The Effect of Magnetic Field on Conductive Films

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Summary: Conductive paints consisting of nickel powder (conductive material), solvent, and binder polymer were treated in a magnetic field. The efficiency of magnetic treatments on conductivity of coating films was evaluated. The effect of the following factors on conductivity of composite films by magnetic treatment was studied: metal powder concentration, magnetic flow density, time difference between film preparation and magnetic treatment, drying time of paint films, and effect of distance between terminals. Results showed that the volume resistivity of paint films treated magnetically was lower than that for untreated films at each nickel content. Magnetic treatment provided high conductivity even at low magnetic flow density, and conductivity increased with magnetic flow density.

Introduction

The electronic industry requires conductive coating films as essential electronic materials because of their simple processing. They are widely used for electric circuit production and electromagnetic field insulation. The latest development in conductive coating films has been directed to better performance and other properties of these films[1)]. It is important to find out new preparations of conductive coating paints and films for reaching the objectives of high performance and to meet a versatility of functions. Originally, conductive films had as a main function the conduction of current only. But now the better understanding of the mechanism of electric current flow and its new functions needs wide endowment of research[2)].

Conductive films are mixtures consisting of three major components namely metal powders, binder polymers, and solvent. At present, conductive paint types may be listed as dry forming, low temperature curing and high temperature burning types. In this paper a possibility of improvement of the conductivity of paint films was investigated via a magnetic treatment of the coatings consisting of metal powder, binder polymer, and a solvent

Experimental procedure

Preparation of coatings and conductive films

The coating films were prepared from a blend consisting of conductive particles – nickel

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powder (flake shape, BET surface value 0,42m^2/g; thickness 1,0 – 1,1 μm; particle size distribution 4,5 – 6,5 μm = 53%; 4,5 – 7,5 μm = 77%; purchased from Fukuda Metal Powder Ltd.), binder polymer (polystyrene Mw 100 000, Sp value 9,10; polymethylmetacrylate Mw 100 000, Sp value 9,25) and solvent (methylethylketone, Sp value 9,3). The paints with various weight concentration of metal powder were prepared by dispersing the powders with a disperser, rotating at 3000 rpm for 10 min in binder polymer solution. The air from mixture after blending was evacuated by water vacuum equipment. Then, polymer blend was poured onto a glass plate covered with PET foil and thickness of film 50 μm was achieved by using an applicator. It is important to maintain the temperature at about 30 °C during mixing to prevent of evaporation of solvent.

The magnetic treatment was applied immediately after film processing, before evaporation of solvent. The magnet was moving under the film in upright direction by speed of 0.1 m/s. Permanent magnets of various magnetic flux density (282G; 2420G and 4500G) were used. Evaporation of solvent and film drying after magnetic treatment was done at room temperature.

Measurements

The surface electrical resistivity was measured with digital multimeter AX 5645 (ADEX Corp.) and TR 6861 (Advantest Co.Ltd.) equipped with 1 cm^2 cross-section electrodes spaced 1 cm apart in dry air at 20 °C. The volume resistivity R_v was calculated from the following equation[3)]:

$$R_v = t\,R_s$$

where t is thickness of the paint film and R_s is the surface resistivity.

Results and Discussion

The conductive properties of prepared coating films were evaluated by measurement of volume resistivity. Samples were cut in parallel or vertical direction to magnetic treatment. It is very important to understand the conductive behavior of paint film as a function of factors, which affect their conductivity. Therefore the effect of following factors on conductivity of composite films after magnetic treatment was investigated: metal powder concentration, magnetic flow density, time difference between film preparation and magnetic treatment, drying time of paint films, and effect of distance between terminals.

Metal powder concentration: This is a very important factor, because the probability of creation of conductive compound chains is determined by the amount of particles. In Fig. 1 the relationship is shown between volume resistivity and Ni powder content in magnetically untreated and treated conductive films. Measurement was done after 24 hours drying. Volume resistivity was evaluated by conductive films with content of metal powder from 20 wt % to 90 wt %. The conductivity of paint increases with metal powder content. At a certain content conductivity peak was followed by a sudden decrease[4-5]. Magnetically untreated film showed the lowest volume resistivity at content nearly 80 wt % of nickel powder. With increasing content of metal powder an increase in resistivity was observed. This means that an optimum filler concentration exists considering the high conductivity of the composite[6].

