PHY6525: ADVANCED WAVE FUNCTIONAL MATERIALS FOR ENERGY APPLICATIONS

Effective Term
Semester B 2024/25

Part I Course Overview

Course Title
Advanced Wave Functional Materials for Energy Applications

Subject Code
PHY - Physics

Course Number
6525

Academic Unit
Physics (PHY)

College/School
College of Science (SI)

Course Duration
One Semester

Credit Units
3

Level
P5, P6 - Postgraduate Degree

Medium of Instruction
English

Medium of Assessment
English

Prerequisites
Nil

Precursors
Nil

Equivalent Courses
Nil

Exclusive Courses
PHY8525 Advanced Wave Functional Materials for Energy Applications

Part II Course Details

Abstract

Nowadays, economic development relies heavily on energy resources and energy technologies. Considerable efforts have been devoted to the design of novel materials for energy related applications, especially for the generation and storage of clean and renewable energies such as solar energy. Among these materials, wave functional materials such as metamaterials and photonic crystals are promising candidates due to their unusual properties. This course aims to provide students a detailed introduction and comprehensive understanding of wave functional materials. It will emphasize the underlying physical mechanism responsible for their unusual properties such as resonance enhancement of light absorption. Practical applications such as energy harvesting and storage, photon detection, and wireless power transfer will also be discussed. By the end of this course, students will gain essential knowledge and master necessary numerical and analytical techniques to design wave functional materials.

Course Intended Learning Outcomes (CILOs)

	CILOs	**Weighting (if app.)**	**DEC-A1**	**DEC-A2**	**DEC-A3**
1	Describe the important concepts in wave physics	20		x	
2	Explain the physical mechanism responsible for the properties of photonic crystals, metamaterials and 2D thin-film materials	30		x	
3	Relate the material properties to the applications	10		x	
4	Identify the limitations of the current wave functional materials	10		x	
5	Apply numerical and analytical techniques to design wave functional materials	30			x

A1: Attitude
Develop an attitude of discovery/innovation/creativity, as demonstrated by students possessing a strong sense of curiosity, asking questions actively, challenging assumptions or engaging in inquiry together with teachers.

A2: Ability
Develop the ability/skill needed to discover/innovate/create, as demonstrated by students possessing critical thinking skills to assess ideas, acquiring research skills, synthesizing knowledge across disciplines or applying academic knowledge to real-life problems.

A3: Accomplishments
Demonstrate accomplishment of discovery/innovation/creativity through producing /constructing creative works/new artefacts, effective solutions to real-life problems or new processes.

Learning and Teaching Activities (LTAs)

	LTAs	**Brief Description**	**CILO No.**	**Hours/week (if applicable)**
1	1	Lectures	1, 2, 3, 4, 5	26 hrs/13 wks
2	2	Tutorials	2, 3, 5	6 hrs/ 6 wks
3	3	Group project and presentation	2, 3, 4, 5	6 hrs/ 6 wks

Assessment Tasks / Activities (ATs)

	ATs	CILO No.	Weighting (%)	Remarks (e.g. Parameter for GenAI use)
1	Assignment	1, 2, 3, 4, 5	10	
2	Presentation	1, 2, 3, 4, 5	20	Group project
3	Report	1, 2, 3, 5	20	Group project

Continuous Assessment (%)

50

Examination (%)

50

Examination Duration (Hours)

2

Assessment Rubrics (AR)

Assessment Task

1. Assignment (for students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter)

Criterion

Understanding the important concepts of wave physics; Ability of applying analytical methods to study material properties

Excellent

(A+, A, A-) High

Good

(B+, B, B-) Significant

Fair

(C+, C, C-) Moderate

Marginal

(D) Basic

Failure

(F) Not reaching marginal levels

Assessment Task

2. Presentation (for students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter)

Criterion

Understanding the physical mechanisms, applications, and limitations of selected/designed wave functional material; Identify challenges and further development

Excellent

(A+, A, A-) High

Good

(B+, B, B-) Significant

Fair

(C+, C, C-) Moderate

Marginal

(D) Basic

Failure

(F) Not reaching marginal levels

Assessment Task

3. Report (for students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter)

Criterion

Having an in-depth understanding of the selected/designed wave functional material, including its properties, wave manipulation functionalities and limitations of performance

Excellent

(A+, A, A-) High

Good

(B+, B, B-) Significant

Fair

C+, C, C-) Moderate

Marginal

(D) Basic

Failure

(F) Not reaching marginal levels

Assessment Task

4. Examination (for students admitted before Semester A 2022/23 and in Semester A 2024/25 & thereafter)

Criterion

Understanding the physical mechanisms, applications, and limitations of selected/designed wave functional material; Identify challenges and further development
Having an in-depth understanding of the selected/designed wave functional material, including its properties, wave manipulation functionalities and limitations of performance

