A highly conductive thermoplastic electrically conductive adhesive for flexible and low cost electronics

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***Abstract*—A commercial thermoplastic screen printing ink is employed as the binder of conductive adhesive (ECA). The electrically resistivity of 3.6 × 10^{-5} Ω·cm is observed at 80 wt% silver loading. The printed circuit based with the ECA is foldable because of the thermoplastic nature of the binder, and it is sufficiently reliable for the practical application. The lap shear test indicates the shear strength of the ECA is 12.5 MPa. Due to the excellent mechanical property and the processability of the resin binder, this formulation is especially advantageous in the application of flexible electronics applications with the features of low cost and convenience for fabrication.**

Keywords—printed electronics; flexible electronics; conductive adhesive

I. Introduction

The conventional patterning technology of conductive circuits is by photolithography. This method usually involves a series of processing steps including metal deposition, photo-resist coating, UV curing, etching, and cleaning etc., which is time consuming and expensive [1]. Therefore, some alternative methods have been proposed including writing [2, 3], ink-jet printing [4, 5] and screen printing conductive ink [6]. The employment of conductive ink to fabricate conductive tracks usually involves metal nanoparticles, which can be sintered at a relatively low temperature. The sintering of nanoparticles substantially reduces the contact resistant so as to obtain a high conductivity [7, 8]. However, the high temperature sintering process may cause reliability issues for the system. To address this problem, electrically conductive adhesive (ECA) can be employed as the materials for printed electronics since it is composed by conductive metal and binder. The binder provide a strong interaction with the substrate to maintain conductance even in the case of bending, folding and scratching, and the processing (curing) temperature for the ECA is relatively low.

Considering the rheological property of ECA, the screen printing is the most suitable one for its patterning because the viscosity of which is relatively high and cost issue. The conventional binders for ECA preparation are usually thermosetting epoxy or polyurethane. As we employ screen printing to fabricate the conductive patterns, it will be interest to investigate the possibility of screen printing ink as the ECA binder. Herein, we systemically investigate the properties of ECA based on commercial ethyl vinyl acetate based ink, including the conductivity, foldability, reliability and the adhesion strength etc. The results indicates that such thermoplastic binder render a low electrical resistivity and a highly flexible character of the ECA. Moreover, a promising reliability and adhesion are also observed. Due to the employment of commercial ink, the ECA can be easily screen printed so that the flexible electronics can be achieved without any further processing.

II. EXPERIMENTAL PROCEDURE

A. Materials

Silver particles were purchased from Chengdu Banknote Printing Complex, China (SF-01C). Commercial screen printing ink was purchased from Zhongshan Zhong-Yi ink & paint co., ltd. (PPVA-100). Silver flakes were pretreated by surface iodination. This process can enhance the conductivity of ECA [9]. Initially, we dispersed the silver flakes in ethanol. Then we modified the surface of silver particles according to literature. The solution was kept stirring for 1 hour at ambient temperature and dried at 60^{o}C for 3 hours. The ECA samples were made by mixing the silver fillers and the screen printing ink in a planetary rotary mixer with 1500 rpm for 5 minutes.

B. Measurements

The electrical resistivity of the ECA was measured by a 4-point probe system (Mitsubishi MCP-T610). The bulk resistance of the ECA in the folding test was recorded by a multimeter (SANWA CD800a, Japan). The reliability test of ECA on papers was carried out by aging the specimen into a chamber (ESPEC SETH-Z-042L). The

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condition in the chamber was maintained at 85°C/85% relative humanity for 1,000 hours. The lap shear strength test was carried out on a MTS Universal Testing Machine (SUNS-6104). Prior to the test, the ECA samples were filled in the gap between two substrates, and the dimension was carefully controlled to be 10×10×0.056 mm^3.

III. RESULTS AND DISCUSSIONS

A. Resistivity of the ECA

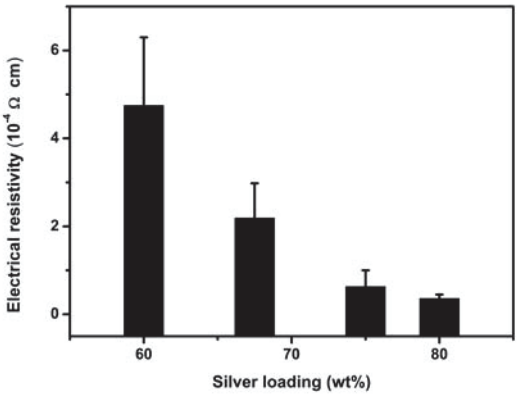

Figure 1 Electrical resistivity of the ECA in various silver loading

The resistivity of the ECA is shown in Figure 1. As can be seen, the increase of silver loading substantially reduces the electrical resistivity of the ECA. Herein, the resistivity is around 4.8 × 10^{-4} Ω·cm in the case of 60 wt% silver loading, and it increases to 2.2 × 10^{-4} Ω·cm with 68 wt% silver loading. With further increasing the silver loading, the electrical resistivity reaches 6.3 × 10^{-5} and 3.6 × 10^{-5} Ω·cm for 75 and 80 wt% silver loading, respectively. Using commercial thermoplastic ink as the binder, the conductivity of ECA may not as high as the one with thermosetting binder [10]. Yet the resistivity at the magnitude of 10^{-5} Ω·cm is a promising value for electronic application due to the prevention of resistive losses [11].

