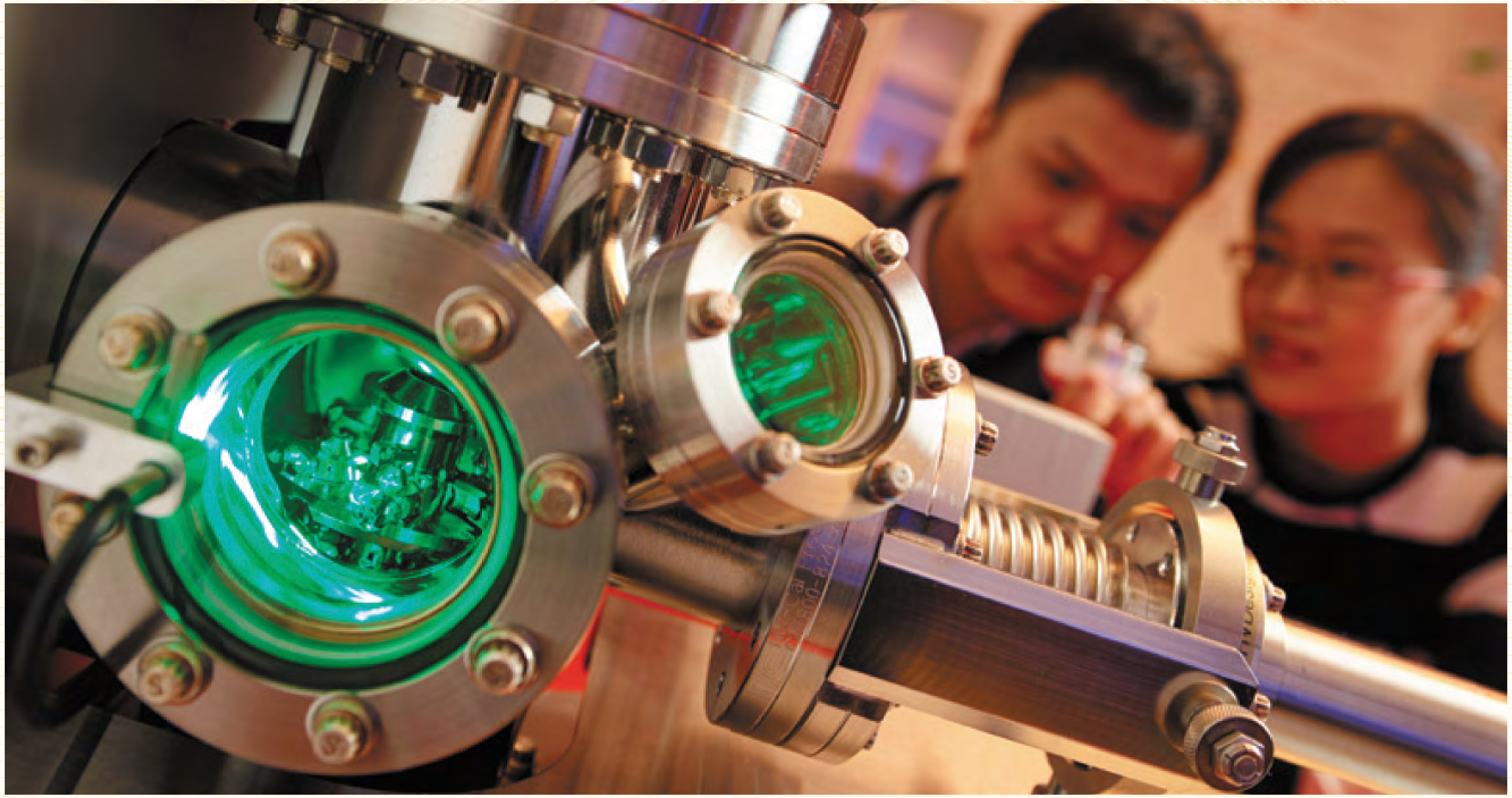
To address this challenge, we propose to develop a new type of high-performance wearable and breathable system integrated with various sensitive, reliable and multiplexed sensors on the basis of highly breathable materials and structures. To achieve this goal, we will develop a set of permeable and flexible/stretchable type of metal conductors, which not only show high level of conductivity, flexibility/stretchability, but also high levels of permeability to gas and moisture. These metals should also be stable in various environment, resistant to a high level of corrosion and friction. In this case, we will develop new type of precious metal through control of the metal synthesis, their nano and microstructures, nanocomposites, and nanointerfaces. Based on these permeable type of soft and durable metal conductors, we will develop permeable type of wearable sensors and sensor arrays. The success of this project will make a paradigm shift of use and design of materials, devices, and systems in the future. It will originally contributes to the new concept of breathable and multifunctional wearable sensor systems. The newly developed breathable materials, devices, and monolithic system should not only be applied in the long-term health monitoring as demonstrated in this proposed project but also have great promise for the applications in IoT and electronic skin, showing remarkable commercialization potential in a long term.

透氣性對未來柔性穿戴電子在健康運動監測、物聯網、電子皮膚等應用極其重要。優良的透氣透濕性能可以使柔性電子穿戴時更加舒適，更適用於長期穿戴，並且還能提高氣體及汗液感測器的性能。過去二十年的柔性電子研究局限於非透氣的彈性材料的基礎上構築，因此得到的柔性電子器件大部分不適合長期穿戴的應用。因此，未來的研究將著重于開發新型的透氣透濕型的柔性貴金屬材料。開發新方法製備貴金屬導體，調控微納、超納結構，納米複合，納米界面。從而得到透氣透濕，高導電，性能穩定，抗腐蝕，抗摩擦的柔性貴金屬導體。進一步應用製備適合長期穿戴的柔性感測器。

Dr. Ye CHEN
陳也博士

- Continue to develop in-depth research on the innovative synthesis, structure characterization, and physicochemical property study of novel precious metal-based nanomaterials, in order to provide fundamental guidance for optimizing their performances in practical applications.
- Explore low-cost and efficient production of precious metal-based nanomaterials in industrial grade.
- Improve the biocompatibility and cost-effectiveness of precious metal-based nanomaterials and explore composite products hybrid with precious metal-based nanomaterials.

- 繼續深入開展新型貴金屬基納米材料的創新合成、結構表徵、以及各類基礎物化性質的研究，為優化其在實際應用中的性能表現提供基本原理指導。
- 探索低成本、高效率的貴金屬基納米材料的規模化生產。
- 提高貴金屬基納米材料的生物安全性和性價比，探索貴金屬基納米材料摻雜的複合材料產品。



5

Bringing out Our Best
攜手業界 相得益彰

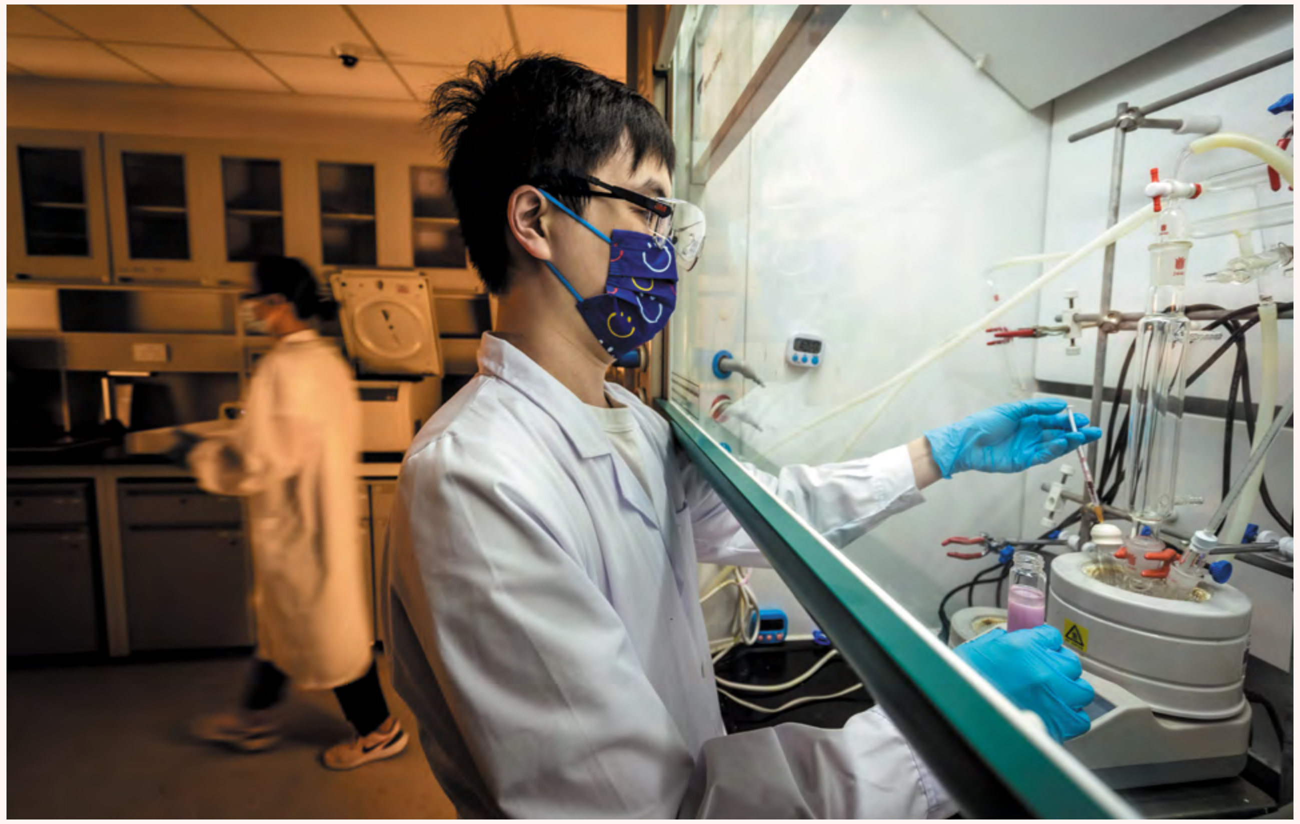
Open Exchange and Services
公開交流及共享服務

The NPMM has been supported by the Shenzhen Research Institute of City University (CityUSRI) through its sharing of the costs of purchasing advanced equipment, such as a high-resolution 3D scanner and a system for residual stress testing. The NPMM has spent approximately HK$23.5 million on the purchase of advanced equipment to enhance its research infrastructure and strengthen its research capabilities. The key items of equipment costing over HK$100,000 are listed below in the table.

In addition to CityU's advantageous location and the engagement of researchers from five CityU engineering departments, the NPMM is equipped with state-of-the-art equipment for materials fabrication, characterization and property analysis, valued at over HK$100 million. All of this advanced equipment is available for use by the NPMM research group. With the recruitment of members from other local universities, NPMM equipment will be shared with increasing numbers of experts in the field and therefore contribute even more to the advancement of materials research.

貴金屬分中心獲城大深圳研究院支持，共同承擔購買先進設備的成本，例如高解像度 3D 掃瞄器和殘餘應力測試系統。貴金屬分中心已為購買先進設備花費約 2,350 萬港元，以提升研究基礎設施和研究能力，以下列表為價值超過十萬港元的主要設備。

城大地理位置優越，貴金屬分中心匯聚來自工程學部五個部門的研究人員，更具備用於材料鑲嵌、材料表徵和性能分析等多個方面的先進設備，價值超過 1,000 萬港元。所有先進設備均可供貴金屬分中心研究團隊使用。隨著外校成員的加入，貴金屬分中心會與越來越多領域中的專家共享設備，建立共享平台，為材料研究發展作出更多貢獻。



Year 年份	Total Cost of Equipment Purchased 已購入設備的總成本	Key Items of Equipment Purchased (Costing over HK$100,000) 已購入的主要設備（價值超過十萬港元）
2021	HK$3 million 300 萬港元	• Milli-Q IQ 7003 Type II and Type I Water Purification System • PS-XHW-200 AEO Custom and 3P Hardware • PS-XHW-100 AEO Custom and 3P Hardware • 2D Manual and Motorized Transfer System • FD-03B Bending Test Equipment • Cellscale Biomaterials Testing Mechanical Testing System • Discovery Thermomechanical Analyzers (TMA) 450EM • Discovery Dynamic Mechanical Analyzer (DMA) 850
2020	HK$5 million 500 萬港元	• XYZ Stage and Controller • Programmable Mechanical System • Temperature Control System • Transducer • Portable Raman System • 2D Manual and Motorized Transfer System • Newport Class AAA Solar Simulator • Kinexus Pro+ Rotational Rheometer • Dynamic Mechanical Analysis System • Thermomechanical Analysis System • 3D Printer for Metallic Materials
2019	HK$10 million 1,000 萬港元	• 3D Scanner • 3D Bioprinter • Bioscaffold Printer • Programmable Mechanical System • Portable Raman Spectrometer • Image Dimension Measurement System • Photonics High Power Supercontinuum Tiber Laser • Electromagnetic Measurement System • High Temperature Tube Furnace • Slow Strain Rate Test Machine • Closed Field Magnetron Sputtering System • Laser System for Measurement • Cooling Chiller System • Rapid Thermal Processing (RTP) Furnace • Microscope for Mico Teg-Si System • Vacuum Sintering Furnace
2018	HK$1.5 million 150 萬港元	• 1 Branson Ultrasonic Actuator • High Resolution 3D Printer • Hysteresis Measurement of Soft Magnetic Materials with Accessories • Differential Scanning Calorimeter with Accessories, 220V/50Hz • SMAT machines • Probe Station and Optical Table • Reflectometer • Vacuum Oven • 3D Scanner • 磁性法測殘餘應力儀 • 3D Printer • Sputtering System • Gas Detection System
2017	HK$2 million 200 萬港元	• Triple Rollers Mills with Accessories • Bio-Architect Work Station (Multi-Materials 3D Printer) • Vacuum Glove Box with Accessories • Raman Spectrometers • Spectrophotometer Main Unit with UV Probe System Software • Gas Chromatograph System with Accessories
2016	HK$2 million 200 萬港元	• 2 Branson Ultrasonic Actuators Hysteresis (2500W and 4000W) • Measurement of Soft Magnetic Materials with Accessories • Differential Scanning Calorimeter with Accessories, 220V/50Hz • TEM In-Situ Tensile Holder (Single Tilt Straining Holder with Motorized Drive) with Accutroller for Strain Control of the Specimen and Speed Control Cable (0 to 1 micron/second Control). • Arc Melting Furnace with Copper Mould Suction Casting under High Purity Argon Atmosphere, including Water Chiller

Key Collaborations and Technology Transfer Achievements
重大合作與技術轉移

Our mission is to generate important fundamental and applied research outcomes by investigating precious metals and nanomaterials, and thereby achieve breakthroughs in technology transfer that benefit the national economy. As such, we are focused on forging collaborations with a wide array of research institutions and industrial partners, both locally and non-locally. The most significant collaborations that we have established are highlighted in this section.

