Effect of Line Width and Thickness on Flexible Printed Electronic Circuit Electrical Performance

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ABSTRACT

Flexible and printable electronics is among the rapidly growing field in many applications. Their performances are affected by many factors such as the interaction between the conductive ink circuit and the type of flexible substrate used as the printed board. In this paper, the effect of the conductive ink circuitry line width and thickness to the flexible printed electronic (FPE) electrical performance is investigated. Commercial type carbon based conductive ink and polyethylene terephthalate (PET) flexible substrate were applied to formulate the FPE circuit, using screen printing technique and cured at room temperature, with varying circuitry line width (between 1.00 mm to 3.00 mm) and thickness (between 0.05 mm to 0.25 mm). Square shape circuit pattern was also utilized. The final resistivity for all samples were later tested using digital multimeter. Results for the experiments showed that the electrical resistivity of the FPE samples were alost inversely proportional to the dimension of the circuit thickness and width. The results obtained shall be used in the next project stage as benchmarking data to establish design guidelines related to circuitry geometrical parameters to obtain optimum FPE electrical performance in actual application.

KEYWORDS: *Flexible Printed Electronic Circuit, Conductive Ink, Line Width, Line Thickness, Electrical performance*

1.0 INTRODUCTION

Flexible printed electronics (FPE) can be defined as printing of circuits and electrical components on flexible substrate such as film, paper or textiles. As stated in previous study by Mitsui et al. (2015), the electrical connections that used flexible circuits stands as one amongst the most advanced and important technologies as because of their useful and beneficial properties as example is their marginal weight, flexible form factors and thinness. For the application in whole devices, it helps in boosting the device functionality by provide portability, freedom of form or flexible, impact resistance, reducing the product weight and thickness. Similar study by Chang et al. (2014) stated that the development of printed electronic technology is prompted by its quality potential of being low-cost, high volume, high-throughput production of electronic components or devices which are lightweight and small, think and flexible, and inexpensive. In time to come, printed electronics will emerge innovative and

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disposable products such as point-of-care applications, diagnosis, power sources, biosensors, and smart/interactive packaging.

Khirotdin et al. (2016) reported that the ability of a material to conduct an electric current is measured by the electrical conductivity. A material of higher resistivity will present a lower conductivity and vice versa. There are few important factors that affect the mechanical and electrical properties and must be taken into use such as the polymer matrix of the ink and electrical conductivity. All these factors play a big role on the quality of the ink and on the control of the production parameters. However, the most influential production parameters affecting conductivity and mechanical properties are the substrate material surface structure, curing parameters (time and temperature), materials composition, and the cross-section area of the conductive layer.

Up to date, there are several finding reported on the performance of FPE at varying type of conductive paste, subtrates and circuit geometry. Happonen (2016) reported on the reliability performance of FPE subjected to cyclic bending load. Silver based conductive ink was used as the conductor, while plastic and paper were used as the substrates. The silver based FPE electrical performance was also studied in term of varying circuitry width and thickness. Elsewhere, Janeczek et al. (2012) studied the effect of different silver nanoparticle based conductive filler size to the electrical performance of FPE. They concluded that smaller nanoparticle size provided higher durability compared to micro-meter particle size when subjected to varying cyclic bending load. Furthermore, Merilampi et al. (2009) reported on the effect of varying ink patterns to the electrical behaviour of FPE under cyclic bending load. Their study showed that higher number of cyclic bending raised the FPE resistivity. In addition, they also stated that composition of the conductive ink and the size of the conductive filler also affected both electrical and mechanical properties of FPE. The failure mechanism of FPE was also reported by Dai et al. (2015). They concluded that there are mainly four (4) interfacial failure modes associated with FPE which are cracking, slipping, delamination in the slipping zone and delamination. The cracking failure occurred due to rupture on the conductive thin film, where as the remainder of the failure modes occurred at the interface between the substrate and the conductive thin film.