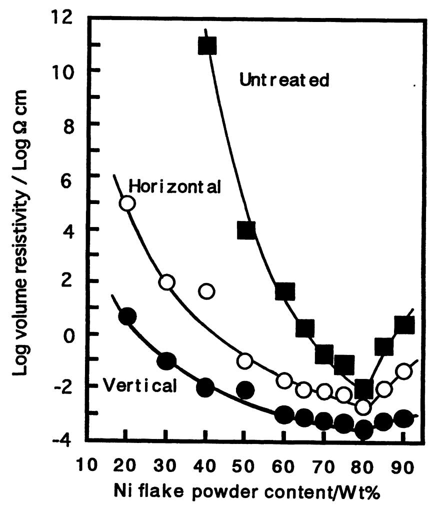

Fig. 1. Relationship between volume resistivity and Ni flake powder content in the magnetic untreated and treated conductive films. Coating system: polystyrene 3 g; Ni powder (various); MEK 12 ml; magnet 2420 G.

When the content of metal powder decreases below certain level, the coating film changes to an insulator. For magnetically untreated samples the threshold was found to be around 40 wt.% of the conductive powder. In materials containing about 40 – 50 wt.% of the filler, conductive metal paths are formed resulting in a conductivity of coating film. For magnetically treated composites the threshold is substantially lower and we found conductivity of coating films with amount of nickel powder content as low as 20 wt %. The conductivity of untreated coating film with content of metal powder of 80 wt. % is the same as that of magnetically treated film with content of nickel of 40 wt. %. Thus, the treatment results in a formation of more flexible conductive films and also to savings of the expensive conductive metal powder.

Different values of volume resistivity, measured by samples cut in horizontal and in vertical directions to the direction of magnetic treatment, are caused by different orientation of metal particles, depending on direction of magnetic treatment.

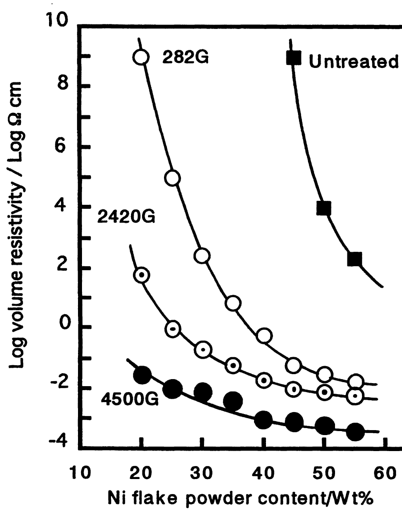

Fig. 2. Effect of magnetic flow density on relationship between volume resistivity and Ni powder content in conductive films. Coating system: polystyrene 3 g; Ni powder (various); MEK 12 ml; magnet (various).

Magnetic flow density: In the subsequent experiment, the effect of magnetic flow density in range 282 – 4500 G on conductivity was evaluated. In Fig. 2 the effect of magnetic flow density is shown in dependence on volume resistivity and Ni powder content in conductive films. The effect of magnetic flow density on conductivity is very high at low content of metal powder. The conductivity of magnetic treated film at 4500G containing 20 wt.% of metal powder is the same as that of treated film at 282 G with content of nickel of 50 wt.%. This fact is very interesting because it indicates a possibility to reduce the amount of metal powder in conductive films.

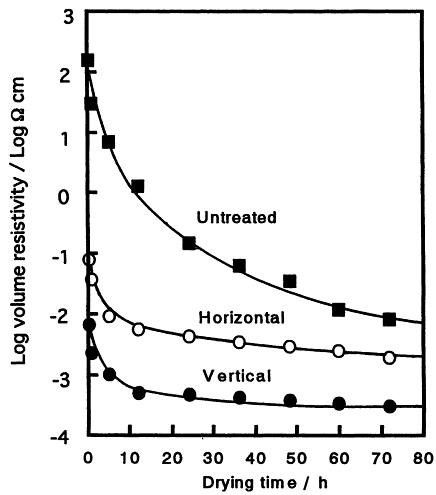

Fig. 3. Effect of magnetic treatment on the relationship between volume resistivity and the drying time of paints. Coating system: polystyrene 3 g; Ni powder 7 g; MEK 10 ml; magnet 4500 G.