貴金屬分中心致力貴金屬和納米材料方面的基礎研究及應用研究，目標是在技術轉移上取得突破，對經濟有所貢獻。因此，我們爭取與各個領域的海內外科研機構和行業夥伴合作，當中主要合作項目將在本章闡述。

Industrial Collaborations 業界合作

Collaboration with Sino-Precious Metals Holding Co., Ltd.

NPMM has forged a comprehensive collaboration with Sino-Precious Metals Holding Co., Ltd. This is a leading precious metal production and development company with a well-established team whose scientific research and production efforts are led by the Chinese Academy of Engineering. With KPIM as one of its subsidiaries, the company has a unique capacity to perform independent research on precious metals. Moreover, it has sufficient space and capability to promote the development of precious metals and their industrial applications. In 2016, Professor Jian LU, Director of NPMM, signed an agreement with the Academician Workstation of Yunnan Province for the industrial-scale development of high-purity gold and silver for electronics applications. An Advisory Steering Committee Meeting is held annually with the management of the Sino-Precious Metals Holding Co., Ltd., to discuss collaboration plans and research directions.

與雲南省貴金屬新材料控股集團有限公司合作

貴金屬分中心跟雲南省貴金屬新材料控股集團有限公司（雲南貴金屬集團）淵源深厚，更擁有長期的合作關係。雲南貴金屬集團是貴金屬製造及發展公司龍頭，旗下擁有由國家工程中心帶領的完善團隊，研究範圍涵蓋科研及製造。作為雲南貴金屬集團的附屬機構，昆明貴金屬研究所有力獨立進行貴金屬研究。加上佔地廣闊，空間和能力上足以推動貴金屬發展和行業應用。2016 年，貴金屬分中心主任呂堅教授與雲南省院士工作站簽訂協議，內容有關高純金原料提純、高純金靶批量化生產關鍵技術、金銀複合鍵合絲銀芯材的結構控制技術、金銀複合鍵合絲超薄複層的結構控制技術的工業化應用計劃。貴金屬分中心每年會與該公司的管理層進行高層學術交流討論會，討論合作計劃和研究方向。

NPMM has profound collaboration with KIPM and the Sino-Precious Metals Holding Co., Ltd.
貴金屬分中心與雲南省貴金屬新材料控股集團有限公司（雲南貴金屬集團）有長期合作關係。

Industrial Collaborations 業界合作

Partnering with the Jewelry Industry

The beauty, value, and symbolism of jewelry make it one of the most popular types of decorative items in the world. Hong Kong is a leader in the jewelry industry, such as jade in Asia, and has long been recognized as the major production center and trading and distribution hub for jewelry. The expertise of NPMM in the use of precious metals is highly attractive to jewelry manufacturers and has aroused significant interest from key local and non-local jewelry companies.

For example, in collaboration with Chow Tai Fook Jewellery Group Limited, SMAT was applied for the fabrication of jewelry from 18K–24K gold. This treatment significantly enhances the surface hardness of jewelry, rendering it resistant to deformation and dramatically reducing the cost of gold production. A Chinese patent was granted for this technique in 2018.

In another example, Darry Jewelry Co., Ltd, one of the leading sellers of high-end luxury jewelry in mainland China, Hong Kong, and Macau, was interested in a dual-phase coating technology developed by NPMM. This economical, environmentally friendly, and efficient magnetron-sputtering coating technology can be used for the preparation of multi-level color coatings with high hardness and wear resistance and enables traditional 18K gold or platinum items to be made in stylish colors and with novel color-change properties.

與珠寶業合作

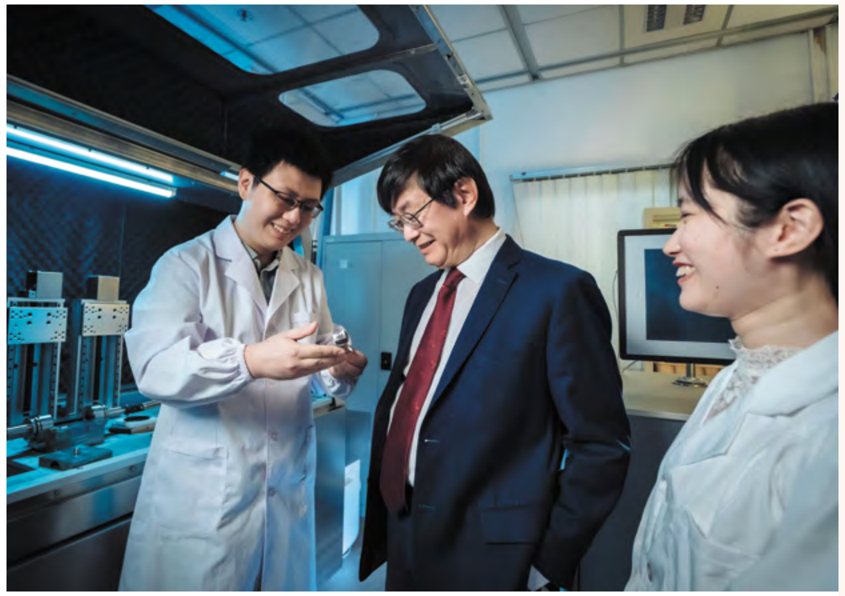
珠寶的華美、價值和象徵意義令人愛不釋手，可說是全世界最受歡迎的飾品。香港作為亞洲珠寶業翹楚，一直是翡翠等珠寶的主要製造中心，貿易和批發中樞。貴金屬分中心對貴金屬應用的專業知識引來海內外著名珠寶公司的強烈興趣。

舉例而言，我們與周大福珠寶集團合作，把表面機械研磨處理方法應用到鑲嵌 18K 至 24K 黃金的珠寶。這種方法大幅增強珠寶的表面硬度，並有效抵禦變形，大大減低製造金屬飾品的成本。這項技術於 2018 年取得中國專利。

戴瑞珠寶有限公司是另一個例子，作為中港澳高檔珠寶重要銷售商之一，戴瑞珠寶，對貴金屬分中心研發的雙相納米結構光学硬膜技術大感興趣。這項磁控濺射技術經濟實惠、環保且有效，可用於打造高強度、耐磨的多色塗層，將傳統 18K 黃金或鑽石變成各種時尚顏色。

Chow Tai Fook Jewellery Group Limited
周大福珠寶集團

Darry Jewelry Co., Ltd
戴瑞珠寶有限公司

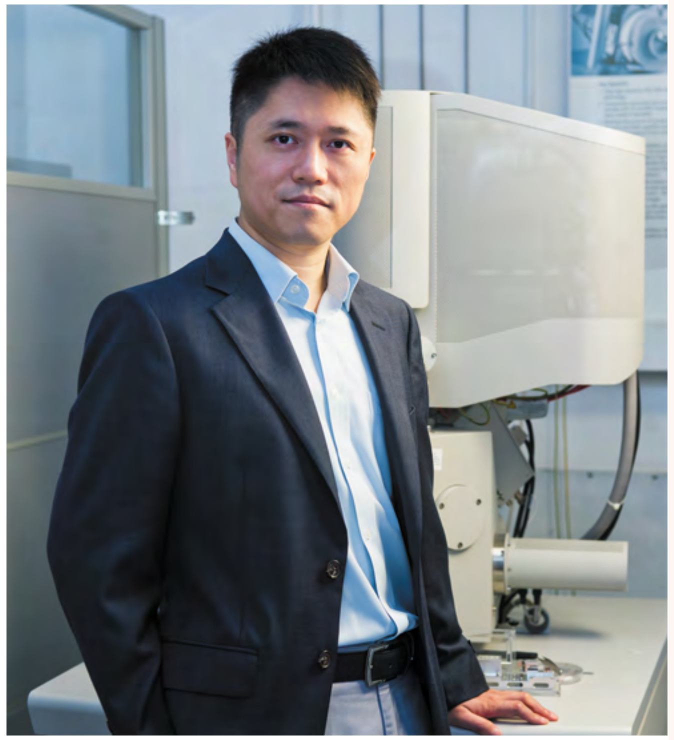


Industrial Collaborations 業界合作

Changsha Shaoguan Chrome Blank Co., Ltd
Professor Yang LU's team worked with the Changsha Shaoguan Chrome Blank Co., Ltd to conduct research on the application of nano-film technology of quartz photomask for chips. Under this collaboration, Hunan ShaoGuang Chrome Blank Co., Ltd. is responsible for the process development and sample preparation of quartz photomask nano-film coating, while Professor Lu's team is mainly responsible for the mechanical characterization test and defect analysis of photomask nano-film. Approved by the State Council and the State Administration of Science, Technology and Industry for National Defence, Changsha Shaoguan Chrome Blank Co., Ltd is an enterprise focusing on manufacturing ancillary mask reticles for integrated circuit chip, as well as the major standard maker for mask reticle.

長沙韶光鉻版有限公司
陸洋教授的團隊與長沙韶光鉻版有限公司合作進行研究，內容有關把石英光罩納米膜技術應用到芯片。後者負責開發石英光掩模納米薄膜鍍膜工藝開發、樣品製備，而前者主要負責進行光掩模納米薄膜表徵、測試與缺陷分析。長沙韶光鉻版有限公司獲國務院及國家國防科技工業局批准，專注製造合成電路芯片的光罩，以及主要標準光罩的製造儀器。

Changsha Shaoguan Chrome Blank Co., Ltd
長沙韶光鉻版有限公司



Professor Yang LU collaborates with
the Changsha Shaoguan Chrome Blank Co., Ltd.
陸洋教授與長沙韶光鉻版有限公司合作。

Academic Collaborations 學術合作

Research Collaboration with the Hong Kong Center for Cerebro-cardiovascular Health Engineering (COCHE)
Professor Jian LU joined COCHE as its chief scientist in 2021 and led the NPMM team to engage in joint research projects with COCHE to develop effective methods for the early detection of cardiovascular disease (CVD), which may enable early intervention for treating CVD. A clinical trial of these methods is currently being performed at the Prince of Wales Hospital.

COCHE is a collaboration, established in 2020, between the CityU, the University of Oxford (UK), and the Karolinska Institute (Sweden). It is financially supported by ITC and has been admitted to Inno-Health Cluster of the InnoHK Programme, which is a major R&D initiative of the Hong Kong Government. COCHE develops flexible sensing, biomedical and molecular imaging, nano-biosensing, and artificial intelligence technologies for health-related applications. In particular, COCHE focuses on the development of innovative wearables that record key vital signs, including but not limited to blood pressure and electrocardiogram signals, unobtrusively, continuously, and in real-time. These wearables transmit such data to workstations for further analysis and integration with other biomarkers, paving the way for the early detection and diagnosis of possible acute CVD.

