Measurement of sheet resistivity on silver nanoparticles-filled epoxy conductive ink using thermoplastic polyurethane

N.A.S. Mahamad Kamel[1], M.A. Salim[1,2,*] and G.Omar[1,2]

[1)] Faculty of Mechanical Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia
[2)] Centre for Advanced Research on Energy, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia

[*]Corresponding e-mail: azli@utem.edu.my

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ABSTRACT – This paper investigate the measurement of sheet resistivity in silver nanoparticles-filled epoxy conductive ink using thermoplastic polyurethane. Firstly, this study was conducted by formulating the conductive ink samples and then carried by experimental testing. The Jandel's Four-Point probe was used to measure the sheet resistivity of silver nanoparticles-filled epoxy conductive ink. The 60 % of filler loading was chosen accordingly to the resistivity behavior and also the economic criteria. Nevertheless, the microscopy study was added to check the dark spot of the silver nanoparticle-filled epoxy conductive ink.

1. INTRODUCTION

Recently, there is an increased attention given on the development of conductive ink. Conductive ink is printed by using inkjet printing that can conduct electricity. Conductive inks have various applications such as in solar cells, organic light-emitting diodes (OLED), radio-frequency identification (RFID) antennas, and electronic circuits. Traditional production of circuit boards is highly time-consuming and uses too much copper. According to Lee, 2016, the traditional method has technical difficulties when applying in large area and flexible-device manufacturing process. Inkjet printing is an attractive technology for flexible devices manufacturing process. Among all the substrates, polymer has low surface energy and hydrophobic [1-2].

The substrates that is used in this study is thermoplastic polyurethanes (TPU). The TPU is thermoplastic elastomers that have many properties such as flexibility, transparency and low temperature performance. TPU is consist of soft and hard segment, which makes it a very flexible material and can be accustomed to many applications [3]. Soft segment consists of polyester or polyether type while hard segment consists of aromatic or aliphatic.

The difference in electric potential (voltage) throughout the metal in the electric field causes the electron to float towards the positive terminal. From the Ohm's law, the voltage difference across a conductor is corresponding to flow of electric current through a conductor.

The correlation between resistivity and resistance needs to be understood in describing the conductor that can be printed out [3]. Resistance can be defined as measurements for objects which opposed the electric current flow through it. The unit for resistance is ohm. The thin and long wire has more resistance than the thick and short wire. Furthermore, resistivity is the measure of the resistance of electrical conduction for different size and material used. The shape and pattern influence the resistance, while the nature of the material influences the resistivity [3]. The correlation between resistivity and resistance is demonstrated in following equation. The measurement for the ability of substance to transmit or carry electric current is defined as electrical conductivity. The higher conductivity means the lower resistivity.

The aims of this study is to investigate the sheet resistivity of silver nanoparticles-filled epoxy conductive using TPU substrate.

2. RESEARCH METHODOLOGY

This section explains in details the methodology that involves in this study to achieve the research objectives. It includes the formulation preparation and testing process. This section describes how the experimental sample process is obtained.

2.1 Formulation preparation

The first phase for the process was selected the material and the apparatus for the experimental works. Materials used in this study are silver nanoparticles as a filler, epoxy as the binder, and finally hardener as the solvent.

The apparatus was used in this experiment are beaker, glass rod, measuring balance, spoon, glove, mask, blade, thermoplastic polyurethane and scotch tapes. Then all materials were measured by using measuring balancer according to the value recorded in Table 2.1. The total mass of silver nanoparticles is 2 g and the percentage of filler is 60 %.

Table 2.1 Composition of Ink Loading

Filler		Binder		Hardener (30%from binder) (g)	Total (g)
(%)	(g)	(%)	(g)		
60	1.2	40	0.8	0.24	2

The second phase was cured and printed processes. All materials were mixed slowly into a beaker and stirred by using glass rod until the filler were completely dissolved around 10 minutes. Then, the mixture was printed by using manual deposition method on TPU substrates. In addition, the printed conductive ink was pre-heated in oven for 60 minutes at 160 °C. After that, the conductive ink was cold down at ambient temperature for two days until it was fully dried.

2.2 Testing

The third phase of this study is a testing works. It was carried out by taking the measurement of sheet resistance by using Jandel's Four-Point probe. At first, the Four-Point probe was calibrated before measuring the conductive ink samples. The calibration process is necessary before start the measurement, and it is defined as comparison between the standard measurement and the measurement by using the instrument. The purpose of this calibration process is to check the precision of the instrument. The following step was measured the conductive samples by placing the TPU substrates under the metal tips of Jandel's Four-Point probe.

Data readings were taken three times for each sample at different locations, and the average amount of data was calculated and recorded. Figure 2.2 shows the Jandel's Four-Point probe instrument has been used in this study.

