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Effects of coating process on the characteristics of Ag–SnO_2 contact materials

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Abstract

Good wettability between the SnO_2 and silver matrix can improve the electrical contact performance of Ag–SnO_2 materials. In this work, Ag was deposited onto the surface of Ti-doped SnO_2 particles using chemical plating to enhance the wettability. X-ray diffraction (XRD) and transmission electron microscopy (TEM) were used to characterize the Ag-coated SnO_2 particles. Scanning electron microscopy (SEM), conductivity tests, differential thermal analysis (DTA), and thermogravimetric analysis (TGA) were performed on the Ag–SnO_2 materials. Our results reveal that the chemical plating process can enhance the wettability between the Ti-doped SnO_2 particles and Ag matrix, and the Ag-coated SnO_2 particles are uniformly distributed in the Ag matrix. Both the thermal and electrical conductivity of the Ag–SnO_2 materials are significantly improved.

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Keywords: Chemical plating; SnO_2; Coating; Electrical conductivity

1. Introduction

As a pollution-free contact material, Ag–SnO_2 has been gradually replacing the toxic Ag–CdO materials in the last two decades. However, SnO_2 has higher thermal stability and is more difficult to be wetted by liquid silver than CdO [1]. Consequently, SnO_2 can easily aggregate to the interface between Ag and SnO_2. Furthermore, the mixture of Ag and SnO_2 can deposit from the silver melt onto the contact surface by the arc reaction. As a consequence, Ag–SnO_2 materials exhibit less favorable high temperature behavior than Ag–CdO materials. Generally, the high temperature properties of Ag–SnO_2 materials produced by powder metallurgical (PM) method can be improved by the addition of some metal oxides such as WO, MoO_3, Bi_2O_3, TeO_2, etc. [2–4], but this measure increases the brittleness of Ag–SnO_2 and makes it difficult to machine in practice. Therefore, it is necessary to develop new methods to enhance the wettability between Ag and SnO_2 while keeping the good properties of Ag–SnO_2.

The chemical plating method has been successfully used to improve the wettability between Ag and additives with high melting point such as WC, TiC and graphite [5]. This is due to the higher adsorption affinity between newly precipitated Ag and additives during the plating process. Ti^{4+} has been successfully doped into the crystal lattice of SnO_2 by using the sol–gel method [6]. In the work reported here, we systematically investigated Ag cladding on the surface of Ti-doped SnO_2 powders using chemical plating and the characteristics of the Ag–SnO_2 contact materials.

2. Experimental details

The raw materials used in our experiments were nano Ti-doped SnO_2 powders with a purity of 99.5% prepared by the sol–gel method and sintered at 500 °C [6]. The nano Ti-doped SnO_2 powders were first added to deionized water with a weight ratio of 1:10 (SnO_2:H_2O), agitated by magnetic stirring, and then polyvinylpyrrolidone (PVP) containing of 1 wt.% of SnO_2 was dripped into the stirred solution as a stabilizing agent. Ammonia was then introduced into the silver nitride solution with continuous stirring to obtain a $(Ag(NH_3)_2)NO_3$ solution. Afterwards, the $(Ag(NH_3)_2)NO_3$ solution was poured into the SnO_2 suspended solution while keeping continuous agitation, and then a hydrazine hydrate ($NH_4N_2{\cdot}H_2O$) solution was dripped into the stirred solution at a high rate to produce Ag-coated SnO_2 powders. Finally, the Ag-coated SnO_2 powders were dried at 100 °C for 48 h in the oven after rinsing with deionized water.

Two kinds of Ag–SnO_2 materials were prepared in our experiments. The coated Ag–SnO_2 materials were fabricated by mixing 99.99% Ag and the Ag-coated nano Ti-doped SnO_2 powders as follows. The Ag and Ag-coated SnO_2

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powders were fully mixed for 4 h and then sieved using an 800-mesh screen. The mixed powders were put into the die and pressed by a pressing machine at a pressure of 200 MPa for 1 min. Afterwards, the pressed samples were sintered as shown in Fig. 1 in a tube furnace under argon. Finally, the Ag–SnO_2 materials were stored in desiccators before use. The uncoated Ag–SnO_2 materials were fabricated as a control from the mixtures of Ag and the uncoated nano Ti-doped SnO_2 powders using similar procedures.