與香港心腦血管健康工程研究中心的合作
呂堅教授於 2021 年以首席科學家身分加入香港心腦血管健康工程研究中心，帶領貴金屬分中心團隊參與聯合研究項目，開發能有效及早檢測心血管疾病的方法，以便盡早介入和治療。現時威爾斯親王醫院正為該檢測方法進行臨床實驗。

在香港特別行政區政府創新科技署的資助下，香港心腦血管健康工程研究中心由香港城市大學、英國劍橋大學和瑞典卡羅林斯卡學院合作於 2020 年成立，並進駐 InnoHK 創新香港研發平台屬下的 Health@InnoHK 創新平台，成為政府主要研發措施的一部分。研究中心負責開發用於保健用的靈活傳感器、生物分子影像及粒子造影、納米生物傳感和人工智能技術，特別是開發記錄主要生命徵象的穿戴創新裝置，包括但不限於血壓和心電圖徵象。該裝置設計簡單，可無間斷實時進行記錄，並把數據傳輸至工作站作進一步分析和結合其他生物標記，以便未來及早檢測和治療潛在急性心血管疾病。

A housewarming of COCHE Office is held on 15 June 2021. (Photo Source: COCHE Website)
香港心腦血管健康工程研究中心於 2021 年 6 月 15 日入駐香港科學園。（圖片來源：COCHE 網站）

The Hong Kong Center for Cerebro-cardiovascular Health Engineering (COCHE)
香港心腦血管健康工程研究中心

Academic Collaborations 學術合作

Collaboration with the Shenyang National Laboratory for Materials Science (SYNL)
As NPMM is one of the Hong Kong branches of the Engineering Research Center, its missions are to perform high-level research, to attract and train outstanding scientists, and to conduct academic exchanges in the Guangdong–Hong Kong–Macau Greater Bay Area. Thus, In 2020, NPMM established a Greater Bay Joint Division, headed by Professor Jian LU, in collaboration with the SYNL to conduct research related to precious metals and examine possible applications of this work.

瀋陽材料科學國家研究中心合作
貴金屬分中心為國家工程技術研究中心香港分中心，旨在進行高端研究、招募和培育傑出科學家，並在粵港澳大灣區進行學術交流。貴金屬分中心於 2020 年跟瀋陽材料科學國家研究中心在大灣區建立聯合研究部，由呂堅教授出任分部主任，進行貴金屬相關的基礎和應用研究。

沈阳材料科学国家研究中心
Shenyang National Laboratory for Materials Science
SYNL

Shenyang National Laboratory for Materials Science
瀋陽材料科學國家研究中心

Mr. Paul CHAN, GBM, GBS, MH, JP, Financial Secretary of HKSAR (Middle), visits NPMM and takes photos with Professor Jian LU (Right) and Professor Xunli WANG (Left).
香港特區政府財政司司長陳茂波 GBM, GBS, MH, 太平紳士（中）到訪貴金屬分中心，與呂堅教授（左）與王循理教授（右）合照。

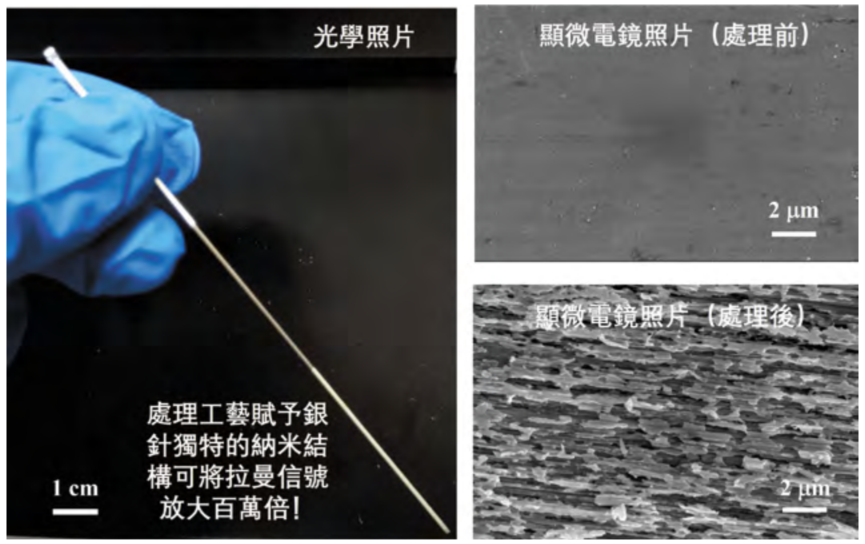
Commercialization through Entrepreneurship
From Zero to One Hundred: Surface-Enhanced Raman Spectroscopy (SERS) Technology
與企業合作進行產業化
由零至一百：表面增強拉曼光譜技術

We regard our basic research—research that aims to develop an understanding of a particular phenomenon—as the “zero-to-one” stage of our work. Our collaboration with the Sino-Precious Metals Holding Co., Ltd., is an example of our “zero-to-one”-stage research. Information obtained from basic research often creates a foundation for applied research, which is focused on devising practical solutions for existing problems. Thus, we regard the scale-up of our research—that is, the development of effective applications—as the “one-to-ten” stage of our work. Our collaborations with COCHE exemplify “one-to-ten”-stage research. Some applications explored in these collaborations are found to have commercial potential, and with mass manufacturing and commercialization, the “ten-to-one-hundred” stage is achieved. Technology has to overcome countless obstacles to reach this stage, and we are excited to be able to share in the commercialization of SERS technology, which represents a breakthrough in technology transfer.

The healthcare industry has been one of the fastest-growing sectors in recent years, and the COVID-19 pandemic has increased the public awareness of healthcare matters. There is high market demand for a broadly applicable material that can be used for detecting disease and ensuring food safety and commodity safety. A SERS substrate developed by NPMM has the potential to meet this demand.

被稱作「零至一」階段的基礎研究旨在理解特定現象。我們與雲南貴金屬集團的合作是「零至一」階段研究的例子，基礎研究所得資訊多會為應用研究奠定發展基礎，再為現有問題設計實際可行的解決方案。因此，我們視開發實際應用方法為下一階段的「一至十」研究，與香港心腦血管健康工程研究中心的合作就是其中一個例子。有些實際應用方法具備商業潛能，經大規模生產和產業化後可達至「十至一百」階段。一項技術需克服無數困難才會到達這個階段，我們很高興能把表面增強拉曼光譜技術產業化，在技術轉移上取得突破。

醫療保健是近年來發展最迅速的行業之一，新冠疫情更增加公眾對該議題的關注。市場對可以同時用於檢測和確保食物及商品安全的產品有強大需求，而貴金屬分中心開發的SERS) 探針有望滿足這項需求。



On the left side is the novel silver needle based SERS sensor,and as shown in the right, are the surface morphologies of sliver alloy based substrate before and after our parented electrochemical treatment.
如圖所示，左側為我們所開發的新型插入式 SERS 納米刻飾探針，右側為我們專利電化學技術處理前後的銀合金基底表面形貌。

From Zero to One: The Study and Application of SERS Technology

SERS is a field-enhanced spectroscopy technique in which the Raman scattering of molecules is enhanced 1 × 10^4 to 1 × 10^8 times in the proximity of precious metals such as gold, silver, and copper. The NPMM team, led by Professor Jian LU and Dr. Yangyang LI, has developed a simple, efficient, and environmentally-friendly electrochemical treatment process that can endow the surface of such precious metal materials with nanotopological structures. This process was used to develop a series of low-cost and high-performance SERS sensors that are one hundred times more sensitive and several tens of times cheaper than commercially available high-performance SERS sensors.

由「零至一」：表面增強拉曼光譜技術的研究與應用

表面增強拉曼光譜是一種增強表面的光譜技術，在金銀銅等貴金屬附近的拉曼散射因子可由 1 × 10^4 增強至 1 × 10^8 倍。貴金屬分中心團隊在呂堅教授及李揚揚博士的帶領下，開發出一種簡單、有效、環保的電化處理程序，為貴金屬物料表面加上納米拓撲結構。這項程序用於一系列低成本、高效能的 SERS 探針，而這種傳感器比市面上的探針靈敏一百倍和便宜數十倍。

The application of SERS sensors is explored in various practical scenarios.
SERS 探針能夠應用於不同場合。

From One to Ten: Joint Research on SERS Technology with Various Partners
由「一至十」：與多名夥伴的表面增強拉曼光譜技術聯合研究

Given the ultra-sensitivity, rapidness, and noninvasiveness of SERS sensors, their utility has been explored in various practical scenarios. They have shown particular promise for disease detection; for example, they can identify early-stage lung cancer by the quantitative analysis of 2-naphthalenethiol, a toxic volatile organic compound that is present in high concentrations in the exhaled breath of patients with lung cancer. Moreover, the NPMM team signed a memorandum of intent with KingMed Diagnostics Co., Ltd., to develop SERS-based rapid screening technology for the detection of SARS-CoV-2 and has also worked with Professor Zhiwei CHEN's team at HKU to study the detection of different subtypes of SARS-CoV-2 based on the platform of the State Key Laboratory of Emerging Infectious Diseases. In addition, the team has conducted blind testing of clinical samples in collaboration with BGI Group and will continue to conduct rapid bacterial screening experiments using a portable SERS system.

SERS sensors can also be used for point-of-care testing of skincare products and antibiotics, the rapid identification of fish freshness, and the analysis of various components in urine. Furthermore, they have shown excellent potential for use in the quality control of edible sugar and liquor.

由於 SERS 探針具有敏感高、快速、非入侵性，其於不同場合的實際應用已被廣泛探討。SERS 探針在檢測疾病方面尤有成效，例如透過對肺癌早期的標志物 2-NT(2- 巯基萘) 的定量測試識別初期肺癌。貴金屬分中心團隊更與廣州金域醫學檢驗集團股份有限公司簽署了備忘錄，共同開發以表面增強拉曼光譜為基礎的新冠病毒快速篩查技術；並與香港大學新發傳染性疾病國家重點實驗室的陳志偉教授團隊合作，研究如何檢測新冠病毒的不同亞種。貴金屬分中心團隊與華大基因集團合作，為臨床樣本進行盲測，並會繼續利用便攜式表面增強拉曼光譜系統，進行快速細菌篩查實驗。

表面增強拉曼光譜傳感器可用於對護膚產品和抗生素、快速識別魚類新鮮度的即時檢驗，以及分析尿液中的不同成分。SERS 探針在控制食用糖和酒精品質方面也有強大應用前景。

SERS detection solution from NPMM includes the self-developed silver needle based SERS sensors, optical adapter and the handheld Raman developed with cooperator.
NPMM 研發 SERS 檢測系統，包括自研的 SERS 探針，光學適配器以及合作研發的手持式拉曼光譜儀。

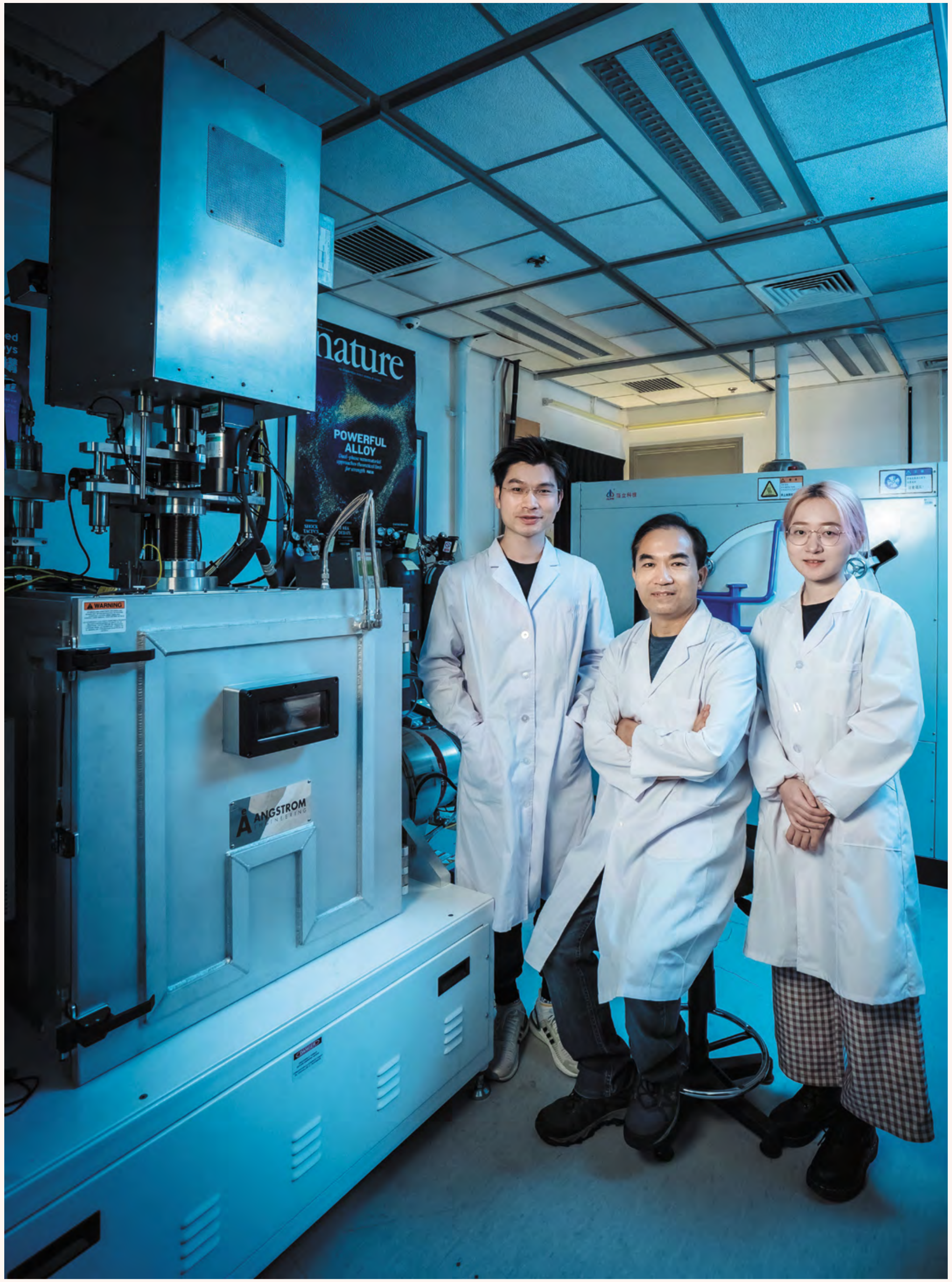
From Ten to One Hundred: Commercialization of SERS Technology via a Start-Up—LUMAT-SERS Limited
把表面增強拉曼光譜技術產業化

NPMM's SERS technology was licensed to LUMAT-SERS Limited, a technology startup established by the NPMM team that has been admitted to the HK Tech 300, a large-scale flagship innovation and entrepreneurship program organized by the CityU. LUMAT-SERS Limited has been recommended for incubation and was granted HK$1 million by the HK Tech 300 Angel Fund in April 2022. It has been admitted to station at the Hong Kong Science & Technology Parts Corporation and is conducting other fundraising endeavors to attract investment. With the support from HK Tech 300, we expect further commercialization of our SERS technology by young entrepreneurs to gain social impact.