Another potential type of filler in producing conductive paste for FPE is carbon black. Carbon balck offers many advantages especially in term of balance between cost and performance (good electrical conductivity and good mechanical properties) which are comparable to conventional silver-based nanoparticles. However, based on current literature review, there are still limited reports on studies involving the relationship between conductive layer geometrical parameters to the electrical performance of FPE made from carbon-based conductive paste. Rozali et al. (2018) used carbon based conductive paste to produce FPE using stretchable thermoplastic polyurethane (TPU) substrate using single line circuit geometry with fix circuit thickness and width. In another report, Suhaimi et al. (2018) used carbon based conductive paste to produce FPE using stretchable thermoplastic polyurethane (TPU) substrate using also single line circuit geometry but with varying circuit thickness. Hence, in this paper, the effect of carbon based conductive layer line width and line thickness to the FPE electrical behaviour is studied for square shaped circuit pattern. Varying square shaped circuit line width and line thickness were formulated using the material onto thin flexible substrate. Screen printing technique was employed to fabricate the test samples and the electrical behaviour of the FPE was measured in term of their electrical resistivity

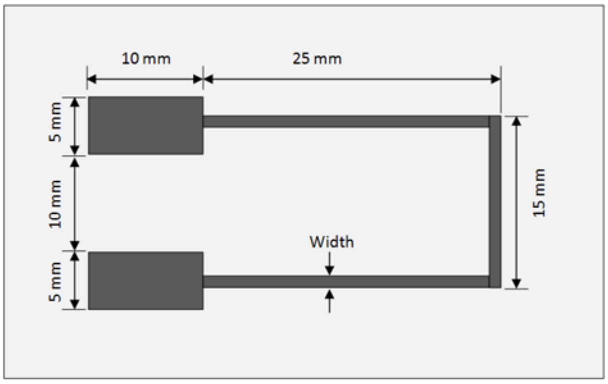
2.0 METHODOLOGY

2.1 Sample preparation

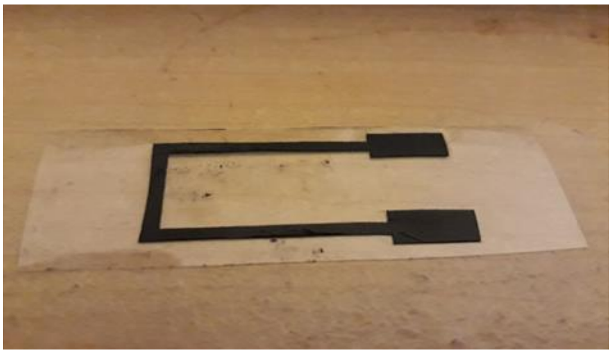
The optically clear polyester film PET of 100µm thickness was obtained from Lohmann Technologies UK LTD. The carbon based conductive ink was obtained from Bare Conductive Ltd, UK, with density of 1.16 g/cm^3 and surface resistance of 55 Ω/sq. The sample preparation consists of two sets which are set A (varies in thickness) and set B (varies in width) as shown in Table 1. Set-A setup, the fix parameter was the line width and variable parameter was line thickness (0.05 mm until 0.25 mm, with 0.05 mm interval). For Set-B setup, the fix parameter was the line thickness and variable parameter was line width (1.0 mm until 3.0 mm, with 0.5 mm interval). The readily engrave circuit design adhesive tape was pasted on PET substrate. Prior to the screen-printing process, the substrate was wiped using Isopropyl Alcohol (IPA) to remove contaminants. After that, conductive ink was poured onto the substrate surface and aligned evenly. Screen printing process conducted were based on ASTM D2739 (ASTM, 2015). All samples were cured at room temperature for approximately 30 minutes. Figure 1 shows the geometrical circuit design parameter and sample of the fabricated FPE.

Table 1. Sample preparation test plan

SET A		SET B	
Width (mm)	Thickness (mm)	Width (mm)	Thickness (mm)
2.0	0.05	1.0	1.0
2.0	0.10	1.0	1.5
2.0	0.15	1.0	2.0
2.0	0.20	1.0	2.5
2.0	0.25	1.0	3.0



(a)



(b)

Figure 1. (a) Square shaped geometrical circuit design parameter (Happonen et al., 2016), and (b) Sample of square shaped flexible printed circuit.

2.2 Electrical testing

The digital multimeter was used to read the resistivity of the circuit with accuracy of ± (1.0% + 1). The resistance was first measured by connecting test lead to “COM” terminal and the red test lead to the “VOHM” input terminal, followed by setting the function range switch to the OHM range. Finally, test leads were connected across the resistance under measurement and the final resistance value was taken based on the given reading. The initial resistance was measured by taking 3 readings for each sample to get the average value. All tests were performed at room temperature. Figure 2 shows the resistivity measurement location taken on the samples (at the termination points of the sample).

