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# PRINTING OF CONDUCTIVE INK TRACKS ON TEXTILES USING SILKSCREEN PRINTING

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## ABSTRACT

Textiles with integrated electrical features are capable of creating intelligent articles and it can be realized by printing of conductive inks. But, the technologies are still under progress of development thus this paper presents the investigation on the feasibility of printing conductive ink using silkscreen printing. A two points probe is employed to measure the resistance and the functionality of the electronics structure printed is tested by introducing strains via bending test. It was found that the resistances obtained from single layer printed ink track were not as expected whereas the result for the double layer printed ink track shows a satisfactory result. It was also observed that the surface finish for single layer printed ink track were rougher, uneven and bumpy compared to double layer printed ink track. The bending test results were as expected since increasing the strains causing the electronics structure to change the resistance incrementally thus proving the functionality of the electronics structure printed. The used of conductive ink is proven suitable to provide some elastic character (stretchable) and highly potential for wearable electronics application.

**Keywords:** textiles, conductive inks, resistance, silkscreen printing, two points probe test.

## INTRODUCTION

Textile materials with integrated electrical features are capable of creating intelligent articles with numerous applications such as sports, work wear, health care, safety and others. Over the past decade, various techniques and materials have been used in order to realize the conductive textiles (Stoppa and Chiolerio, 2014). Nowadays, the techniques used to create conductive textiles are conductive fibers, treated conductive fibers, conductive woven fabrics and conductive ink (Kazani and Hertleer, 2012). There are two types of conventional techniques to print conductive ink on textile materials which is inkjet printing and silkscreen printing.

## BACKGROUND

Research on textile materials with integrated electrical features was carried out by different field background such as engineers, fashion designers, biomedical, chemists and also safety communities. In general, the application of the conductive textile is to develop a functional wearable smarts textiles. Different application can be applied into different field of use, for example stretch sensors, pressure sensors, textile energy harvesting and portable power supply system, and wearable antenna (Stoppa and Chiolerio, 2014). The stretch sensors are used for sensing and monitoring body parameters. It can be used to measure or determining heart rate, respiration movement and pressure blood (Pacelli *et al.* 2006). The pressure sensors are commonly used either as switches and interfaces with electronic devices or to monitor vital signs of the users (Rothmaier *et al.* 2008). Textile energy harvesting and portable power supply system is aim to develop wearable systems capable of accumulating energy dissipated by the body, nature energy including sun, rain, wave and tide (Nishide and Oyaizu, 2008). The provided electrical power can be used to provide the electricity for mobile phone. The purpose to develop a wearable antenna system is to allow it transfer information from the sensors hosted inside the garment to a control unit or to monitor other electronics parameters (Grupta *et al.* 2010). The wearable antenna can be used in several fields like life jacket, GPS system and jacket for elderly person or patient for medical application.

## OBJECTIVE

However, the right materials and techniques used are still not being established yet especially on textile materials. Most of them are still under development stages. Furthermore, to enhance the conductivity of the ink track as a part of printing process, a proper control of curing process is essential to prevent under-cure and over-cure phenomenon which reducing the conductivity of the tracks. Therefore, this study is to investigate the feasibility of printing conductive ink using silkscreen printing method on textile material which it will focus on finding the right materials (inks) and technique to be used for printing and curing a pre-defined electronics structure on textile materials. The performance of the electronics structure printed is evaluated and the relationship between the variations of curing parameters used to the conductivity obtained are also determined.

## METHODOLOGY

### Silkscreen printing

Silk screen printing is appropriate for fabrication of electronics structure due to its ability to produce patterned, thick layers form paste-like materials. This technique gives benefits such as low cost, easy to set up and more flexible compared to other methods. The

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silkscreen printing process is a process of printing a viscous paste through a patterned fabric screen via stencil and is usually followed by a drying process (Sauer and Meilchen, 2004).

**Pattern design**

The design pattern of the electronics structure printed is a strain gauge sensor as shown in Figure-1. The total length of the strain gauge is 221.42 mm long with a 2 mm width of track.