B. Foldability

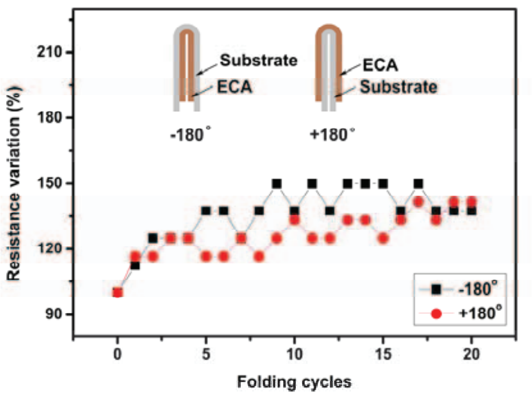

Figure 2 Resistance variation of the ECA (80 wt%) in folding test.

In order to evaluate the foldability, the ECA was printed on a PET substrate and then was folded acutely (-180°) and obtusely (+180°) for 20 cycles, respectively. As shown in Figure 2, the electrical resistance increases when the ECA is being folded. In the case of acutely folding, the resistance increases around 50% after 10 folding cycles, and it maintains stable in following cycles. The case of obtusely exhibits the similar increasing trend. Even though some conductive path in the network may be changed so that the resistance increases, the thermoplastic feature of the commercial binder allows the movement of molecular that prevents the connection of conductive network from being totally broken. As a result, the ECA based on screen printing ink is foldable and it is available to flexible electronics.

C. Reliability and adhesion of ECA

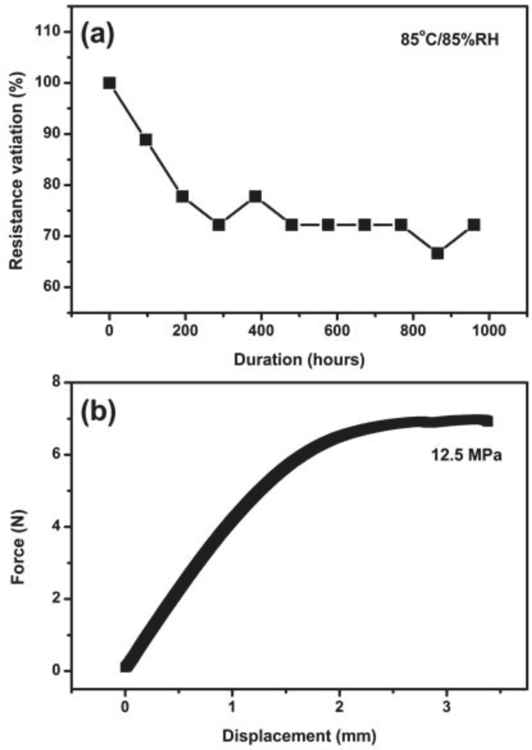

Figure 3 (a) Resistance variation of the ECA in reliability test (85°C/85%RH) for 1000 hours (80 wt%). (b) Lap shear test of the ECA (80 wt%).

In addition to the conductive and foldability, the reliability and adhesion are also important for ECA in the practical applications. The reliability test of the ECA was carried out by placing the sample in a chamber with 85°C/85%RH (relative humidity) for 1000 hours. The resistance variation was recorded by the step of 196 hours. As shown in Figure 3 (a), the electrical resistance shows a decreasing trend in the first 300 hours, and then the resistance variation maintains stable at 70%. The decrease of the resistance may caused by the further evaporation of the solvent, which results in the shrinkage of the binder and the better contact of the silver flakes. After 1000 hours, the conductivity is preserved, indicating that ECA is sufficiently reliable for application. On the other hand, the adhesion of the ECA is evaluated by the lap shear test. Prior to the test, the ECA sample (80 wt%) was filled in the gap between two PET films (40×10×0.05 mm). The size of the ECA is controlled within 30×10×0.056 mm by the tapes. Then two PET films were stretched in the opposite direction until fracturing the ECA. Figure 3 (b) shows the force–displacement relationship. The sample fractures at around 3 mm displacement and the nominal shear strength is 12.5 MPa.

D. Prototype

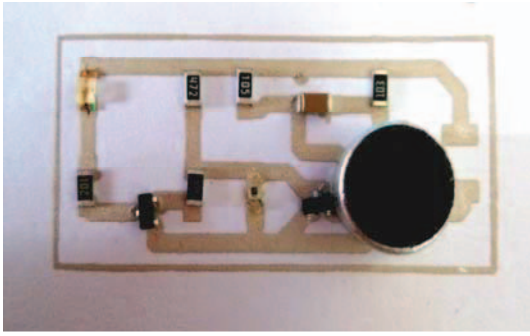

Figure 4 A prototype screen printed with 80 wt% ECA and the electronic components

In order to demonstrate the possible application of the screen printed ECA, we printed a sound sensitive circuit on a regular paper. The optical photograph of the prototype is exhibited in Figure 4. It is clear that the patterning of the conductive plane can be easily achieved by a common screen printing process. The screen printing ink which acts as the binder renders the ECA printable on many substrates such as PET, papers, plastics and so on. Accompanied by the SMT (surface mount technology) of the electronic components, a system can be easily fabricated with flexibility and low cost.

IV. Conclusions

The current work introduces a ECA based on the commercial screen printing ink. The ECA shows the resistivity of 3.6×10^{-5} Ω·cm, corresponding to 80 wt%, and the value increases around 50% after being folded for 20 cycles. This allows its application on flexible electronics. Moreover, the ECA shows sufficient reliability and adhesion for practical application. Using screen printing ECA, the flexible electronics can be easily achieved without any further processing and it is advantageous to minimize the production cost.

Acknowledgment

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