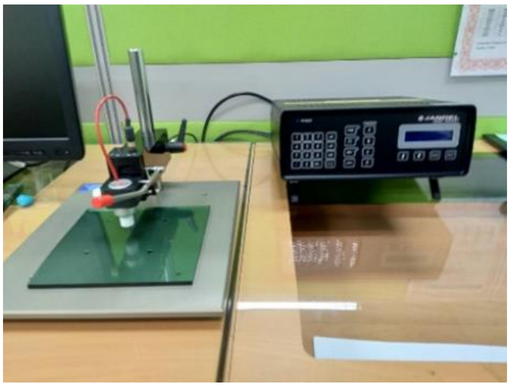


Figure 2.2 Jandel's 4-Point Probe

2.3 Printing method

Manual deposition method had been used to print conductive ink on substrates. TPU has been used as substrates in this study. For this method, spoon was used to apply conductive ink on the uncovered area. Then, the blade coated the substrate in upward to downward motions until the ink was evenly distributed on the substrate. The essential process after printing process was curing process. The conductive inks that had been printed on substrates were heated in the oven at 160 $^{\circ}$C for 60 minutes. The curing temperature was set based on previous research. In previous research, silver nanoparticles based ink were heated at curing temperature over 150 $^{\circ}$C [2]. After 60 minutes, the conductive ink was dried at room temperature for 2 days.

2.4 Morphological study

Morphological study is a one option to investigate the dispersion of filler and binder in conductive ink sample. First of all, the assumption is necessary which is the dark spot represents the filler and the rest presents the epoxy and hardener. The microscope scale is around 100 µm and the magnifications are from 5x to 20x, respectively.

3. RESULTS AN DISCUSSION

3.1 Resistivity

This section discussed the data was obtained in this study. Silver nanoparticles-filled epoxy conductive ink should have good conductivity which is proportional with low resistivity to make the better. After analyzing the data, 60 % of filler for silver nanoparticles conductive ink had low resistivity and economic criteria. Table 3.1 shows the value of estimation error that had been calculated between sample A and B.

Estimation of error between true value and estimated value was examined. The formula for estimation error is shown, and the summary of estimation error is shown in Table 3.1, respectively,

$$Estimation\ error = \frac{Y - Z}{Z} \times 100\%$$

where, Y is a theoretical value and Z is an experimental value

Example of calculation is demonstrated as below:

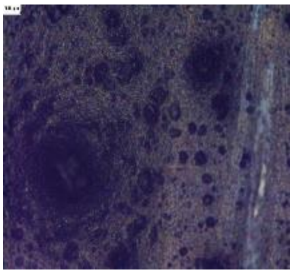
$$Estimation\ error = \left|\frac{108.36 - 119.89}{119.89}\right| \times 100\%$$

Table 3.1 Summary of estimation error

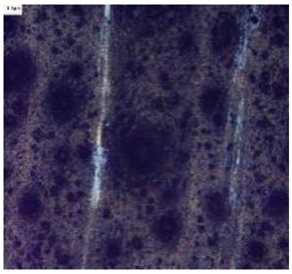
Filler (%)	Estimation Error (%)					
	Sample A			Sample B		
	1	2	3	1	2	3
60	7.06	21.16	32.23	6.41	17.46	16.23

3.2 Morphological study

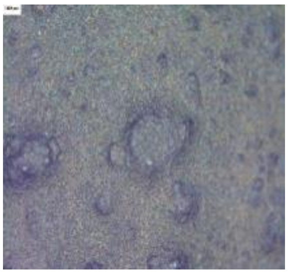
Figure 3.1 shows the morphological imaging for silver nanoparticles-filled epoxy conductive ink. The dark spot is presumed as silver nanoparticles while the bright area presumed filled by an epoxy. Overall, the silver nanoparticles was continued particle and finally gave the low resistivity.



(a)



(b)



(c)

Figure 3.1 Morphological imaging for silver nanoparticles-filled epoxy conductive ink at (a) 5x magnification, (b) 10x magnification and (c) 20x magnification

4. SUMMARY

This study was conducted to examine the sheet resistivity and the morphological effect on silver nanoparticles-filled epoxy conductive ink using TPU substrate. The 60 % filler loading was chosen as a baseline formulation due to resistivity level and economic criteria.

REFERENCES

[1] Lee, S., Choi, D., Piao, H., & Son, Y. (2016). One step synthesis of Ag nano-filler for e-ink and its low temperature metallization. *Microelectronic Engineering*, *163*, 98-104.

[2] Cruz, S., Rocha, L. A., & Viana, J. C. (2016). Enhanced printability of thermoplastic polyurethane substrates by silica particles surface interactions. *Applied Surface Science*, *360*, 198-206.

[3] Mirkin, C. A., Letsinger, R. L., Mucic, R. C., & Storhoff, J. J. (1996). A DNA-based method for rationally assembling nanoparticles into macroscopic materials. *Nature*, *382*(6592), 607-609.