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ARTICLE

Microstructure and Properties of Ag-SnO_2 Coating Fabricated by Plasma Spraying

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Abstract: Ag-SnO_2 coating on copper substrate has been prepared by an atmospheric plasma spraying method using high energy ball milled Ag-12wt%SnO_2 composite powder as raw material. The microstructures of the Ag-SnO_2 coating were characterized by XRD and SEM. The mechanical properties and arc erosion performance of the as sprayed coating have been determined by tensile test, microhardness and arc erosion tests, respectively. The results show that the Ag-SnO_2 coating presents a compact microstructure, and the nanosized SnO_2 particles are uniformly dispersed in the Ag matrix of the coating. The mechanical properties and the arc erosion performance of the Ag-SnO_2 coating are close to those of Ag-SnO_2 bulk. After arcing test, the surface of the coating presents the dispersion of cathode spots and a little erosion, indicating that the Ag-SnO_2 coating has excellent arc-erosion resistance. Plasma spray technique is an effective approach to manufacture Ag-SnO_2 contact coating with good mechanical properties and arc erosion resistance.

Key words: plasma spraying; Ag-SnO_2; contact material; arc erosion

The Ag-SnO_2 contact material has shown a promising prospect in applications of low-voltage switches because of its remarkable resistance to arc-erosion and welding during arcing test and friendly environmental characteristic [1,2].

Two traditional commercial methods preparing Ag-SnO_2 contact alloys include:[3,4] the internal oxidation technology (IO) of a silver-tin alloy; powder metallurgy approach (PM), and the Ag-SnO_2 composite powders can be prepared by high-energy ball milling [5], chemical plating [6], reactive synthesis [7], reactive milling [8] and hydrothermal method [9]. However, the internal oxidation of Ag-Sn alloys can result in oxide-rich layers on the surface and an oxide-free zone in the center of alloys [2]. The powder metallurgy route includes pressing, sintering and extrusion, but it has some difficulty because of the brittleness of Ag-SnO_2 materials, which results in the repeating press working and annealing during manufacture process [10,11].

Plasma spraying is a versatile method which can be used to deposit powders as dense, adherent and homogeneous coatings with low porosity. A dispersion of hard and brittle phases in a ductile matrix has been achieved by co-deposition of powder mixtures, and a suitable distribution of reinforcement phase can be obtained by plasma spraying under optimized processing parameters [12,13].

In the present paper, Ag-SnO_2 coating on the Cu substrate was prepared by atmospheric plasma spraying, and the phase structure, the microstructure, the mechanical properties and the arc erosion performance of Ag-SnO_2 coating have been studied further.

1 Experiment

SnO_2 nanopowder with an average particle size of 30~50 nm was synthesized by the chemical co-precipitation method [14]. And then, Ag powder (99.9% purity) with an average particle size less than 70 μm and SnO_2 nanopowder (12 wt%) were mixed uniformly for 2 h in a high-energy

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ball mill (QM-3A) using stainless steel ball, the rotation speed was 1200 r/min and the weight ratio of ball to mixed powder was 10:1. The concept of Ag-SnO_2 feedstock design in the present study is schematically shown in Fig.1.

The HEPJ-100 atmospheric plasma spraying equipment with PQ-1S plasma gun was applied to prepare Ag-SnO_2 coating. During spraying, the substrate and the coating were cooled by compressed air. Before spraying, the pure copper substrates were cleaned by acetone solution and sandblasted by corundum, and the prepared feedstock powder suffered sieving and drying. The thickness of the prepared coating was about 600 μm. The spraying parameters are shown in Table 1. For comparison, Ag-SnO_2 bulk material was prepared by hot-pressing-sintering using the same ball-milled powder. The ball-milled mixture was pressed into green compact under a pressure of 100 MPa for 1min, and further hot-pressing sintered in an electric resistance furnace at a pressure of 200 MPa for 2 h [15].

