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ARTICLE

Physical and Electrical Contact Properties of Ag-SnO$_2$ Contact Materials Doped with Different Particle Size Additives

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Abstract: Ag-SnO$_2$ contact materials were prepared by powder metallurgy technology. Bi$_2$O$_3$, TiO$_2$ and CeO$_2$ were chosen as additives, and four kinds of particle sizes were selected. Meanwhile, the proportion of additives was selected through wetting ability tests. The physical and electrical contact properties of Ag-SnO$_2$ contact materials doped with additives of different kinds and particle sizes were studied. The results show that the influence of particle sizes of three additives (Bi$_2$O$_3$, TiO$_2$ and CeO$_2$) on the properties of Ag-SnO$_2$ contact materials is consistent. With the decrease of additive particle size, the physical and electrical contact properties of Ag-SnO$_2$ contact materials are improved, and the optimal particle size of additive is 200 nm.

Key words: Ag-SnO$_2$ contact materials; wetting ability; additive particle size; physical properties; contact resistance

Ag-SnO$_2$ materials are usually used in low-voltage switching and power relay because of their remarkable resistance to arc erosion and welding[1-5]. In order to fully understand the properties of Ag-SnO$_2$ contact materials, many experiments and researches on electrical contact performances have been done. The main disadvantages of Ag-SnO$_2$ contact materials are poor over-temperature behavior and poor plasticity, which restricts their commercial production and application[6-8]. Therefore, many attempts have been done to improve the properties of Ag-SnO$_2$ contact materials.

The properties of Ag-SnO$_2$ contact materials are related to a lot of factors, such as particle size, morphology and distribution of SnO$_2$ particles. Zhang et al[9] explored the arc erosion behaviors of Ag-SnO$_2$ contact materials prepared with SnO$_2$ of different particle sizes. The results indicate that fine SnO$_2$ particle size is beneficial to increasing the density and hardness of Ag-SnO$_2$ contact materials, but to decreasing conductivity.

Wen et al[10] explored the influence of particle size on double metal properties of tungsten and molybdenum. The results show that the particle size of tungsten powder directly affects the combination of two metal samples.

Zhang[11] et al explored the influence of metal oxides particle size on the properties of Ag-*Me*O contact materials. The results show that particle sizes of metal oxides have great influences on the properties of Ag-*Me*O contact materials.

These studies suggest that particle size has an effect on the properties of materials, and it is necessary to investigate optimum particle size of additive. However, it is found that there are few studies about the effects of additive particle sizes on Ag-SnO$_2$ contact materials after consulting relevant studies. Therefore, it is necessary to study the influence of additive particle size on Ag-SnO$_2$ contact materials.

1 Experiment

1.1 Wetting ability experiment

A sessile drop method was used to measure the wetting angle between Ag and SnO$_2$ with additives of different kinds and ratios, and the proportion of additives were 1.0%, 1.5%, 2.0%, 2.5% and 3.0%[12,13]. And the proportion of additives

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was selected through wettability test.

1.2 Materials preparation

Bi_2O_3, TiO_2 and CeO_2 were selected as the additive of Ag-SnO_2 contact materials, and in order to fully explain the effects of additive particle sizes on the properties of Ag-SnO_2 contact materials, 200 nm, 500 nm, 1 μm and 10 μm were chosen as the particle sizes of additive.

Ag-SnO_2 contact materials were prepared by powder metallurgy technology[14]. The manufacturing process of Ag-SnO_2 contact materials is shown in Fig.1.

The Ag, SnO_2 and additive powders were dried at 120 °C under 0.08 MPa for 30 min in a vacuum drying oven. Then the powders were mixed in a Simoloyer mill for 2 h, while keeping rotational speed 500 r/min for 5 min and opposite rotational speed 600 r/min for 8 min. The powders were compacted under the pressure of 38 MPa for 5 min and sintered at 500 °C for 90 min, then repressed under the pressure of 58 MPa for 5 min and resintered at 800 °C for 90 min. Finally, the contact materials sheet was cut into a contact terminal of diameter of 4.5 mm, and thickness of 3.5 mm.

1.3 Physical property experiment

Archimedes principle was employed to measure the density of Ag-SnO_2 contact materials[15]. HXD-1000TM microscope hardness tester was used to measure the hardness of Ag-SnO_2 contact materials. Conductivity of Ag-SnO_2 contact materials was measured using SIGMASCOPE SMP10 Conductivity tester.