貴金屬分中心把表面增強拉曼光譜技術授權予由本中心團隊成立的初創企業路馬特有限公司，企業已成功晉身 HK Tech 300 行列，於 2022 年 4 月成功取得由 HK Tech 300 天使基金投資提供的 100 萬港元資助作進一步發展。HK Tech 300 是香港城市大學舉辦的一項大型創新創業計劃，旨在將城大的研究成果及知識產權轉化為實際應用。路馬特也獲准入駐香港科技園公司的創科培育計劃，並正透過其他渠道籌募資金。在 HK Tech 300 的支持下，我們預計年青企業家會進一步把表面增強拉曼光譜技術產業化，為社會帶來正面影響。

LUMAT-SERS Limited is established by the NPMM team to commercialize SERS technology. (Photo Credit: Ta Kung Pao)
貴金屬分中心成員成立路馬特有限公司把 SERS 技術產業化。（圖片來源：大公報）

HK Tech 300 is a large-scale flagship innovation and entrepreneurship programme organized by CityU for aspiring entrepreneurs among CityU students, alumni, research staff and the general public using CityU's intellectual property (IP) and/or technology to launch start-ups and ignite their entrepreneurship journey.
HK Tech 300 是由城大學辦的一項創新創業計劃，目的是協助有志創業的城大學生、城大校友、城大研究人員以及有意使用城大開發的知識產權或技術去成立初創公司的其他人士成立初創公司，令他們的創業之旅得以啟航。



Public Engagement
心繫社會

When thinking of precious metals, people tend to consider them as a luxury that is far from their reach. However, precious metals are a part of our daily necessities, such as Computers / Communications / Consumer (3C) products and accessories. To raise the public's awareness of and interest in the field, NPMM members deliver various talks to the public and industrial partners as part of their knowledge transfer endeavors. Highlights of the NPMM's community activities can be found in this section.

每當談到貴金屬，大家傾向認為它們是遙不可及的奢侈品，但事實上，貴金屬的我們日常生活息息相關，例如電腦、通訊、消費電子等產品及配件。為增進公眾對貴金屬領域的認知和興趣，貴金屬分中心成員參與多個公眾和業界講座，為知識轉移盡一份力。

InnoTech Expo 2018
2018 創科展覽

The InnoTech Expo 2018 was a large-scale innovation and technology (I&T) exhibition hosted by the Our Hong Kong Foundation. With the support of MOST, the Expo showcased China's I&T achievements and many high-tech inventions. The InnoTech Expo 2018 focused on industry, agriculture, and medicine. Besides the exhibition, a significant number of experts were invited to deliver public talks at the Expert Forum. Professor Jian LU delivered a talk entitled "Structured Nanomaterials and their Application" in the Engineering Science and the Future World forum. With a record-high attendance of over 150,000, the Expo significantly raised public awareness of I&T development and collaboration in Hong Kong and mainland China.

2018 創科展覽是由團結香港基金舉辦的大型創新科技展覽，在國家科技部鼎力支持下，該年展覽以「工」、「農」、「醫」為三大主題，展出中國多項創科成就和一系列高科技發明。除了展覽外，基金更邀請多個專家於專家論壇公開演講，其中呂堅教授在「工程科學與明日世界」論壇就「結構納米材料與應用」進行演講。展覽入場人次超過150,000，創歷年新高，並大幅提升公眾對中港創科發展協作的認識。

Professor Jian LU delivers a talk at the InnoTech Expo 2018: Driving innovations from strength to strength organized by Our Hong Kong Foundation.
呂堅教授在創科博覽 2018：工程科學與明日世界上發表演説。

Automotive Lightweight Conference and Exhibition (ALCE) 2019
2019 汽車輕量化大會暨展覽會

ALCE2019 was held in September 2019 at the Yangzhou International Exhibition Centre. The conference and exhibition was hosted by the China Society of Automotive Engineers (China-SAE), Jiangsu Association for Science and Technology and China Auto Lightweight Technology Innovative Strategic Alliance (CALA), and jointly organized by the Yangzhou Municipal People's Government.

Focusing on key technologies of advanced lightweight materials, lightweight design, advanced joining technology, forming technology and equipment, the ALCE is the largest international automotive lightweight communication and docking platform in China and is highly recognized among the global automotive industry. International and local experts are invited to share their views on automotive lightweight industrial policies and the technical routes to explore cutting-edge technologies from home and abroad. As a speaker in the plenary session of ALCE2019, Professor Jian LU gave a talk on "Lightweight New Energy Vehicles: Principle, Process and Case Analysis."

The four-day conference attracted over 1,200 participants from 400 companies and 50 universities and research institutes. More than 200 of the participants were foreign representatives from over 20 countries and regions, including the United States, the United Kingdom, Germany, Japan and South Korea.

2019 汽車輕量化大會暨展覽會於 9 月在揚州市國際展覽中心舉行，該活動由中國汽車工程學會、江蘇省科學技術協會、汽車輕量化技術創新戰略聯盟，以及揚州市人民政府主辦。

大會以先進輕量材料、輕量設計、先進連接技術、成形工藝與裝備等關鍵技術為主題，為中國最大型汽車輕量化交流平台，備受全球汽車工業認可。大會邀請了海內外專家分享對輕量化產業政策和技術路線的看法，探討多項先進技術。呂堅教授作為大會主會場講者之一，以「新能源汽車輕量化：原理、工藝與案例分析」為題進行演講。

本次會議歷時四天，超過 1,200 人參與，他們分別來自 400 多家企業和 50 多家高校及科研院所，同時有來自美國、英國、德國、日本、韓國等 20 多個國家和地區的 200 多位國外代表。

Professor Jian LU presents in the 13th International Automotive Lightweight Conference and Exhibition.
呂堅教授在 2019 汽車輕量化大會暨展覽會發表演説。

KingMed Diagnostics Academic Committee Conference 2020
2020 金域醫學學術委員會專題研討會

In December, the KingMed Diagnostics Academic Committee Conference 2020 was held in Guangzhou with the theme of "Technology Helps Novel Coronavirus Prevention and Control through Data-driven Medical Developments." Professor Jian LU, together with another nine academics including Professor Nanshan ZHONG, the top respiratory disease expert in China, were invited to join the conference to discuss the present and future of technological anti-epidemic and data-driven medical developments with over 500 experts from different medical fields in mainland China.

2020 金域醫學學術委員會專題研討會於 12 月在廣州舉行，主題為「科技助力新冠防控 數據驅動醫學發展」。呂堅教授連同國家呼吸系統疾病專家鍾南山院士等九位學者在研討會中，與來自中國不同領域的 500 位專家齊聚一堂，共同探討科技抗疫與數據驅動醫學發展的當下與未來。

KingMed Diagnostics (KingMed) is the first third-party independent medical laboratory in China to be accredited by both the College of American Pathologists (CAP) and ISO15189, and the test reports issued by KingMed are accepted by more than 50 countries and regions around the world. KingMed took a proactive role during the COVID-19 pandemic by carrying out novel coronavirus tests on more than 170 million people. It also established the Clinical Respiratory Virus Diagnosis and Transformation Center within the Guangzhou Institute of Respiratory Health, with Professor Nanshan ZHONG serving as Director.

金域醫學為中國首個獲得美國美國病理學會和 ISO15189 認證的第三方獨立醫療實驗室，其發出的檢驗報告得到全球超過 50 個國家和地區認可。金域在新冠疫情期間主動為超過 1 億 7,000 萬人進行檢測，並與廣州呼吸健康研究院聯合成立「臨床呼吸道病毒診斷與轉化中心」，由鍾南山院士親自擔任主任。

Professor Jian LU presents at the KingMed Diagnostics Academic Committee Conference 2020.
呂堅教授在 2020 金域醫學學術委員會專題研討會發表演說。

The 20th Science of Asia (SCA) Conference
第 20 屆亞洲科學理事會大會

The 20th SCA Conference was held in Guangzhou, China in May 2021 with the theme "The Age of New Materials: Innovation for Sustainable Society." The Conference was organized by SCA and the China Association for Science and Technology (CAST), administered by the Shanghai Institute of Microsystem and Information Technology (SIMIT) CAS, the Department of Science and Technology of Guangdong Province, the Guangdong Provincial Association for Science and Technology and the People's Government of Guangzhou Municipality, and co-organized by the Advanced Materials Alliance of CAST Member Societies (AMAC).

第 20 屆亞洲科學理事會大會於 2021 年 5 月在廣州舉行，主題為「新材料時代：為可持續發展社會而創新」。大會由亞洲科學理事會和中國科學技術協會主辦，中國科學院上海微系統與資訊技術研究所、廣東省科學技術廳、廣東省科學技術協會、廣州市人民政府承辦，中國科協先進材料學會聯合體協辦。

The conference consisted of nine keynote speeches, six parallel sessions and two poster sessions, as well as the SCA Management Board Meeting and SCA General Assembly. Professor Jian LU gave a keynote speech at a session moderated by Professor Xiaoming XIE, Director of SIMIT CAS, and Professor Weihua WANG, Director of Guangdong Songshan Lake Materials Laboratory. Among the prestigious speakers who presented at the session was Professor Nanshan ZHONG.

大會設有九場主題演講、六個分論壇和兩場海報環節，並召開了亞洲科學理事會管理委員會會議和全體會員大會。呂堅教授在開幕式主旨報告環節發表了主題演講，該環節由信息功能材料國家重點實驗室主任謝曉明教授和松山湖材料實驗室主任汪衛華院士主持，大會更成功邀請國家呼吸系統疾病專家鍾南山院士參與演講。

This was the first time that the SCA Conference had been held in hybrid mode. Nearly 500 people from 21 countries/regions attended the conference, and more than 70 distinguished experts and scholars from Chinese and foreign scientific and technological circles attended and gave speeches.

本屆大會首次以混合模式舉行，吸引了來自 21 個國家/ 地區將近 500 位人士參與，海內外科技界有 70 位著名專家學者出席會議並發表報告。

Professor Jian LU gives a plenary talk at the 20th Science Council of Asia (SCA) Conference successfully held in Guangzhou, China.
呂堅教授在第二十屆亞洲科學理事會大會發表主題演講。

Nature Conferences - Chemistry of 2D Materials
自然學術會議：二維材料化學

In 2022, the "Nature Conferences - Chemistry of 2D Materials" was held at CityU. Professor Hua ZHANG, Dr. Zhanxi FAN and Professor Jian LU took an active role in the conference as organizing committee members. As part of the Hong Kong Tech Forum, this conference brought together leading experts from all over the world to exchange views on recent trends in a variety of topics on the chemistry of 2D materials. The discussion covered bottom-up and top-down syntheses of 2D materials, and their chemical functionalization. An overarching theme was the experimental and theoretical methods by which materials can be characterized with atomic precision. Attention was also paid to the applications of 2D materials, particularly those with applications in catalysis and energy storage.

城大在 2022 年舉辦「自然學術會議：二維材料化學」，該論壇為香港科技論壇一部份，雲集全球頂尖專家，更由張華教授、范戰西博士和呂堅教授出任籌委會成員，會上專家們就有關二維材料化學的最新趨勢展開交流。主題涵蓋二維材料的自下而上和自上而下的合成方法，以及其化學功能化。其中一個首要的主題是實驗和理論方法，通過這些方法以原子精度表徵材料。二維材料的應用也受到關注，特別是那些在催化和能量儲存中表現出反應性的材料。

Professor Way KUO, CityU President, officiate the opening ceremony of Nature Conferences - Chemistry of 2D Materials.
城大校長郭位主持了自然學術會議：二維材料化學開幕式。

A Simple Model to Predict COVID-19 Evolution
以簡單模型預測新冠病毒的演變

The pandemic has prompted a rethink on how research can limit the global spread of disease. With the spread of COVID-19 worldwide, there is an urgent need for a simple model to predict how the pandemic will evolve in individual countries. Supported by the Chinese Academy of Sciences and the Alliance of International Science Organizations (ANSO), Professor Jian LU worked with Shanghai Jiao Tong University, Beihang University and the Naval Medical Research Institute to develop the Braking Force Model on Virus Transmission to evaluate the validity and efficiency of non-pharmaceutical interventions (NPIs) and vaccine in controlling the COVID-19 pandemic. Based on the historical information of the COVID-19 pandemic worldwide, this model classifies the level of effectiveness of NPIs and SARS-CoV-2 vaccination and thus forecasts the time required to control the pandemic and provides an indication of future trends. Based on the Braking Force Model, a pandemic control strategy framework has been devised that allows policymakers to determine when and how long to implement NPIs, such that a balance can be achieved between public-health risk management and economic recovery.