Excellent

(A+, A, A-) High

Good

(B+, B, B-) Significant

Fair

(C+, C, C-) Moderate

Marginal

(D) Basic

Failure

(F) Not reaching marginal levels

Assessment Task
1. Assignment (for students admitted from Semester A 2022/23 to Summer Term 2024)

Criterion
Understanding the important concepts of wave physics; Ability of applying analytical methods to study material properties

Excellent
(A+, A, A-) High

Good
(B+, B) Moderate

Marginal
(B-, C+, C) Basic

Failure
(F) Not reaching marginal levels

Assessment Task
2. Presentation for students admitted from Semester A 2022/23 to Summer Term 2024)

Criterion
Understanding the physical mechanisms, applications, and limitations of selected/designed wave functional material; Identify challenges and further development

Excellent
(A+, A, A-) High

Good
(B+, B) Moderate

Marginal
(B-, C+, C) Basic

Failure
(F) Not reaching marginal levels

Assessment Task
3. Report (for students admitted from Semester A 2022/23 to Summer Term 2024)

Criterion
Having an in-depth understanding of the selected/designed wave functional material, including its properties, wave manipulation functionalities and limitations of performance

Excellent
(A+, A, A-) High

Good
(B+, B) Moderate

Marginal

(B-, C+, C) Basic

Failure

(F) Not reaching marginal levels

Assessment Task

4. Examination (for students admitted from Semester A 2022/23 to Summer Term 2024)

Criterion

Understanding the physical mechanisms, applications, and limitations of selected/designed wave functional material; Identify challenges and further development
Having an in-depth understanding of the selected/designed wave functional material, including its properties, wave manipulation functionalities and limitations of performance

Excellent

(A+, A, A-) High

Good

(B+, B) Moderate

Marginal

(B-, C+, C) Basic

Failure

(F) Not reaching marginal levels

Part III Other Information

Keyword Syllabus

- Wave physics
- Wave equations, harmonic modes, eigenvalue problems, symmetry of eigenmodes, periodic systems, band structures, Bloch wave, phase velocity, group velocity, density of states, retarded Green's function
- Transmission, reflection, permittivity and permeability tensors, polarizability, bulk modulus, mass density
- Electromagnetic wave vs. acoustic wave
- Metamaterials
- Resonant elements, dispersion, effective material parameters, effective medium theory, negative refractive index, subwavelength imaging, perfect lens, cloaking, effect of loss
- Metamaterial wave absorber, metamaterials-based energy harvester, metamaterial photodetectors, wireless power transfer with metamaterials
- Photonic crystals
- Photonic band gaps, multilayer film, evanescent modes in band gaps, defect modes, surface states, photonic crystal waveguide, woodpile crystal, quality factor of lossy cavities
- Photonic-crystal fibers, photonic-crystal lasers, narrow-band filter, resonant light absorption and radiation, photonic crystals for solar energy applications
- 2D materials
- Properties of graphene, graphene electronic devices, graphene spintronics, transparent conducting electrodes, graphene-based supercapacitors, graphene-based materials in lithium-ion batteries, graphene-based fuel cells and solar cells
- Other layered 2D materials (e.g., boron nitride nanosheets, transition metal oxides, silicene, etc.)

Reading List

Compulsory Readings

	Title
1	“Photonic Crystals: Modelling the Flow of Light”, J. D. Joannopoulos, S. G. Johnson, J. N. Winn, R. D. Meade, Princeton University Press, 2nd ed., 2008.
2	“Waves in Metamaterials”, L. Solymar; E. Shamonina, Oxford University Press, 2009.
3	“Acoustic Metamaterials and Phononic Crystals”, P. A. Deymier, Springer, 2013.
4	“Graphene: Fundamentals and Emergent Applications”, J. H. Warner, F. Schaffel, M. Rummeli, A. Bachmatiuk, Elsevier, 2012.

Additional Readings

	Title
1	“Optical Properties of Photonic Crystals”, K. Sakoda, Springer, 2nd ed., 2004.
2	“Tutorials in Metamaterials”, M. A. Noginov, V. A. Podolskiy, CRC Press, 2011.
3	“Metamaterials for Perfect Absorption”, Y. P. Lee, J. Y. Rhee, Y. J. Yoo, K. W. Kim, Springer, 2016.
4	“Graphene: A New Paradigm in Condensed Matter and Device Physics”, E. L. Wolf, Oxford University Press, 2016.