1.4 Electrical contact property experiment

The electrical contact properties of Ag-SnO_2 materials were tested using the JF04C electric contact materials tester, when the current parameter was set to DC 13 A, and the voltage parameter was set to DC 24 V. The instrument must be adjusted before a new round of electrical properties test, and the system protection voltage was set to ±40 V. The contact pressure was set to 86 cN, and the number of operation was 25 000. The contact resistance was measured after each 100 times normal make-and-break operation.

2 Results and Discussion

2.1 Wetting angle test

The wetting angle between Ag and SnO_2 with additives of different kinds and ratios is shown in Fig.2.

As is shown in Fig.2, when the proportion of Bi_2O_3 is 1.5%,

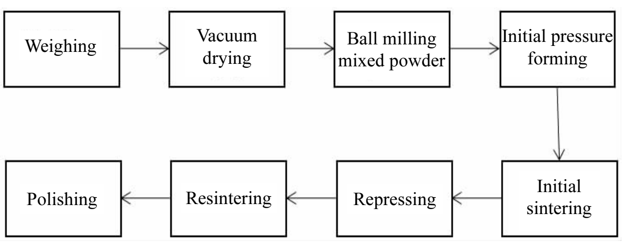

Fig.1 Manufacturing process of contact materials

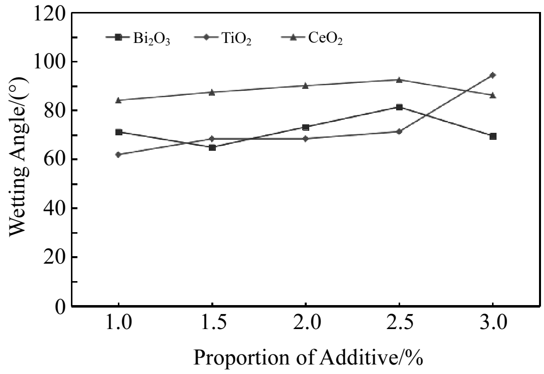

Fig.2 Wetting angle between Ag and SnO_2

the proportion of TiO_2 is 1.0% and the proportion of CeO_2 is 1.0%, the wetting angle is the minimum, and the contact material exhibits the best wettability. Young's equation has proved that the smaller the wetting angle is, the better the materials wetting ability. The better wettability implies the better properties of Ag-SnO_2 contact materials to some extent[4,16]. From above analysis, the proportions of additive are shown in Table 1.

2.2 Physical properties analysis

The physical properties of Ag-SnO_2 contact materials doped with additives of different kinds and particle sizes are shown in Table 2, 3 and 4.

Table 2, 3 and 4 show that with the decrease of additive particle size, the physical properties of the Ag-SnO_2 contact materials have been improved, and the influence of particle size of three additives (Bi_2O_3,TiO_2 and CeO_2) on the properties of Ag-SnO_2 contact materials is consistent. Meanwhile, the optimum additive particle size is 200 nm. When the particle size of Bi_2O_3, TiO_2 and CeO_2 is 200 nm, Ag-SnO_2

Table 1 Composition and proportion of Ag-SnO_2 contact materials

Composition	Proportion
Ag:SnO_2:Bi_2O_3	88:10.5:1.5
Ag:SnO_2:TiO_2	88:11:1
Ag:SnO_2:CeO_2	88:11:1

Table 2 Physical properties of Ag-SnO_2/Bi_2O_3 contact materials

Bi_2O_3 particle size/nm	Density/ $g \cdot cm^{-3}$	Hardness, HV/ ×10 MPa	Conductivity/ %IACS
200	9.371	76.486	63.687
500	9.035	72.418	60.360
1000	9.061	71.445	61.697
10000	8.982	69.912	59.453

Table 3 Physical properties of Ag-SnO_2/TiO_2 contact materials

TiO_2 particle size/nm	Density/ $g \cdot cm^{-3}$	Hardness, HV/ ×10 MPa	Conductivity/ %IACS
200	9.233	89.623	60.053
500	9.078	81.028	55.370
1000	9.030	79.580	53.773
10000	8.891	75.687	53.027

Table 4 Physical properties of Ag-SnO_2/CeO_2 contact materials

CeO_2 particle sizes/nm	Density/ $g \cdot cm^{-3}$	Hardness, HV/ ×10 MPa	Conductivity/ %IACS
200	9.285	82.098	60.907
500	9.160	74.467	58.143
1000	9.130	68.633	54.977
10000	8.931	65.596	53.583

contact materials exhibit the best physical properties. This is because fine additive particles increase the contact area between Ag matrix and SnO_2 particles, thus promoting the formation and growth of sintering necks. Moreover, the main densification mechanism of powder metallurgy materials is diffusion mechanism, and the driving force of the diffusion is derived from the surface energy of particles. With the decrease of additive particle size, the surface energy of additive increases; therefore, fine additive has larger surface energy, which is beneficial for sintering, giving rise to more densification of Ag-SnO_2 contact materials. Meanwhile, fine additive particle is beneficial for the decrease of porosity, and the density of Ag-SnO_2 contact materials is also affected by the elimination of pore structure, vacancies and other defects in the sintering process. These factors lead to the increase of the density.