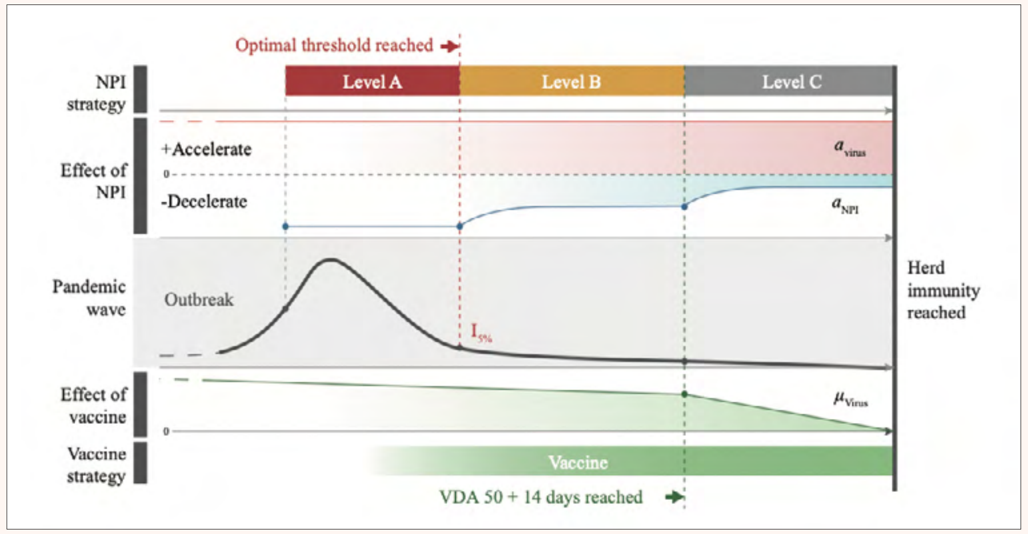
This work was published in China CDC Weekly and posted on Professor Lu's personal website: http://staffweb1.cityu.edu.hk/jianlu/.

NPMM members also deliver talks to mainland universities, and many serve as committee members of external advisory bodies, including professional, industry, government, statutory and non-statutory bodies. Two examples are the Daya Bay Nuclear Safety Consultative Committeeand the Committee on Innovation, Technology and Re-industrialization under the Innovation, Technology and Industry Bureau (ITIB).

疫情在全球持續肆虐，令我們反思如何有效控制病毒在全球擴散，同時亦急切需要開發簡單模型預測新冠病毒在個別國家的演變。在中國科學院和「一帶一路」國際科學組織聯盟的支持下，呂堅教授與上海交通大學、北京航空航天大學、中國人民解放軍海軍醫學研究所聯手建立了有別於傳統流行病學模型的新冠病毒傳播制動力模型，基於世界各國各地區的新冠疫情歷史資料，通過峰型擬合的方法，預測基於當前防疫政策下的疫情發展。這個模型為非藥物干預措施和新冠疫苗的有效程度分級，預測疫情受控的所需時間和未來走向。我們已根據這個模型制定疫情控制策略框架，讓政策制定者決定實施非藥物干預措施的時機和長度，以便在公共衛生管理與經濟復甦之間取得平衡。

有關工作已刊登在中國疾病預防控制中心週報，呂堅教授亦堅持每天在個人網站上更新：http://staffweb1.cityu.edu.hk/jianlu/。

貴金屬分中心一眾成員也經常到內地大學演講，並參與專業界別、工商業、政府及其他法定與非法定機構等委員會的成員，其中兩個例子是大亞灣核電站核安全諮詢委員會，以及創新科技及工業局下屬的創新、科技及再工業化委員會。



The Braking Force Model facilitates policy making regarding the COVID-19 Pandemic.
新冠病毒傳播制動力模型有助制定疫情相關政策。

6

From Strength to Strength
溫故知新 繼往開來

Highlights of Past Events
精彩活動回顧

One of NPMM's missions is to serve as a platform in a regional cluster to allow academic experts and students from top institutions around the world to share their research achievements, exchange ideas, establish relationships leading to future high-level research in the nano-research field, and facilitate mutually beneficial experiences for world-leading scientists, delegates and sponsoring firms.

The COVID-19 pandemic has posed challenges to event organization. However, NPMM has adapted to the ever-changing situation by moving its events online. Such virtual events are unrestricted by physical venues and unaffected by borders, and can thus accommodate greater numbers of participants of a broad range of ages and nationalities than in-person events. This enables NPMM to disseminate its frontier research to a wider audience, which tremendously benefits the nano-research community.

Since 2020, the world has had to cope with the COVID-19 pandemic, one result of which has been the cancellation of many in-person events. NPMM strived to maintain "business as usual" and even stay ahead by innovating during the pandemic, such as by moving its events online. NPMM's first online academic research seminar was held in 2020, where approximately 65 members delivered talks and shared advanced research findings. Given the positive feedback on this online seminar, NPMM has since continued to organize online and hybrid events to provide platforms for academic exchange.

貴金屬分中心的其中一個宗旨是在香港打造一個學術交流平台，讓世界頂級機構的學術專家及學生分享學術成就、交流建議、建立合作關係，促進高端納米研究發展，以及促成世界頂尖科學家和工商界合作，互惠互利。

受新冠疫情影響，貴金屬分中心在舉辦活動時遇上重重困難，但貴金屬分中心能夠隨機應變，把活動移師網上舉行。虛擬活動不受場地和地域限制，相比起實體活動，可接納更多不同年齡、不同國籍的人士參與。因此，貴金屬分中心可將其前瞻研究向更多人士公布，對納米研究界大有助益。

由 2020 年起，受新冠疫情影響，很多實體活動被迫取消。貴金屬分中心致力維持「正常運作」，在疫情期間推出創新措施，例如舉辦網上活動。首個網上學術研究工作坊於 2020 年舉行，約 65 個成員發表演講和分享深入研究結果。有見網上工作坊反應熱烈，貴金屬分中心繼續舉辦更多網上和混合模式的活動，提供學術交流的平台。

The International Conferences on Nanostructured Materials (NANO) 2018
第 14 屆納米結構材料國際會議 (NANO 2018)

NANO aims to disseminate and develop research worldwide on nanostructured materials and their applications. In June 2018, NPMM hosted the 14th edition of NANO, NANO 2018, at the CityU, which was the first time this conference had been held in China. At this conference, distinguished scientists and scholars from around the world discussed future trends and the latest developments in nanomaterials in 12 themed sessions. Around 600 world-leading scholars and researchers in nanotechnology field from 35 countries/regions and 300 research organizations attended the conference.

At the opening ceremony, Professor Jian LU, Chairman of the conference organizing committee, spoke on how the establishment of MSE had boosted CityU's efforts to become an international hub for nanoscience and nanotechnology.

The conference organizers capitalized on NPMM's connection with mainland China—especially its collaboration with the SYNL and Chinese Materials Research Society (CMRS)—by inviting Professor Hua ZHANG, who was then serving as Professor at Nanyang Technological University, and Professor Ming WEN from KIPM, to chair the session "Nanostructured Precious Metals" together with NPMM's Professor Kaili ZHANG and Dr. Yangyang LI.

The Materials Summit was also held during the conference. The 10 invited speakers at the summit, including HKIAS Senior Fellows and distinguished professors from universities in the US, Germany, mainland China and Hong Kong, discussed structural materials, materials performance and functional materials through lectures and a panel discussion.

納米結構材料國際會議，旨在向全世界提供平台，以發布和進行有關納米結構物料及其應用方法的研究。2018 年 6 月，貴金屬分中心於城大學辦第 14 屆納米結構材料國際會議 (NANO 2018)，這是 NANO 首次在中國舉辦。全球的傑出科學家與學者於 12 個主題環節討論納米材料的未來趨勢和最新發展。會議大獲成功，吸引約 600 位分別來自 35 個不同國家和地區納米技術領域的研究人員和 300 個研究機構的頂尖學者出席。

NANO2018 籌辦委員會成員呂堅教授於開幕禮上致辭，指城大透過成立材料科學及工程學系，矢志成為納米科學和納米技術研究的世界樞紐。

NANO2018 籌辦者強調貴金屬分中心與內地的聯繫，尤其是與瀋陽材料科學國家實驗室和中國材料研究學會的合作。時任南洋科技大學教授張華教授和昆明貴金屬研究所聞明教授，連同張開黎教授及李揚揚博士共同主持「納米結構貴金屬」環節。

材料峰會亦在 NANO2018 期間舉行，十位受邀講者包括城大高等研究院資深院士，以及來自美國、德國、中國內地和香港等大學的傑出教授。他們在多個講座及小組討論中探討結構材料、材料表現和功能性材料。

(From Left) Professor Lei LU and Professor Ke LU, Co-chair of NANO 2018; Professor Jian LU, Chair of Nano 2018; Dr. Elisabetta AGOSTINELLI, Chairman of International Committee on Nanostructured Materials; and Professor Jianfeng NIE, Chair of the next NANO, officiate the conference.
（左起）第 14 屆國際納米結構材料會議籌委會聯合主席盧磊教授、盧柯教授；籌委會主席呂堅教授；國際納米結構材料委員會主席 Elisabetta Agostinelli 博士；下屆國際納米結構材料會議籌委會主席聶劍鋒教授主持開幕禮。

Around 600 world-leading scholars and researchers in nanotechnology field from 35 countries/regions and 300 research organizations attend NANO 2018 at CityU.
約 600 位來自世界各地的頂尖學者，分別來自 35 個不同國家和地區的 300 個研究機構，一同出席城大所舉辦的 NANO 2018。

Advanced Design and Manufacturing Conference 2021
2021 先進結構設計與製造研討會

Since 2020, the world has had to cope with the COVID-19 pandemic, one result of which has been the cancellation of many in-person events. NPMM strived to maintain "business as usual" and even stay ahead by innovating during the pandemic, such as by moving its events online. NPMM's first online academic research seminar was held in 2020, where approximately 65 members delivered talks and shared advanced research findings. Given the positive feedback on this online seminar, NPMM has since continued to organize online and hybrid events to provide platforms for academic exchange.

To enhance the interaction between science and technology, and the cooperation between high-tech industry partners in Hong Kong and those in mainland China, the NSFC and the BHKAEC provide support to three local universities every year to organize a conference on their respective areas of strategic technology. Under this initiative, NPMM was invited to organize the Advanced Design and Manufacturing Conference in November 2021, delivered in a hybrid mode at CityU, to connect with Beijing. Thirty-nine experts and scholars from mainland China and Hong Kong, including six joint academicians of the Chinese Academy of Sciences and the Chinese Academy of Engineering, joined the conference online or physically to share state-of-the-art research on the development of new materials, which is one of the fastest-growing research fields in China.

Capitalizing on CityU's solid research background in materials science, the conference addressed the dilemma of the lack of new materials in China and discussed how to strengthen basic research to raise the competitiveness of the nation. CityU has made developments in the field of additive manufacturing in recent years, and its faculty have published many papers in leading journals such as *Nature* and *Science*. In particular, the 4D printing-based ceramic technology invented by Professor Jian LU was listed in the European Commission's *"100 Radical Innovation Breakthroughs for the Future,"* as an example of innovation in 4D printing.

由 2020 年起，受新冠疫情影響，很多實體活動被迫取消。貴金屬分中心致力維持「正常運作」，在疫情期間推出創新措施，例如舉辦網上活動。首個網上 W 學術研究工作坊於 2020 年舉行，約 65 個成員發表演講和分享深入研究結果。有見網上工作坊反應熱烈，貴金屬分中心繼續舉辦更多網上和混合模式的活動，提供學術交流的平台。

為進一步促進內地、香港兩地的科學與技術交流，以及高科技行業夥伴之間的合作，國家自然科學基金委員會與京港學術交流中心每年會向三間本地大學提供支援，讓它們各自為其戰略技術領域舉辦會議。貴金屬分中心在這項措施下，於 2021 年 11 月舉辦先進結構設計與製造研討會，該研討會於城大和北京兩地以混合形式同時進行。會上有 39 位來自內地及香港的專家學者發表學術報告，當中包括六位兩院院士。他們或親身參與，或在網上演説，分享他們中國研究中發展最快的領域之一——開發新物料的最新研究。

城大在材料科學領域赫赫有名，會議針對中國缺乏新材料的兩難，討論如何加強基礎研究以提升中國競爭力。城大近幾年在 3D/4D 列印方面取得一定成果，學院也在*《自然》*、*《科學》*等多份頂尖期刊刊登了多篇論文。特別是由呂堅教授發明、以 4D 列印為基礎的陶瓷技術獲歐盟委員會列入*「面向未來的 100 項突破式創新」*，成為 4D 列印的創新典範。

Professor Bingheng LU conducts his online presentation online.
盧秉恆院士進行線上演講。

The six main themes of the conference were advanced design and manufacturing, bionic design and manufacturing, flexible device design and manufacturing by 3D/4D printing, smart design and manufacturing, 2D material and device design and manufacturing, and functional design and manufacturing of new materials. Presentations from prestigious scholars, such as Professor Bingheng LU and Professor Benzhong TANG, showcased the latest developments and achievements in the materials field in China. In the wrap-up discussion, participants made suggestions to the NSFC and the HKSAR Government, expressing the hope that they could provide more support to Hong Kong scholars and strengthen the scientific research cooperation between the mainland China and Hong Kong.