The density of the Ag–SnO_2 materials was measured by Archimedes method and their hardness was determined by using a Vickers hardness tester. The 7501 vortex conductivity apparatus was used to investigate the electrical conductivity of Ag–SnO_2 materials. The microstructure of the Ag–SnO_2 samples was examined by scanning electron microscopy (PHILIPS XL-20), transmission electron microscopy (TEM) (JEOL-100CXII) and XRD (Rigakudmax X-ray diffractometer with a 40 kV, 100 mA, Cu Kα X-ray source) were employed to examine the chemical composition and the structure of the Ag-coated Ti-doped SnO_2 powders. Differential thermal analysis (DTA) and thermogravimetric analysis (TGA) were performed on the Ti-doped SnO_2 powders and the coated/uncoated Ag–SnO_2 contact materials.

3. Results and discussion

Chemical plating is one of the liquid coating techniques. It can significantly improve the bonding strength of the interface between the matrix and coated particles such as SiC, MgO, CaO and ZrO_2 as well as the mechanical properties [7–9]. In this work, the silver ions were deacidized by the reductant hydrazine hydrate and nucleated and grew preferentially around the surface of the suspended Ti-doped SnO_2 particles in a mixed solution because the Ti-doped SnO_2 particles in the solution acted as nucleation sites. The reactions in the chemical plating process are as follows:

$$AgNO_3 + 2NH_3{\cdot}H_2O \rightarrow (Ag(NH_3)_2)NO_3 + 2H_2O \quad (1)$$

$$(Ag(NH_3)_2)NO_3 + NH_4N_2{\cdot}H_2O \rightarrow Ag + N_2 + 2NH_3 + NH_4NO_3 + H_2O \quad (2)$$

As shown in Fig. 2, curve 1 shows an obvious peak corresponding to silver, implying that the Ti-doped SnO_2 powders are coated with Ag during chemical plating. The TEM image displayed in Fig. 3 reveals that the size of Ag-coated Ti-doped SnO_2 particles is in the range of 100–200 nm, whereas, the size of the uncoated Ti-doped SnO_2 particles before coating varies from 8 to 10 nm [6]. It indicates that Ag deacidized by the reductant hydrazine hydrate successfully nucleates and grows on the surface of the Ti-doped SnO_2 particles suspended in the mixed solution.

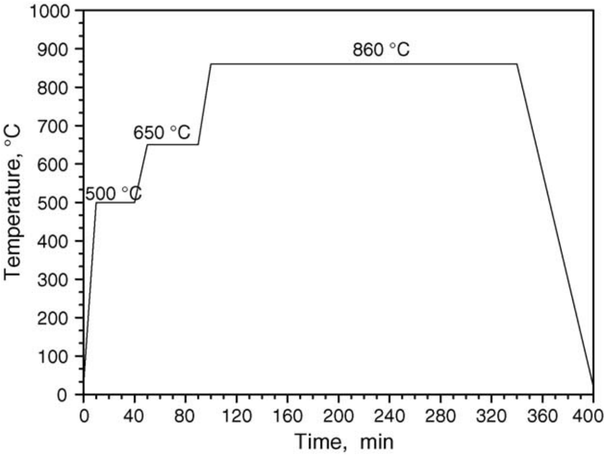

Fig. 1. Schematic diagram of the sintering process of Ag–SnO_2.

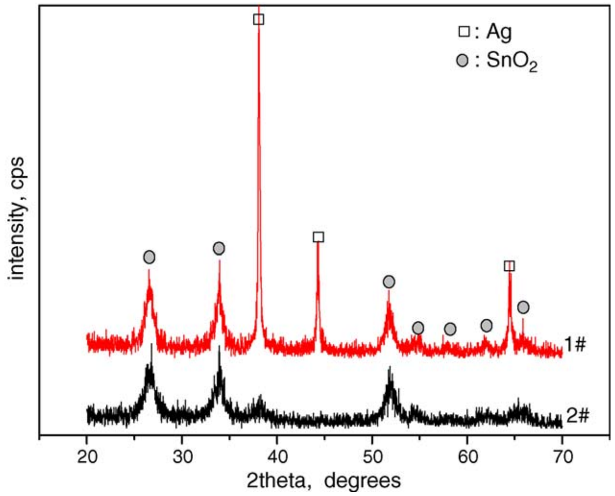

Fig. 2. XRD spectra of Ti-doped SnO_2 powders: (1) coated with Ag and (2) uncoated (as a control).