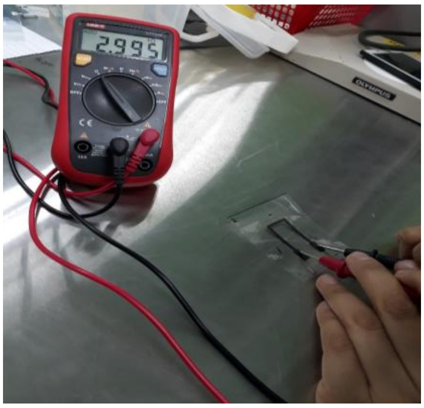


Figure 2. Resistivity measurement location on sample

3.0 RESULTS AND DISCUSSION

Figure 3 and Figure 4 show the comparison of resistivity between thickness and width of conductive ink circuit for square shaped FPE circuit pattern. Based on Figure 3, the sample with thicker layer conductive ink (0.25 mm) showed lowest resistivity (0.751 kΩ) compared to the sample with a thinner layer of conductive ink (0.05mm) that has higher resistivity (3.766 kΩ). This indicates that increasing conductive ink thickness resulted in lower resistance reading. Meanwhile based on Figure 4, the largest width circuit (3.0 mm) gave the lowest resistance value (1.301 kΩ) while the smallest width circuit (1.0 mm) showed highest resistance value (6.961 kΩ), which indicates a wider circuit line caused less resistance compared to thinner circuit line. From both graph, the average resistance of conductive ink sample was found to be almost inversely proportional to the dimension of the circuit line width and thickness.

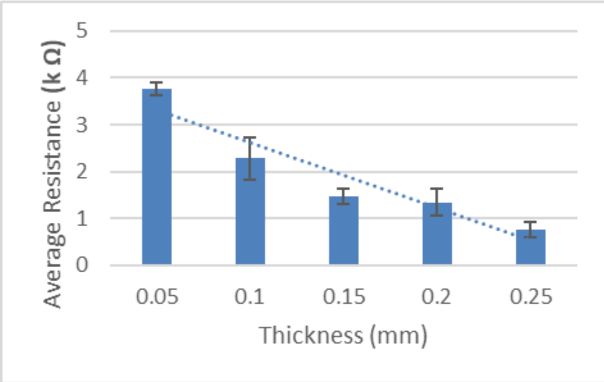


Figure 3. Average resistance of varies conductive layer thickness

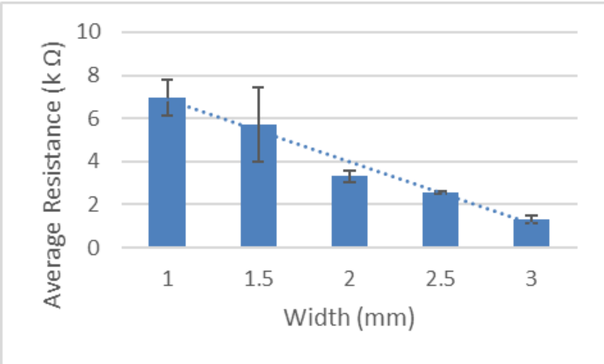


Figure 4. Average resistance of varies conductive layer width

Similar pattern of performance as shown in Figure 3 for FPE from carbon black at varying circuit thickness was also reported by Suhaimi et al. (2018). In their study, single straight line FPE using TPU subtrate were fabricated with varying circuit thickness between 1 layer until 10 layers of conductive paste. They concluded that as the conductive circuit thickness increase, the resistivity and sheet resistivity decreased.

4.0 SUMMARY

In conclusion, it was verified that the width and thickness of carbon conductive ink on the PET substrate affect the resistivity of the overall FPE. From both results, the average resistance of conductive ink sample was found to be almost inversely proportional to the dimension of the circuit line, which provided good correlation information especially for FPE circuit design performance estimation.

Further works shall be carried out to further characterize the electrical and thermal performance of the carbon based conductive ink on PET polymer substrate especially when subjected to varying cyclic bending load

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