Due to pandemic-related travel restrictions between Hong Kong and mainland China, collaborations and connections have been interrupted since 2020. NPMM took the initiative to organize the conference and thereby re-establish research dialogue between Hong Kong and mainland China. This reunited top scholars and showcased NPMM determination to take an active role in research exchange with mainland China to synergize research outputs and thus achieve breakthroughs in the development of advanced materials. The publication of research inspired by the conference will result in new patented technologies, and industrial collaborations to commercialize the output from fundamental research, ultimately contributing to society in Hong Kong and beyond.

會議六大主題為先進結構設計與製造；仿生結構設計與製造；柔性器件設計與製造；3D/4D 列印、智慧結構設計與製造；2D 材料與器件設計與製造；以及功能導向的新材料設計與製造。盧秉恆院士、唐本忠院士等多位重量級講者的報告，展示了中國在材料領域的最新發現和成就。最後討論環節時，各與會人士向國家自然科學基金委員會和香港特區政府提出建議，有意向香港學者提供更多支援，加強中港兩地的科研合作。

由於中港兩地因疫情關係有旅遊限制，兩地合作和聯繫自 2020 年大受影響，甚至中斷。貴金屬分中心主動舉辦會議，重新築起兩地頂尖學者的研究交流橋樑，並展示本中心有志與內地進行研究交流，結合各方的研究成果，繼而在發展先進材料方面取得突破。會議上公布的研究有望促成新專利技術，並透過行業合作把基礎研究產業化，最終讓香港以至其他地方受惠。

Professor Way KUO, CityU President, Mr. Maozhou LIU, Deputy Inspector of the Department of Educational, Scientific and Technological Affairs, Liaison Office of the Central People's Government in the Hong Kong Special Administrative Region, Mr. Hoishan HSU, President of the Beijing-Hong Kong Academic Exchange Centre, took a group photo with scholars from Hong Kong and mainland China.
城大郭位校長、中央人民政府駐港聯絡辦公室教育科技部二級巡視員劉懋洲司長、京港學術交流中心總裁徐海山先生與香港及內地學者拍攝大合照。

A Series of Events with Sino-Precious Metals Holding Co., Ltd.
與雲南省貴金屬新材料控股集團有限公司合辦的活動

NPMM was jointly established by CityU and the National Research Centre for Precious Metal Materials and Engineering Technology at KIPM, and has since maintained close ties with KIPM and its parent company, Sino-Precious Metals Holding Co., Ltd. NPMM has thus participated in numerous events organized by Sino-Precious Metals Holding Co., Ltd., a few of which are highlighted below.

貴金屬分中心由城大與昆明貴金屬研究所國家貴金屬材料工程技術研究中心（昆明貴金屬研究所）共同創立，其後一直與昆明貴金屬研究所及其母公司雲南貴金屬集團維持緊密聯繫。貴金屬分中心因此參與了雲南貴金屬集團舉辦的多個活動，現列舉重要活動介紹如下。

2017 High-end Forum on Academic Exchange and Strategic Cooperation between CityU and Sino-Precious Metals Holding Co., Ltd.

2017 年雲南貴金屬集團與香港城市大學學術交流暨戰略合作高端論壇

The High-end Forum on Academic Exchange and Strategic Cooperation between CityU and Sino-Precious Metals Holding Co., Ltd., was held in August 2017. Professor Way KUO, the President of CityU, and Ms. Junmei GUO, General Manager of Sino-Precious Metals Holding Co., Ltd., together with senior management of the company and other NPMM members, came together to discuss achievements in the precious metals area and future development directions. This forum built a foundation for long-term collaborations between the two parties.

2017 年雲南貴金屬集團與香港城市大學學術交流暨戰略合作高端論壇於 8 月舉行。城大校長郭位教授、公司總經理郭俊梅及其他公司高層，以及貴金屬分中心成員聚首一堂，討論在貴金屬領域取得的研究成果和未來發展方向，建立兩者的長期合作基礎。


NPMM members exchange views with the senior management of Sino- Precious Metals Holding Co., Ltd. at 2017 High-end Forum on Academic Exchange and Strategic Cooperation.
貴金屬分中心成員在 2017 年雲南省貴金屬集團與香港城市大學學術交流暨戰略合作高端論壇與貴金屬集團高級管理層進行討論。


Professor Jian LU presented at the Precious Metals Forum of China 2018.
呂堅教授在 2018 年中國貴金屬論壇發表演說。

Precious Metals Forum of China

中國貴金屬論壇

In 2018 and 2019, Professor Jian LU participated on behalf of NPMM in the Precious Metals Forum of China organized by Sino-Precious Metals Holding Co., Ltd. The forum is the most influential event in the precious metals industry in China and provides a platform for academic exchange and industrial collaboration. In 2018, the forum was held in Ruili and had the theme “Open innovation, win–win cooperation.” In this two-day forum, Professor Lu gave a talk entitled “Latest Development in Precious Metals and Nanomaterials Research.” The 2019 forum was held in Shenzhen, lasting three days, and Professor Lu gave a presentation on “The past, present and future of precious metals and non-precious metal materials.” The presentation was well received and Professor Lu’s world-class basic research on precious metals was recognized by the forum. Both the 2018 and 2019 fora attracted over 200 participants, and enhanced connections and collaboration within the precious metals industry. With strong support from Professor Lu, Sino-Precious Metals Holding Co., Ltd., sent a second PhD student to Hong Kong to conduct joint research on precious metals and application-related research.

呂堅教授於 2018 年和 2019 年代表貴金屬分中心參與由雲南貴金屬集團舉辦的中國貴金屬論壇。該論壇為中國貴金屬業界最具影響力的活動，提供學術交流和行業合作平台。2018 年的論壇在瑞麗舉辦，主題為「開放創新、合作共贏」，呂教授在這場為期兩日的論壇以「貴金屬及納米材料研究新進展」為題發表演説。而在 2019 年在深圳舉辦的三天論壇裡，呂教授則以「貴金屬與納米貴金屬材料：過去，現狀與未來」為題發表報告。報告引起了全國貴金屬研究界的廣泛關注，一致認為呂教授在貴金屬領域做出了卓有成效、國際一流的基礎研究工作。2018 年和 2019 年的論壇均吸引了超過 200 名人士參與，成功加強與貴金屬行業的聯繫和合作。同時，在呂教授的大力支持下，雲南貴金屬集團選送了第二位博士生赴香港開展聯合課題研究工作。

80th Anniversary Conference of KIPM

In 2018, Sino-Precious Metals Holding Co., Ltd., held a conference to celebrate KIPM's 80th anniversary. Over 100 experts participated in the conference to review the development of the Institute, exchange academic achievements and develop collaborations. The conference was chaired by the company's Deputy Secretary of the Party Committee, Deputy Director, General Manager , Ms. Junmei GUO, and was attended by Professor Jian LU and other joint academicians of the Chinese Academy of Sciences and the Chinese Academy of Engineering. At the conference, Professor Lu delivered a talk entitled "Research Progress on Precious Metals and Nanomaterials: Concepts, Processes, Properties and Applications," which introduced the then-current state of research and development on nanostructured metals. The conference was followed by an unveiling ceremony for Professor Lu's academician workstation, highlighting the promising prospects for collaboration between NPMM and the company.

昆明貴金屬研究所成立 80 周年紀念大會

雲南貴金屬集團於 2018 年舉辦了昆明貴金屬研究所成立 80 周年紀念大會暨學術報告會，慶祝昆明貴金屬研究所成立 80 周年。百多位專家聚首一堂，回顧了昆明貴金屬研究所八十年發展之路，交流學術成果，討論產業發展。大會由雲南貴金屬集團黨委副書記、副董事、總經理郭俊梅主持，呂堅教授，連同其他兩院院士獲邀出席。呂教授在會上以「貴金屬及納米材料研究新進展：概念、工藝、性能及應用」進行演講，介紹了納米金屬的研究發展史。會後舉行了呂堅院士工作站揭牌儀式，顯示雲南貴金屬集團與工作站均對合作前景非常有信心。

80th Anniversary Conference of KIPM is held by Sino-Precious Metals Holding Co., Ltd.
貴金屬集團舉行昆明貴金屬研究所成立 80 周年紀念大會暨學術報告會。

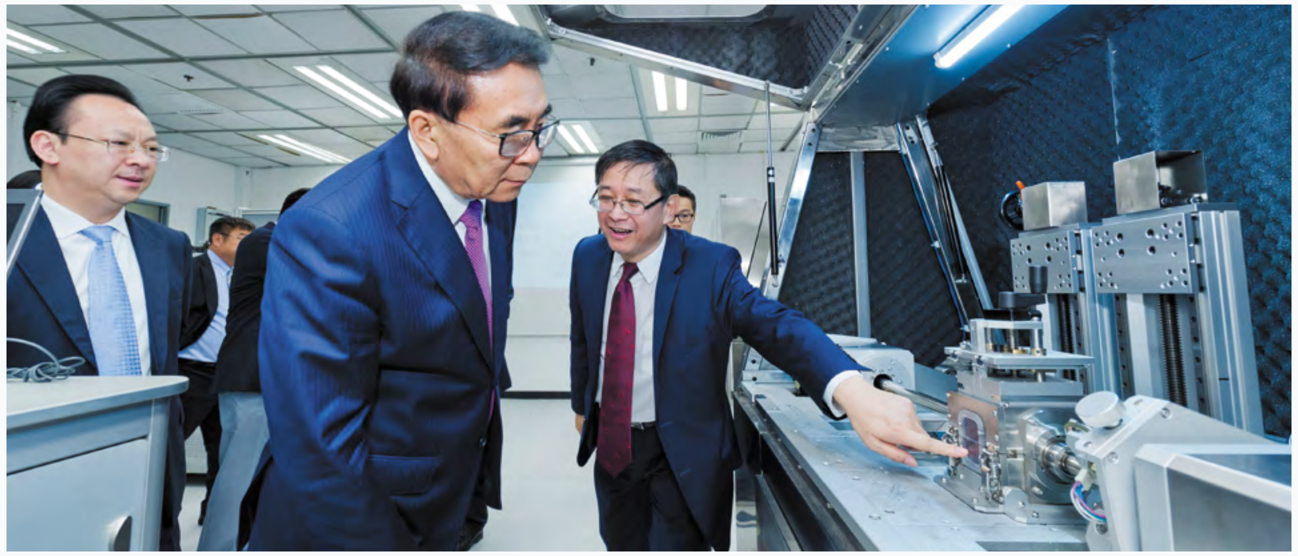
Management Training Course for Leaders in Precious Metals Industry

To bolster interactions between the center and industry, NPMM joined forces with CityU's College of Business in 2018 to organize a management training course for executives of Sino-Precious Metals Holding Co., Ltd. The course inaugurated a new form of collaboration to establish a corporate innovation culture with the assistance of the university. NPMM is honored to serve as a platform for the recruitment and cultivation of talents for the company.

貴金屬集團幹部培訓班

為了加強學校與產業的互動，貴金屬分中心與城大商學院共同為雲南貴金屬集團行政人員舉辦貴金屬集團幹部培訓班。這次培訓是城大與雲南貴金屬集團合作的一個新嘗試，以期能藉大學的支持建立企業創新文化。貴金屬分中心很榮幸能成為雲南貴金屬集團招才引智、人才培養的平台。

Professor Jian LU attends the opening ceremony of Sino-Precious Metals Holding Co., Ltd.
呂堅教授出席貴金屬集團的開幕典禮。



The Chinese Academy of Sciences and the Liaison Office of the Central People's Government in HKSAR visit NPMM.
中國科學院及中央人民政府駐香港特區聯絡辦公室訪問貴金屬分中心。

Visits from the mainland Chinese and Hong Kong governments

As the exemplary unit of the Hong Kong Branch of the Engineering Research Center, NPMM is highly regarded by the mainland Chinese and HKSAR governments. NPMM is thus honored to receive occasional visits from units of both governments.

中港政府訪問

作為國家工程技術研究中心的香港分中心，貴金屬分中心備受中港兩地政府重視，經常接待兩地政府代表到訪。

Professor Jian LU was introduces NPMM to the visiting group of MOST in Inter-University 3D Atom Probe Tomography Unit (APTU)
呂堅教授在三維原子探針聯合研究實驗室與中國科學技術部訪問團介紹中心的運作。

Visit by MOST

In 2017, MOST visited CityU and NPMM to learn more about their operation and research directions, and to explore the feasibility of future cooperation.