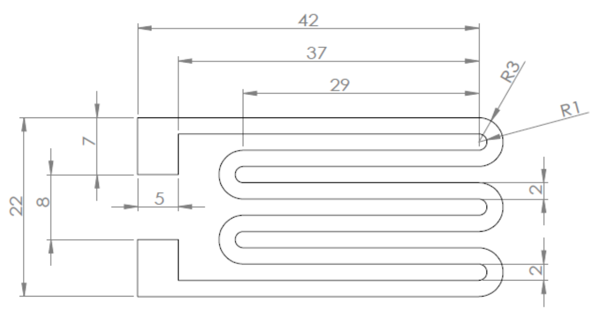


**Figure-1.** Dimension of the strain gauge sensor.

**Conductive inks**

The conductive inks must contain an appropriate highly conductive metal such as copper, gold and silver. The type of conductive inks can be separated into two different types; one is particle and another one is nano-particle. The nano-particle inks also can be classified as an organic and non-organic because of the different solvent used in the inks. Most of the organic type of conductive inks used water as the solvent to control the viscosity of the inks and water is the main ink component and it must be as pure as possible (Stoppa and Chiolerio, 2014). The silkscreen printing requires high viscosity of conductive inks to prevent the ink simply passing through the net of the screen onto the substrates. Most of the conductive inks available commercially possess surface tension and viscosity that exceed levels which allow droplet formation in the range of 30-100μm size using ink jet technology (Huang and Liao, 2003). The silver conductive inks via on-the-shelf silver conductive paint RS186-3600 is used due to it is free from oxidation, easily available and easily formulated into inks and the adhesion to substrates is better than others.

**Curing process**

Digital Light Process (DLP) via DLP projector is one of the process for photonic curing process and it is used since the light energy absorbed by the substrate is not damaging the substrate, portable, easy to set up and cheaper process. The light source from the projector is focused on the printed substrate and result in heat which is absorbed by the conductive ink track and followed by the evaporation of solvent from the ink tracks. The distance between the projector lamp to the converging lens is set to be constant at 165 mm and the curing time is varied accordingly.

Oven curing process is used as well in this experiment as a comparison since oven curing provides a consistent and stable temperature and the samples could be cured at a higher temperature if needed. Generally, to achieve higher conductivity, heating to a higher temperature is the option to burn-out all organic contaminants (solvents). In this study, the temperature is set to be at 100ºC and the curing time is varied accordingly.

**Resistance measurement**

For a long thin wire-like specimen or serpentines pattern conductive ink track with very thin thickness, the two points probe method (Source Meter model 2400) is suitable to be used for resistance measurement (Figure-2). To understand the resistance, the relationship between resistance and resistivity is important to be understood when describing the printable conductor. Resistance is a measurement for an object which resist or opposes an electric current flow through it. The electrically resistive nature of the material is an intensive property known as resistivity. The resistance depends on the physical shape and pattern, but the resistivity depends on the nature of the material. The relationship between the resistance and resistivity is shown below:-

$$\rho = \frac{A}{L} R \tag{1}$$

$\rho$ = volume resistivity
$A$ = cross-section area
$L$ = length
$R$ = resistance

Electrical conductivity is to measure the ability of a material to transfer or conduct an electric current. The higher resistivity will present the lower conductivity and it is commonly represented by the Greek letter σ (sigma).

$$\sigma = \frac{1}{\rho} \tag{2}$$

$\sigma$ = conductivity
$\rho$ = volume Resistivity

**Functional test**

A functional test is performed to evaluate the performance of the conductive inks track in changing resistance and its elastic behavior when deforms with variation of strains via bending angles. The sample is placed on a developed bending jig shown in Figure-2 and a two points probe is connected to the source meter using an electrical wire clip. The strain is introduced at 10 degrees angle initially and the step is repeated until a maximum of 160 degrees of bending angles is applied with 10 degrees interval for each bending test. All of the results are recorded using the Oriel IV Test Station software.