The electric resistance of the pores is very large, and the conductivity increases by decreasing porosity to some extent. In addition, the increase of conductivity is also attributed to a high density, microstructure homogenization and few structure defects of Ag-SnO_2 contact materials doped with fine additive particles.

The increase of hardness can be derived from the different strengthening effects of additive particle sizes. According to the Hall-Petch equation[17], the hardness of Ag-SnO_2 contact materials increases with the decrease of additive particle sizes. In addition, the degree of densification increases, which also increases the hardness of Ag-SnO_2 contact materials.

2.3 Contact resistance analysis

The contact resistance of Ag-SnO_2 contact materials doped with Bi_2O_3 of different particle sizes is shown in Fig.3 and their variation range of contact resistance, average contact resistance and variance are shown in Table 5.

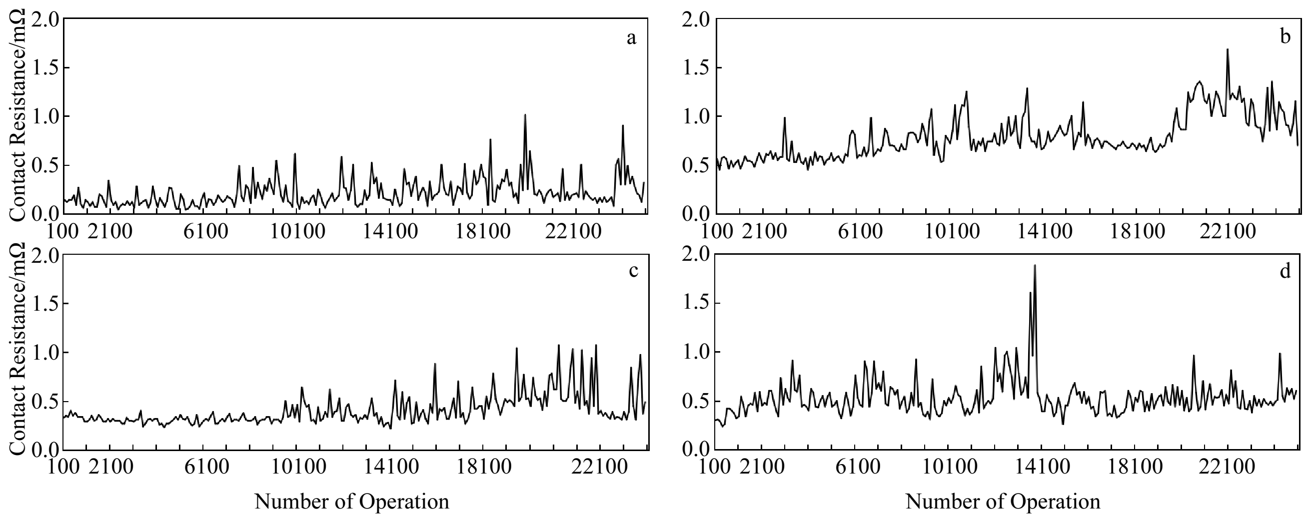

Fig.3 Contact resistance of Ag-SnO_2 contact materials doped with Bi_2O_3 of different particle sizes: (a) 200 nm, (b) 500 nm, (c) 1 μm, and (d) 10 μm

The contact resistance of Ag-SnO_2 contact materials doped with TiO_2 of different particle sizes is shown in Fig.4 and their variation range of contact resistance, average contact resistance and variance are shown in Table 6.

The contact resistance of Ag-SnO_2 contact materials doped with CeO_2 of different particle sizes is shown in Fig.5 and their variation range of contact resistance, average contact resistance and variance are shown in Table 7.