中國科學技術部訪問

中國科學技術部於 2017 年到訪城大及貴金屬分中心，了解兩者的運作和研究方向，並探討未來合作的可行性。

Visit by the Innovation and Technology Bureau (ITB) (The former ITIB)

Innovation and Technology Bureau (ITB) (the former ITIB) demonstrated its full support for NPMM by visiting the center in 2021. Despite the pandemic, Mr. Alfred SIT, JP, the former Secretary for Innovation and Technology, Dr. David CHUNG, JP, Under-Secretary for Innovation and Technology and other ITB representatives were able to tour NPMM's laboratories and have face-to-face conservations with NPMM members and young researchers. NPMM valued this opportunity to discuss the development of the center with Mr. Sit and his team, and to share their thoughts. It is encouraging to learn that Mr. Sit and his team were highly impressed by and supported NPMM.

創新科技局（前創新科技及工業局）到訪

創新科技局（前創新科技及工業局）於 2021 年到訪貴金屬分中心，以表對貴金屬分中心的支持。前局長薛永恒太平紳士、副局長鍾偉強博士太平紳士，連同其他創新科技及工業局代表不畏疫情，親自參觀貴金屬分中心的實驗室，並與中心核心成員和年青研究人員對話。貴金屬分中心非常珍惜這次與局長及團隊的見面機會，得以了解他們的想法。創新及科技局代表十分欣賞和支持貴金屬分中心，令人鼓舞。

Delegates of the Innovation and Technology Bureau (the former Innovation, Technology and Industry Bureau) visits NPMM.
創新及科技局（前創新科技及工業局）代表訪問貴金屬分中心。

International and National Award-winning Inventions

The essence of research is to increase understanding of the world, make a meaningful impact on global value creation and generate solutions to societal problems. In keeping with this, NPMM members have won numerous awards for their innovative research.

海內外得獎發明

研究本質在於了解世界，為全球創造意義和價值，並提供解決社會問題的方法。貴金屬分中心成員憑藉創新研究贏得多個獎項。

International Exhibition of Inventions of Geneva

The International Exhibition of Inventions of Geneva is one of the biggest global events showcasing innovations and inventions from around the world. During the pandemic, it has been held in virtual form as the Inventions Geneva Evaluation Days (IGED). Three NPMM members were honored to receive awards at the International Exhibition of Inventions of Geneva and IGED throughout the years.

Professor Yang LU and his team won the Gold Medal at IGED 2021 for their project "Super Bamboo – Sustainable Structural Bamboo Materials with High Strength and Multi-function." Their novel bamboo-processing technique involves both mechanical and chemical treatments for densifying natural bamboo without destroying its key internal microstructure, which is critical to its superior mechanical performance. This technique also does not release formaldehyde, making it more environmentally friendly than other treatments. The mechanical properties (stiffness, strength and dimensional stability) of their "super bamboo" prototype are much better than those of existing materials or products on the market, including those of wood, bamboo scrimber, plastic composites and even metals. Moreover, because of its densified microstructure, this super bamboo is waterproof and fireproof, which enhances its attractiveness to the construction industry.

Researchers from CityU won the largest number of awards of all Hong Kong universities at IGED 2021, including a Gold Medal with Congratulations of the Jury, five other Gold Medals, three Silver Medals and three Bronze Medals. This demonstrates the excellence of the research carried out at CityU, and the award winners were honored at a special reception officiated by the former Chief Executive Mrs. Carrie Lam Cheng Yuet-ngor.

日內瓦國際發明展

日內瓦國際發明展（發明展）為展示全球各地創新發明的大型活動，在過去五年，三名貴金屬分中心成員曾在該發明展榮獲獎項。

陸洋教授及其團隊以研發的「超級竹子—高強度、多功能的可持續結構材料」獲得 2021 年發明展金獎，嶄新處理技術通過機械和化學處理，在不破壞關鍵內部微觀結構的情況下，使天然竹子更緻密，從而達致優異的機械性能。這項技術不會釋放甲醛，因此比其他方法更為環保。這種「超級竹子」在機械性能（剛性、強度和尺寸穩定性），均大大優於市場上現有的木材、竹材、塑膠，甚至部分金屬。此外，由於其緻密的微觀結構，這種原型材料還具備防水、甚至防火性能，在建造業更具競爭力。

城大的研究人員在 2021 年發明展取得最多獎項，包括一項評審團嘉許金獎、五項金獎、三項銀獎和三項銅獎，數量為全港大學之冠，展示城大的卓越研究獲得國際肯定。城大得獎者獲邀行政長官林鄭月娥主持的嘉許禮。

(Eighth from left) Professor Way KUO, CityU President; (ninth from left) Professor Michael YANG, Vice President (Research and Technology) ;and CityU winners attend the special reception on 17 May 2021.
（左八）城大校長郭位教授、（左九）副校長（研究及科技）楊夢甦教授與城大得獎者於 2021 年 5 月 17 日出席嘉許禮。

This was not the first time that NPMM members had been bestowed with awards at the Geneva Exhibition. "Origami and 4D Printing of Ceramic Structures," developed by Professor Jian LU and his research team, won a Silver Medal at the 47th International Exhibition of Inventions of Geneva in 2019. This project developed a novel "ceramic ink"—a mixture of polymers and ceramic nanoparticles—and thus the world's first method for the 4D printing of ceramics. The resulting 4D-printed ceramics are more mechanically robust, larger and stronger than other printed ceramics. They have considerable prospects in the manufacturing of electronic products, as ceramics are superior to metallic materials for transmitting electromagnetic signals. They also have high potential for use in the aerospace and space exploration fields.

Another silver medal awarded by NPMM members at the Geneva Exhibition in the same year was "Structural Morphing Enabled Underwater Quality Monitoring System", which was led by Professor Jian LU and Professor Xiaoqiao HE. This technique provides a new approach to achieving underwater mobility in an efficient, economical and robust way. It includes multi-stable shells that are developed by nanotechnology SMAT. The shape transitions of the bistable or multistable shells in the structure create a volume change to adjust to the buoyant force in the water and enable submerging and surfacing without changing the weight of the structure. Data collected underwater at different depths can be transmitted when the device is on the surface of the water. The research results can be applied to underwater vehicles, monitoring and surveillance, and can be transformed into consumable products, such as underwater devices.

這並非貴金屬分中心成員首次於發明展獲獎，呂堅教授及其研究團隊發明的「摺紙陶瓷和 4D 列印陶瓷」於 2019 年的第 47 屆發明展榮獲銀獎。研究團隊成功研發出一種新型的「陶瓷墨水」—一種聚合物和陶瓷納米顆粒的混合物，成功開發了全球首套 4D 列印陶瓷技術。4D 列印陶瓷結構堅固，而且和一般的列印陶瓷相比，它的尺寸更大、強度更高。陶瓷材料在傳輸電磁訊號方面較金屬材料優越，因此適合用作生產電子產品。此外，4D 列印陶瓷有極高潛力應用於航空工業及太空探索。

同年貴金屬分中心成員在日內瓦發明展獲頒銀獎的項目還有「由結構變形實現的水下質素監察系統」，這個項目由呂教授及何小橋教授領導，旨在提供一種高效率、低成本及可靠的水下移動方法。內藏監察儀器的盒子，外殼由基於納米技術，即表面機械研磨技術，開發的多穩態板殼製成，通過雙穩態或多穩態板殼之間的變形，改變整個盒子的體積，從而調節在水中的浮力，使整個監察系統在重量不變情況下，能夠在水裡升降或浮沉。當結構上升至水面時，可傳輸在水下不同水深收集的數據。這項研究技術可應用於水底運輸、水底活動監察及水監測，並可改造為消費者使用的水下器材。

Professor Jian LU's team won two silver medals at the 47th International Exhibition of Inventions of Geneva.
呂堅教授團隊在第 47 屆日內瓦發明展獲得兩個銀獎。

National Exhibition of Inventions

China's National Exhibition of Inventions is the country's only large-scale science and technology exhibition of innovative technical and cultural inventions from across various emerging industries. In December 2021, the three-day 25th National Invention Exhibition–One Belt One Road & BRICS Skills Development and Technological Innovation Competition with the theme "invention and innovation, self-reliance and self-improvement" was held in Foshan, and attracted more than 2,300 inventions and innovation projects and participants from 800 enterprises.

NPMM members won three awards at the exhibition, including a gold, a silver and a bronze medal. The gold medal-winning project, "Water Quality Monitoring System Using Structural–Morphological Transformation," was performed by the team of Professor Jian LU and Professor Xiaoqiao HE. Their novel system was derived from a patented technology for material processing and structure manufacturing, and was prepared using a multi-stable plate and shell with a high bearing capacity and a designable shape developed by nanometer-surface technology. Through the controllable deformation of the multi-stable plate and shell, the volume of the underwater equipment is determined and the adjustment of the underwater buoyancy is achieved obtained, and thus efficient subsidence and floating movement of the underwater profile is realized. The plate is equipped with commercial sensors and communication modules to realize monitoring of the water quality of an underwater profile. As only a small amount of energy is required to excite the elastic-state transformation of the multi-stable plate and shell to provide the driving force required for settlement or floating, the energy consumption of the equipment is zero during the entire vertical monitoring procedure. This renders the device suitable for periodic water-profile quality monitoring. The system is small, can be arranged with one hand by an individual, is easy to recycle, has a long working life and uses commercial materials, and thus is inexpensive. It therefore has good practical value, and related technologies have obtained invention patents authorized by China and the United States.

全國發明展

全國發明展是國內唯一以發明創新為主題的大型科技展，展出多個新興行業的創新技術和文化發明。第二十五屆全國發明展覽會—「一帶一路」暨金磚國家技能發展與技術創新大賽以「發明創新，自立自強」為主題，於 2021 年 12 月在佛山舉行，為期三天，吸引來自 800 間企業超過 2,300 項發明創新專案和代表參與。

貴金屬分中心成員於全國發明展勇奪金、銀、銅三個獎項，金獎項目「由結構形態轉換實現的水下剖面水質監測系統」來自呂堅教授及何小橋教授團隊，該發明核心部件源自發明人自主智慧財產權的材料加工和結構製備技術，利用由表面納米化技術開發的具有較高承載力且可以設計形態的表面納米化多穩態板殼製備。通過多穩態板殼的可控變形獲取水下設備體積及水下浮力的調整，實現高效的水下剖面沉降上浮運動，搭載商用感測器和通訊模組，實現水下剖面水質監測。由於只需要有限能量激發多穩態板殼的彈性形態轉換，提供沉降或上浮所需的驅動力，設備在整個垂直運動過程中並無能量消耗，這種高效垂直運動適用於週期性的剖面水質監測。該發明設備體積較小，個人單手即可佈置，回收方便，工作週期長，加上採用商用材料，成本較低，在水下剖面水質監測、近海岸生態環境科考、水下機器人等領域具有良好的實用價值，相關技術已取得中國和美國授權發明專利。


全国发明展览会
NATIONAL EXHIBITION OF INVENTIONS
获奖证书
AWARD CERTIFICATE
项目编号：E61797　证书编号：2501162　国科奖社证字第0123号
发 明 者：吕 坚 何小桥 易圣辉
完成单位：香港城市大学
项目名称：由结构形态转换实现的水下剖面水质监测系统
该项目在第二十五届全国发明展览会上荣获"发明创业奖项目奖"金 奖，特颁此证予以表彰。
中国发明协会
2021年12月

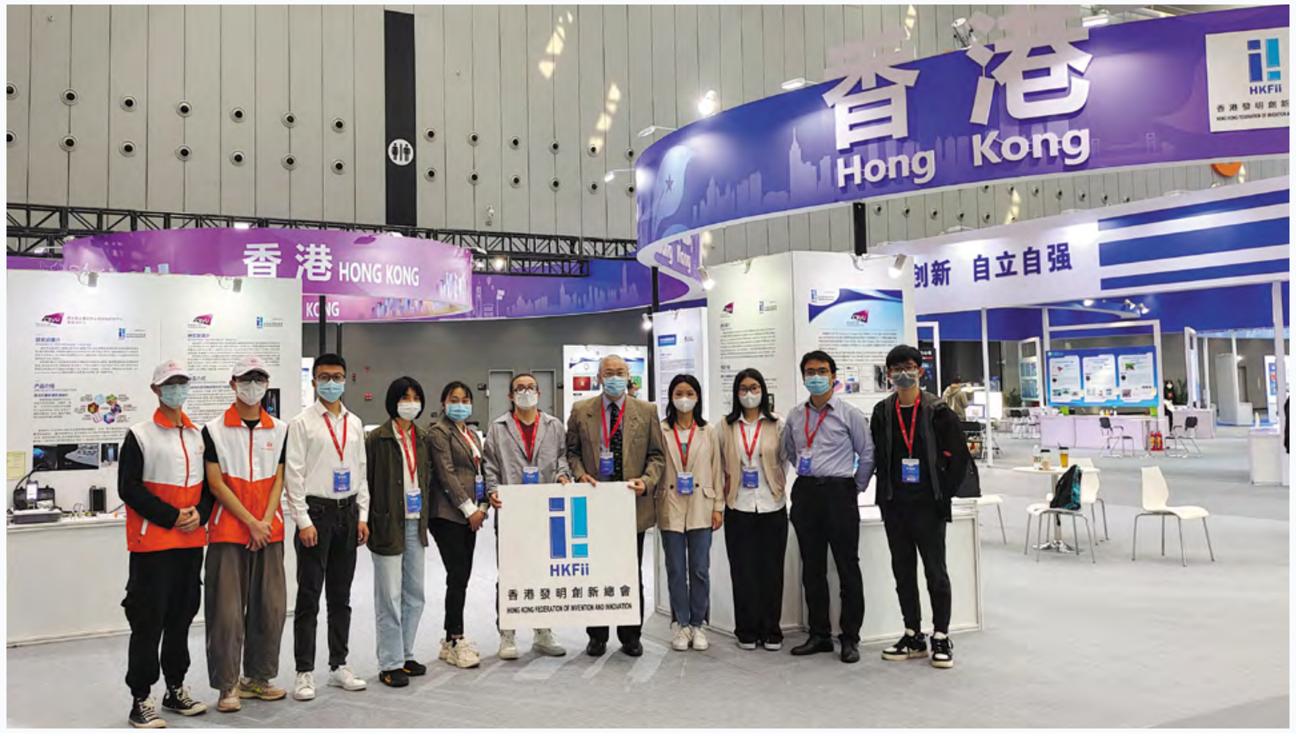
" Water Quality Monitoring System Using Structural-Morphological Transformation" won the gold medal at The 25th National Exhibition of Inventions.
" 由結構形態轉換實現的水下剖面水質監測系統 " 在第二十五屆全國發明展覽會 2021 奪得 "發明創業將項目將" 金獎。

The "High-Quality Multifunctional Sensor at Low Cost" project led by Professor Jian LU and Dr. Yangyang LI, won the silver medal. Also led by Professor Jian LU, the project "4D Printing Ceramics and Its Application in 3C Products" won the bronze medal.