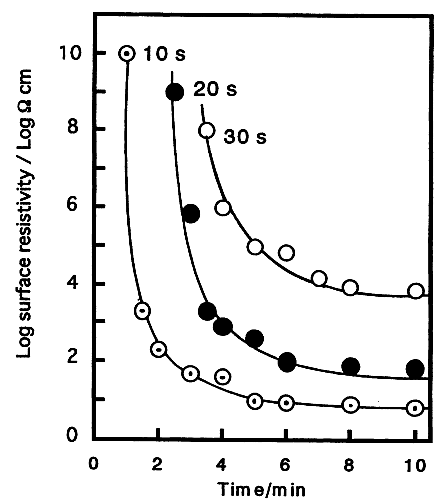

Fig. 4. Effect of time difference between film preparation and magnetic treatment in dependence on time of solvent evaporation. Coating system: polystyrene 3 g; Ni powder 7 g; MEK 12 g; magnet 2420 G

Drying time: The effect of magnetic treatment on the relationship between volume resistivity and drying time is seen in Fig. 3. The volume resistivity of nontreated film did not level off after 60 hours, and was still decreasing. The decrease of volume resistivity is caused by shrinking of the polymer film. On the other hand, the resistivity of magnetically treated films is substantially lower and it levels off after approximately 10 hours of drying. A requirement of shorter time for stabilization of conductivity of coating films after magnetic treatment is explained by structural changes in metal particles distribution in coating film. The improved conductivity is caused by contact between metal particles, which create chains connected together as a result of the orientation of metal particles in magnetic field.

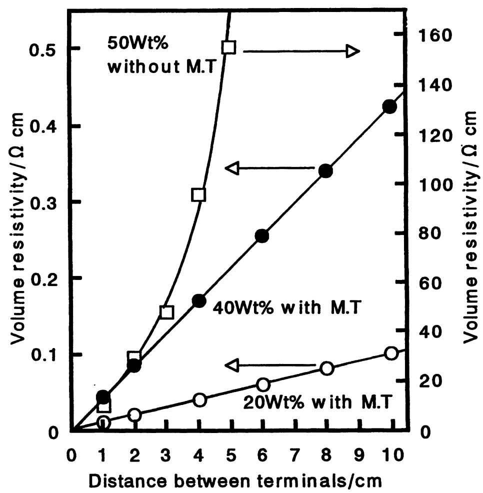

Fig. 5. Effect of distance between terminals on the volume resistivity of magnetic treated (M.T) and untreated conductive films with 20 wt.% and 40 wt.% of Ni powder. Magnet 4500 G.

Effect of time difference between film preparation and magnetic treatment: The effect of magnetic treatment on improvement of conductivity is also a function of coating dispersion viscosity, which depends on time of storing between film preparation and magnetic treatment. The effect of time of storing is shown in Fig. 4. The total efficiency of treatment is influenced by an increase of viscosity after solvent evaporation, if magnetic treatment was done after more complete solvent removal. Orientation of metal particles in the magnetic field becomes more difficult to achieve because of high viscosity of polymer binder and the efficiency of the process is sufficiently lower (Fig. 4).

Effect of distance between terminals: The value of volume resistivity of conductive films in dependence to a distance between terminals (resistivity measurement points at the surface of sample) demonstrate the formation of conductive surface of composite film at low content of conductive material. Magnetically treated films with low content of metal powder have higher conductivity in comparison with nontreated film containing 50 wt. % of metal powder. Untreated film lost conductivity as a function of distance between terminals very quickly unlike the treated film, whose conductivity grew linearly with a decreasing distance (Fig. 5). This demonstrates a basic change in conductive properties of composite films, due to metal particle orientation and creation of short metal particle chains resulting from magnetic field treatment.

Conclusion

For improving the conductivity of paint films, the coatings consisting of nickel flake powder, solvent and polymer binder have been treated magnetically. The volume resistivity of paint films treated magnetically was lower than that for untreated films containing the same content of nickel powder at any filler concentration. The increase of conductivity of paint films due to magnetic treatment is explained by the shortening of contact distance between particles. Magnetic treatment provides high conductivity even at low magnetic flow density and conductivity increases with magnetic flow density. After a proper treatment a conductive film can be produced with the metal powder content as low as 20%.

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