Table 5 Contact resistance of Ag-SnO_2/Bi_2O_3 contact materials

Bi_2O_3 particle size/nm	Contact resistance variation range/mΩ	Average contact resistance/mΩ	Variance/ $\times 10^{-3}$
200	0.04~1.01	0.21	20.4
500	0.45~1.69	0.79	48.4
1000	0.22~1.07	0.84	25.8
10000	0.24~1.88	0.85	33.8

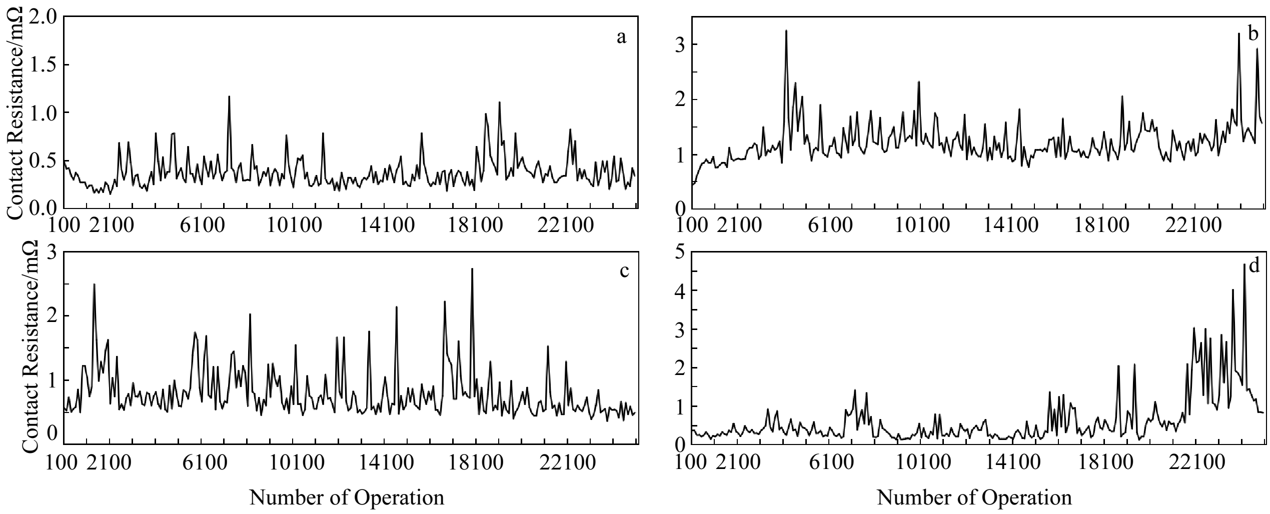

Fig.4 Contact resistance of Ag-SnO_2 contact materials doped with TiO_2 of different particle sizes: (a) 200 nm, (b) 500 nm, (c) 1 μm, and (d) 10 μm

Table 6 Contact resistance of Ag-SnO_2/TiO_2 contact materials

TiO_2 particle size/nm	Contact resistance variation range/mΩ	Average contact resistance/mΩ	Variance/ $\times10^{-3}$
200	0.37~1.16	0.37	24.3
500	0.3~1.8	0.65	62.2
1000	0.18~2.08	0.62	116.7
10000	0.36~4.23	0.81	251.1

The average contact resistance of Ag-SnO_2 contact materials doped with different kinds and particle sizes additive is shown in Fig.6.

Table 5, 6, 7, and Fig.6 show that with the decrease of additive particle size, contact resistance decreases gradually, and the influence of particle size of three additives (Bi_2O_3, TiO_2 and CeO_2) on the properties of Ag-SnO_2 contact materials is consistent. When the particle size of the additive is 200 nm, the contact resistance value, the range of changing and variance are all the minimum. Therefore, the contact resistance is small and stable, which is beneficial for reducing thermal load and improving electrical contact endurance. Moreover, the optimum particle size is consistent with the optimum particle size obtained by physical property tests. On