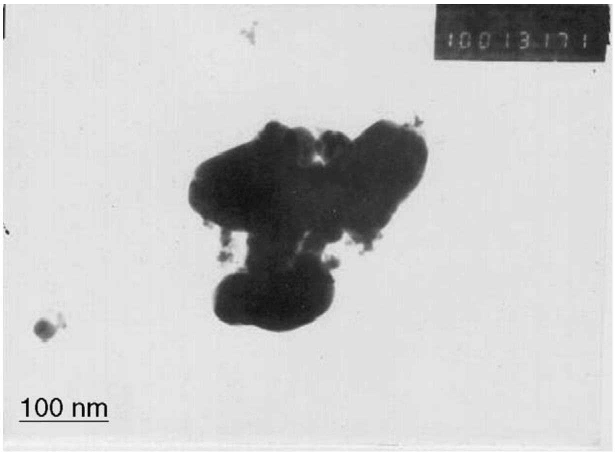

Fig. 3. TEM image of nano Ti–SnO_2 particles coated with silver.

The SEM image of the coated Ag–SnO_2 materials is depicted in Fig. 4. The Ag-coated Ti-doped SnO_2 particles (white color) are uniformly distributed in the Ag matrix. It arises from the improvement of wettability between the Ag-coated SnO_2 particles and Ag matrix.

Table 1
Physical and electrical properties of Ag–SnO_2 contact materials

Samples	Hardness (Hv-MN/m^2)	Density (g/cm^3)	Electric conductivity (% IACS)
Coated	98.4	9.74	68.3
Uncoated	95	9.71	58.1

Note: The value in the form is the average of three samples. IACS: International Annealed Copper Standard.

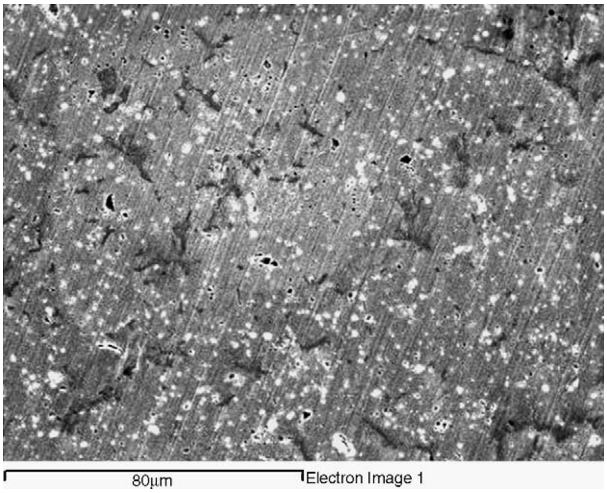

Fig. 4. SEM image of coated Ag–SnO_2 contact materials.

As shown in Table 1, both the Vickers hardness and density of the coated Ag–SnO_2 contact materials are higher than those of the uncoated ones because the Ag coat on the surface of SnO_2 can increase the wettability between the SnO_2 and Ag matrix. It can avoid aggregation of SnO_2 particles and make them uniformly disperse in the Ag matrix. The SnO_2 dispersed in the Ag matrix can strengthen the matrix. Furthermore, the bonding strength of the interface between the matrix and the second phase particles can be strengthened after the second phase particles are coated with the matrix metal by chemical plating [7]. Here, the Ag deposited on the surface of SnO_2 can eliminate the gap between the SnO_2 and Ag matrix. Therefore, the hardness and density of the coated Ag–SnO_2 are enhanced slightly. The electrical conductivity of two kinds of Ag–SnO_2 contact materials listed in Table 1 shows significant improvement of up to 68.3% that is higher than that of uncoated Ag–SnO_2 materials. Based on the International Annealed Copper Standard (% IACS), it is 58.1% IACS. In general, the uncoated Ag–SnO_2 materials consist of a mixture of two phases, i.e. Ag and SnO_2 powders. Consequently, the contact resistance between the uncoated SnO_2 particles and Ag matrix is higher due to direct contact between the SnO_2 particles and Ag matrix [10]. However, Ag deposited on the surface of SnO_2 particles converts the two phase mixture into a homogeneous single phase substance, i.e. Ag(SnO_2), thereby significantly reducing the contact resistance between the SnO_2 particles and Ag matrix.