Going forward, NPMM will continue to build the platform for academic exchange by organizing different event, locally and non-locally.

呂堅教授及李揚揚博士領導的「質優價廉的多功能快檢儀」項目奪得銀獎，而同樣由呂堅教授領導的「4D 列印陶瓷及其在 3C 產品中的應用」則獲銅獎。

貴金屬分中心未來會繼續舉辦各項活動，擴大學術平台。



The inventions of NPMM members won the gold, silver and bronze medals at the 25th National Exhibition of Inventions in 2021.
貴金屬分中心成員的發明在第二十五屆全國發明展覽會上包攬金銀銅獎。


全国发明展览会
NATIONAL EXHIBITION OF INVENTIONS
获奖证书
AWARD CERTIFICATE
项目编号：C21022　证书编号：2502173　国科奖社证字第0123号
发 明 者：吕 坚 周彬斌 沈君达 李杨杨
完成单位：香港城市大学
项目名称：质优价廉的多功能快检仪
该项目在第二十五届全国发明展览会上荣获"发明创业奖项目奖"银 奖，特颁此证予以表彰。
中国发明协会
2021年12月

The "High-Quality Multifunctional Sensor at Low Cost" project led by Professor Jian LU and Dr. Yangyang LI, won the silver medal at the 25th National Exhibition of Inventions.
呂堅教授及李揚揚博士領導的「質優價廉的多功能快檢儀」項目在第二十五屆全國發明展覽會奪得銀獎。


全国发明展览会
NATIONAL EXHIBITION OF INVENTIONS
获奖证书
AWARD CERTIFICATE
项目编号：A31424　证书编号：2503212　国科奖社证字第0123号
发 明 者：吕 坚 刘 果 赵 岩 殷建安 张小伟 鲁馨雅
完成单位：香港城市大学
项目名称：4D打印陶瓷及其在3C产品中的应用
该项目在第二十五届全国发明展览会上荣获"发明创业奖项目奖"铜 奖，特颁此证予以表彰。
中国发明协会
2021年12月

Led by Professor Jian LU, the project "4D Printing Ceramics and Its Application in 3C Products" won the bronze medal at the 25th National Exhibition of Inventions.
呂堅教授領導的「4D 列印陶瓷及其在 3C 產品中的應用」在第二十五屆全國發明展覽會獲得銅獎。

Looking Forward
勇闖未來

NPMM initially received annual funding of up to HK$5 million from ITC for the recruitment of researchers and the acquisition of advanced equipment. However, the funding amount has increased over the past five years, and raised to HK$20 million from the 2022/23 funding cycle onwards. With this increasing support of the ITC, the Hong Kong Branch of National Precious Metals Material Engineering Research Center (NPMM) has been able to scale up by recruiting more talent and purchasing advanced equipment, thereby strengthening its research capabilities. NPMM will continue to conduct research projects, publish pioneering research findings in leading international journals, file patent applications and commercialize its technology via industrial partners and entrepreneurs. As NPMM is a comprehensive platform for academic exchange and industrial collaboration, it aims to achieve the status of a world-class precious metals material engineering center within the next five years.

The NPMM will be a significant supporting influence for the introduction, local adaptation, and integration of new technologies. Technological progress and industrial development are also meaningful for research on precious metals and nano-materials. Therefore, the NPMM aims to leverage Hong Kong's support and advantages to promote scientific research at home and abroad, especially in mainland China, and to collaborate with mainland China on various aspects of technology knowledge transfer, commercialization, and industrialization.

In the future, NPMM will contribute to and focus on basic research related to the various research areas stipulated in its initial proposal. NPMM will continue to conduct systematic studies on the phase-dependent physicochemical properties of noble metal nanomaterials and on the effects of phases on other properties of noble metal nanomaterials, including optical, electrical, magnetic and mechanical properties, in addition to exploring other applications. The feasibility of ultrafine gold nanostructures in a variety of unique applications will also be examined. The development of high-entropy alloys comprising various combinations of materials will continue, allowing us to study their feasibility in catalysis applications. In addition, the NPMM's team will investigate the 3D/4D printing of precious metals and ceramics with complex shapes that can serve as the matrices of noble metal–based catalysts. The novel gold/silver (Au/Ag) wires we have previously developed are supersensitive: they can detect trace amounts or even single molecules of pesticide residues, drugs and other chemicals in living tissues, food and healthcare products. Thus, we will explore the potential application of these novel Au/Ag wires in other areas, such as in the detection of SARS-CoV-2.

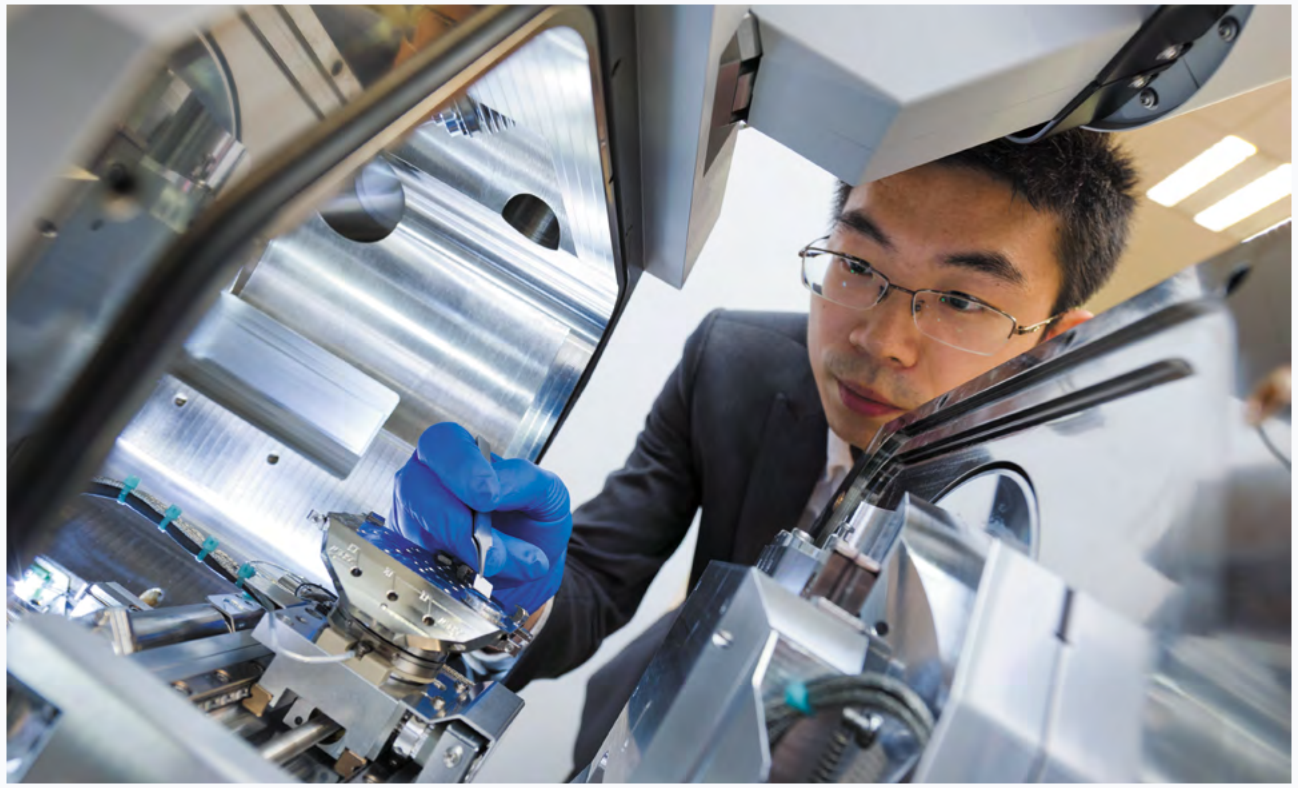
貴金屬分中心起初僅獲香港創新科技署每年最高資助500萬港元，以聘請研究人員和購置先進儀器。不過，資助金額過去五年來按年上升，於2022/23年度起金額更會上升至2,000萬港元。有賴創新科技署的鼎力支持，貴金屬分中心得以招攬更多人才和購置先進儀器，提升科研能力。貴金屬分中心會繼續進行研究、在頂尖國際期刊公布先鋒研究結果、申請專利，並與行業夥伴和企業合作推進產業化。貴金屬分中心作為學術交流和行業合作的全方位平台，致力在未來五年成為世界級貴金屬物料工程中心。

貴金屬分中心會成為引入、按本地情況調整和融入新技術的一大助力，同時技術製程和工業發展對貴金屬和納米材料研究也極具意義。因此，貴金屬分中心旨在活用香港的支援和優勢推動海內外科研，尤其是與內地展開多方面的知識轉移、產業化和工業化合作項目。

貴金屬分中心未來會繼續履行當初建立時的承諾，專注不同領域的基礎研究，並進行系統性研究，研究貴金屬納米材料相依賴的物化性質和相對貴金屬納米材料其他性質的影響，如光學性質、電學性質、磁學性質和力學性質等及其應用。貴金屬分中心會繼續探索納米金結構在各種獨特應用上的可行性，並深入探索多組分合金材料在催化領域的應用。而且，貴金屬分中心會研究複雜形狀的貴金屬和陶瓷3D/4D列印技術，這項技術可用作以貴金屬為本的催化劑。我們先前開發的新金／銀線敏感度極高，可偵測殺蟲劑殘留物、生物組織的藥物和其他化學物，以及食物及健康產品中的微量甚至單一分子。因此，我們會探討新金／銀電在其他方面如篩查新冠病毒等的潛在用途。

As NPMM is part of the Hong Kong Branch of Chinese National Engineering Research Centre, it is committed to extending this platform through the establishment of a research organization that upholds high-level research, engages in the recruitment and training of superior scientists, and facilitates academic exchanges in the Greater Bay Area (GBA). To achieve this goal, NPMM joined the Shenzhen/Hong Kong Innovation Circle in Futian in 2020. Although the pandemic has slowed its progress, NPMM has been working closely with Sino-Precious Metals Holding Co., Ltd., to establish a branch of the State Key Laboratory of Advanced Technologies for Comprehensive Utilization of Platinum Metals in the GBA. At the NPMM Annual Advisory Steering Meeting 2021, a consensus was reached on the establishment of a front office and an industrialization facility in the GBA to promote fundamental research and research with commercialization potential. We look forward to the opening of this research platform, as it will provide training for outstanding scientists and facilitate the transfer of research outcomes to industry. This new institute will not only provide space for research related to industrialization in Hong Kong but will also facilitate research collaborations and technology transfer, thereby fostering entrepreneurship in the GBA. With a team of world-class scientists and this well-equipped research platform, NPMM looks forward to more outstanding research outcomes and collaborations in the GBA within the coming years.

貴金屬分中心作為國家工程技術研究中心香港分中心之一，致力透過發展高端研究、招攬和培訓頂尖科學家，設立研究機構，擴闊多方面合作平台，促進大灣區學術交流。為此，貴金屬分中心於2020年加入位於福田的深港創新圈。儘管進度受疫情影響，貴金屬分中心一直與雲南省貴金屬新材料控股集團有限公司緊密合作，於大灣區建立深圳稀貴金屬創新研究院。雙方更在2021年度管理及學術委員會年會中達成共識，於大灣區設立前沿辦公室，推動基礎研究及產業化項目。我們期待開設研究平台，為傑出科學家提供培訓，把研究成果轉移到業界。這座新研究院不單為香港的產業化研究提供空間，同時能夠促進研究協作和技術轉移，繼而推動大灣區創業風氣。貴金屬分中心擁有世界級科學家團隊和設備精良的研究平台，期待未來能大展拳腳，推出更多出色的研究成果，增進和大灣區合作。



Until We Meet Again
後會有期


NPMM

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