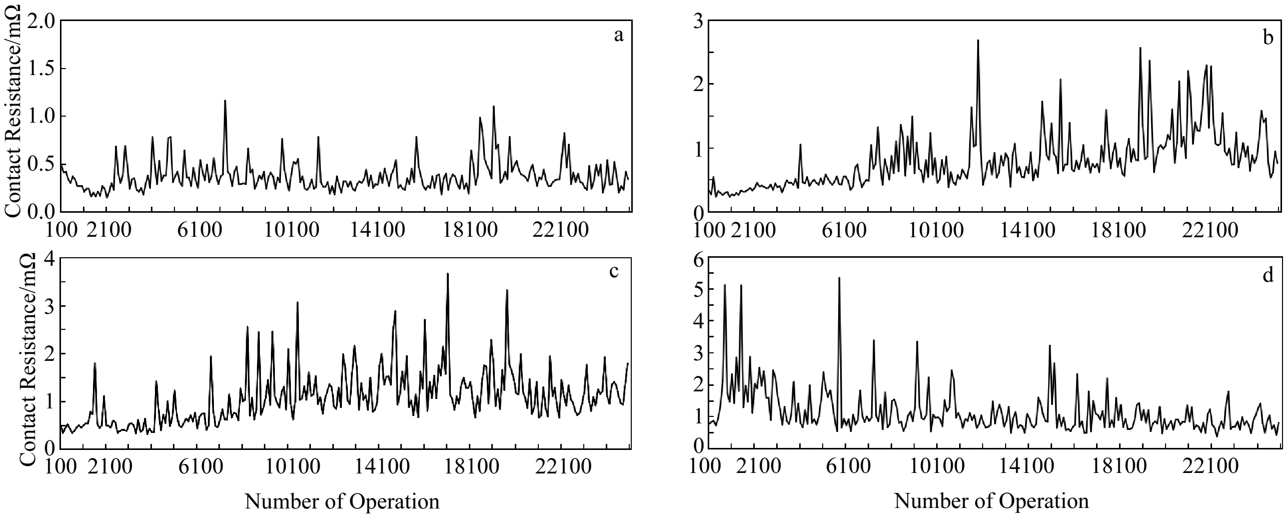

Fig.5 Contact resistance of Ag-SnO_2 contact materials doped with CeO_2 of different particle sizes: (a) 200 nm, (b) 500 nm, (c) 1 μm, and (d) 10 μm

Table 7 Contact resistance of Ag-SnO_2/CeO_2 contact materials

CeO_2 particle size/nm	Contact resistance variation range/mΩ	Average contact resistance/mΩ	Variance/ $\times10^{-3}$
200	0.15~1.16	0.37	24.3
500	0.21~6.44	0.97	1155.2
1000	0.31~3.66	1.07	309.2
10000	0.38~5.34	1.14	500.09

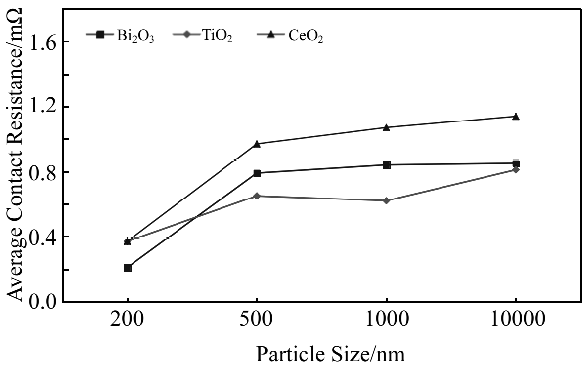

Fig.6 Average contact resistance of Ag-SnO_2 contact materials

the one hand, fine additive can improve the wettability between Ag matrix and SnO_2 particle, and the variation tendency of wetting angle and contact resistance are basically identical[18]. On the other hand, it can be ascribed to the combined effect of the densification and interface morphology, and the interface morphology may play a more significant role, thus decreasing contact resistance for Ag-SnO_2 contact materials doped with fine additive. Therefore, contact resistance decreases with the decrease of additive particle size.

3 Conclusions

1) Additive particle sizes really have an influence on the physical properties and electrical contact properties of Ag-SnO_2 contact materials, and the influence of particle size of three additives (Bi_2O_3, TiO_2 and CeO_2) on the properties of Ag-SnO_2 contact materials is consistent. Moreover, the properties of Ag-SnO_2 contact materials can be improved by selecting the optimal additive particle size.

2) Fine additive particle is beneficial to the improvement of the properties of Ag-SnO_2 contact materials. With the decrease of additive particle size, the physical and electrical contact properties of Ag-SnO_2 contact materials are improved, and the optimal particle size of additive is 200 nm.

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掺杂不同粒度添加剂的 Ag-SnO_2 触头材料的物理性能和电接触特性

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摘 要：通过粉末冶金法制备了 Ag-SnO_2 触头材料。选择 Bi_2O_3、TiO_2 和 CeO_2 为添加剂，每种添加剂选取 4 种粒度，添加剂的比例通过润湿性试验获得。对掺杂不同种类不同粒度的 Ag-SnO_2 触头材料的物理和电接触性能进行了研究。结果表明，3 种添加剂（Bi_2O_3、TiO_2 和 CeO_2）的粒度对触头材料性能的影响趋势是一致的，随着添加剂粒度的减小，Ag-SnO_2 触头材料的物理和电接触性能都得到了提高，并且添加剂的最佳粒径为 200 nm。

关键词：Ag-SnO_2 触头材料；润湿性；添加剂粒度；物理特性；接触电阻

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