Figs. 5–7 display the thermal and thermogravimetric properties of the Ti-doped SnO_2 powders produced by the sol–gel methods as well as uncoated and coated Ag–SnO_2 contact materials. All three DTA curves show one exothermal peak at about 300 °C corresponding to dehydration reaction of Ti-doped SnO_2. Both of the DTA curves acquired from the coated and uncoated Ag–SnO_2 contact materials show another endothermic peak at about 960 °C corresponding to the melting point of Ag. There are two weight loss steps in the TG curves of the Ag–SnO_2 contact materials (Figs. 6 and 7). Both the coated and uncoated Ag–SnO_2 contact materials show weight losses at lower temperature similar to the Ti-doped SnO_2 powders produced by the sol–gel method. It reveals that the weight loss is mainly caused by dehydration of the Ti-doped SnO_2 at a low temperature. Another weight loss of the Ag–SnO_2 contact materials occurs at a higher temperature. This is induced by evaporation of Ag. The weight losses from the coated Ag–SnO_2 contact materials are 0.5% at the low temperature and 0.3% at the high temperature. They are much less than those of the uncoated ones due to Ag deposition. Furthermore, the higher bonding strength between the Ag matrix and Ag-coated SnO_2 particles helps to reduce evaporation of Ag at higher temperature.

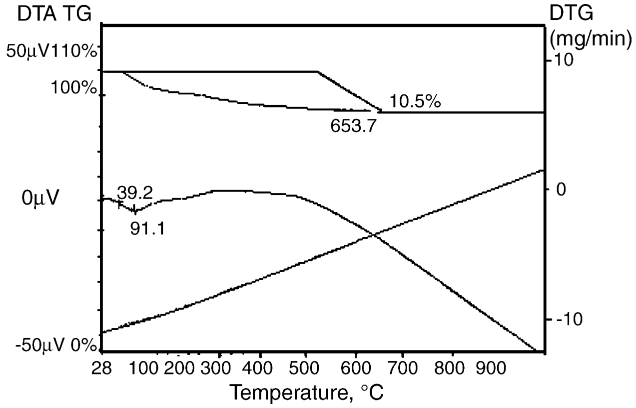

Fig. 5. DTA–TG curve of nano Ti-doped SnO_2 powders.

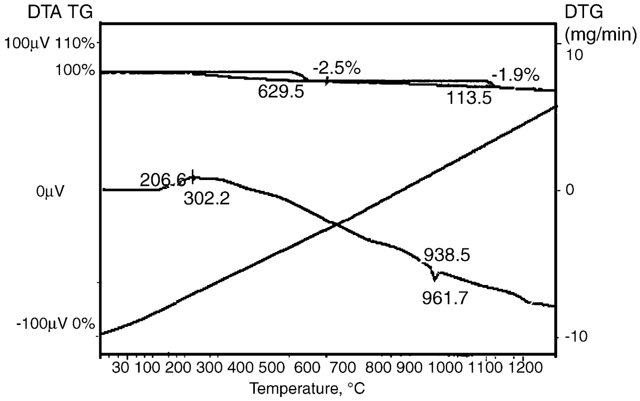

Fig. 6. DTA–TG curve of uncoated Ag–SnO_2 contact materials.

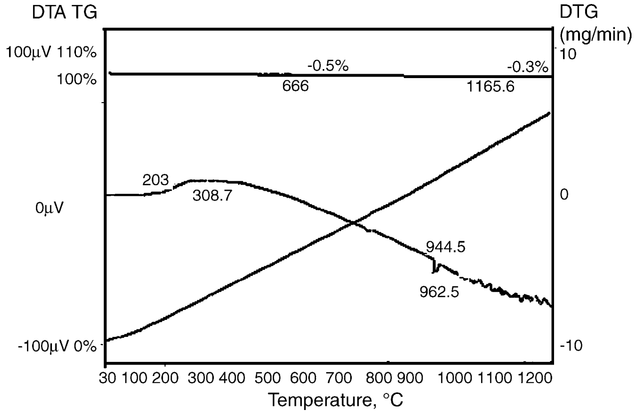

Fig. 7. DTA–TG curve of coated Ag–SnO_2 contact materials.

4. Conclusion

Nano Ti-doped powders have been successfully coated with Ag by using the chemical plating process. Our results indicate that the Ag-coated particles are uniformly distributed in the Ag matrix and the coating process can improve the wettability between the Ti-doped SnO_2 particles and Ag matrix. The coating process can enhance the physical properties such as the density and hardness as well as the electrical conductivity of the $AgSnO_2$ contact materials. The DTA–TG analysis shows that the weight loss of $AgSnO_2$ at higher temperature decreases significantly after the nano Ti-doped SnO_2 particles are coated with Ag. It suggests that the coating process can improve the thermal stability at higher temperature.

Acknowledgements

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