The phase compositions of the powder and the as-sprayed coating were analyzed by the X-ray diffraction (XRD, Shimadzu 7000), using Cu Kα radiation (λ=0.154 18 nm). The 2θ scan range was 15°~80°, with a step size of 0.02° and a resolution of 0.01°. The morphologies of the coating were investigated by scanning electron microscope (SEM, JEOL JSM-6700F).

The bonding strength of the coating with Cu substrate was evaluated by tensile test (SANS-CMT5000) according to the ASTM C 633-79. Five measurements were performed to determine the average bonding strength of the coating. The microhardness was determined on the polished surface of the coating at room temperature using a Vickers microhardness tester (MH-3, Light-Mach Ltd, Shanghai, China) under a load of 200 g for 10 s. The average of 10 tests was used as an indicator of the coatings hardness.

A self-designed experimental apparatus was used for the arc erosion test [15-17]. The Φ10 mm coating and bulk samples were fixed into brass holders for 500 times discharging operation. The arc current and the arcing time were recorded by Tektronics TDS-2024B (200MHz) digital memory oscilloscope. After discharging operation, the samples were weighed by ES-180J Photovoltaic Analysis Balance (the resolution is 0.1 mg) to measure the mass loss and the surface of sample was examined by SEM. The arc erosion rate of coating could be calculated as follows:

$$V = \frac{\Delta m}{Q} \quad (1)$$

where V is the arc erosion rate of coating, μg/C, Δm is the mass loss of coating before and after arcing, μg, and Q is the total discharge quantity during acing test, C.

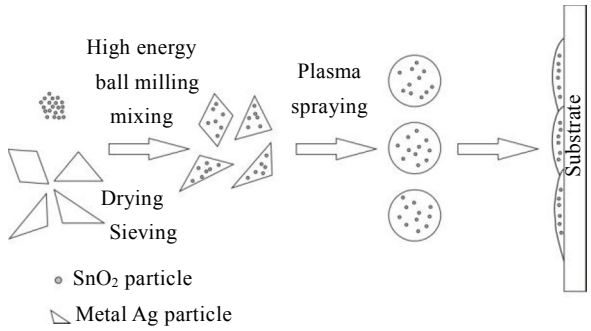

Fig.1 Schematic diagram showing the concept of spraying powder design of Ag-SnO_2 coating

2 Results and Discussion

2.1 Characterization of spraying powder

Fig.2 shows the surface morphologies of the spraying powder. It can be observed that the Ag particles with irregular and angular morphology uniformly embed SnO_2 nanoparticles, as shown in Fig.2b and 2c. During the high-energy ball milling, the hard and brittle SnO_2 nanoparticles are embedded into the high plastic Ag, which is attributed to the enormous energy of high-energy ball milling.

2.2 Characterization of the coating

Fig.3 presents the XRD patterns of Ag-SnO_2 powder and the prepared coating. It can be found that there is no obvious change of the phase structure of Ag-SnO_2 before and after plasma spraying, which consist of Ag and SnO_2 phases.

The cross-sectional micrograph of as sprayed Ag-SnO_2 coating is shown in Fig.4. It is illustrated that the interface between the coating and the substrate has no crack and porosity, which manifests that the bonding between the coating and the substrate is very tight. Fig.5 shows the cross-section SEM backscattered electron images of Ag-SnO_2 coating. In Fig.5a, it can be observed that the coating has the typical splat-like morphology of the thermally sprayed coating, and there are few pores in the coating, indicating that the coating has high relative density. Fig.5b shows the magnified area in the frame of Fig.5a. In this area, SnO_2 particles are distributed in the silver matrix homogeneously with an average particle size less than 100 nm.

Table 1 Plasma spray parameters of Ag-SnO_2 coating preparation

Current/A	Voltage/V	Primary gas (Ar) flow rate/L·min^{-1}	Secondary gas (H_2) flow rate/L·min^{-1}	Carrier gas (Ar) flow rate/L·min^{-1}	Powder feed rate/g·min^{-1}	Spraying distance/mm
330	95	95	10	4	25	100