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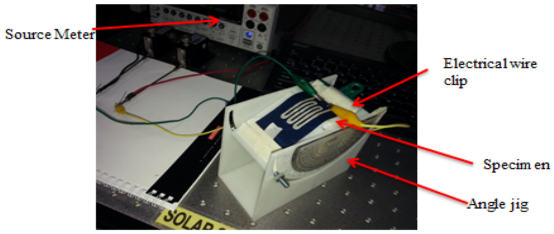
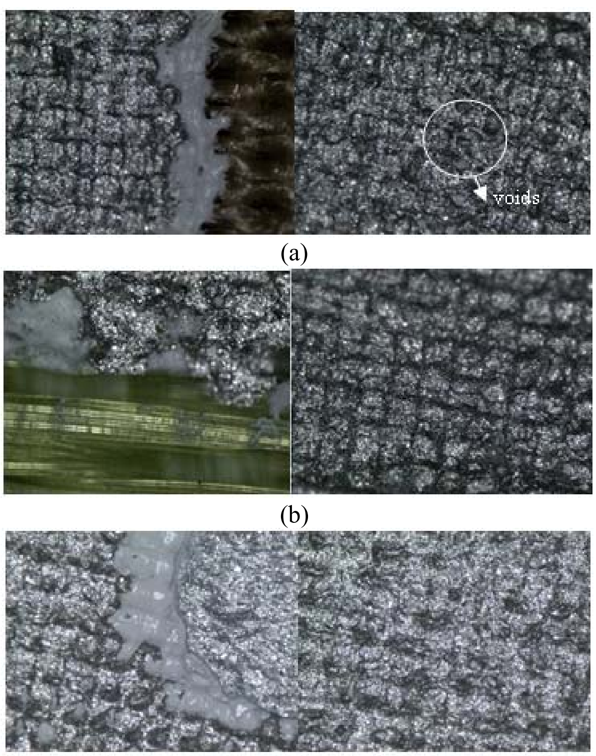



**Figure-2.** Resistance measurement with functional test.

## RESULT AND DISCUSSION

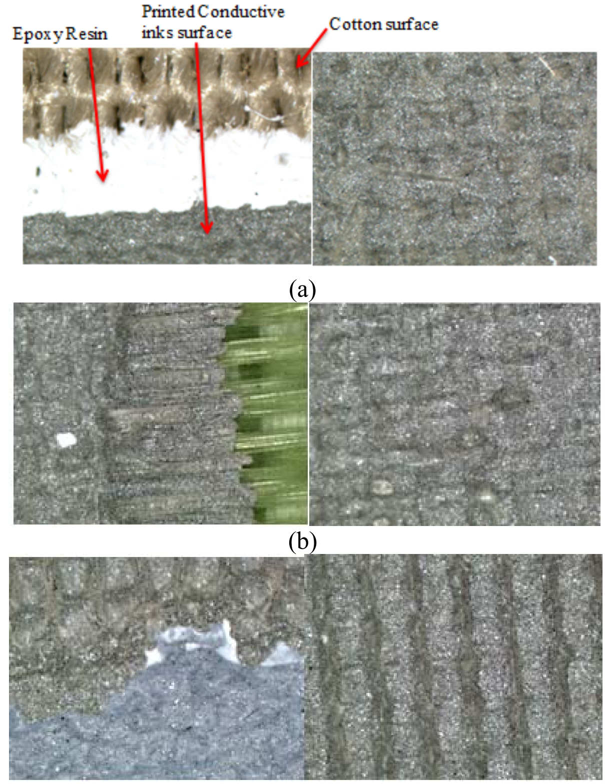
### Micro-structure analysis

The optical microscope is employed to observe the surface finish and to measure the thickness of the conductive ink track. Figure-3 (a), (b) and (c) show the texture of woven cotton, polyester and nylon printed with single layer of conductive ink. The structure of the woven cotton consist of braid texture while the structure of the woven polyester has a criss-cross pattern. Nylon is a synthetic woven which is tougher, stiffer, and stronger and wrinkle free. It is also observed that the surface finish for all substrates were rougher due to the reverse image of the silkscreen net (pattern of small square-like) and some voids were noticed. It is not in the case of double layer printed ink track where most surface finish of the substrates were much smoother as depicted in Figure-4.




(a) (b) (c)

**Figure-3.** Surface finish for single layer conductive ink on (a) cotton sample (b) polyester sample (c) nylon sample.




(a) (b) (c)

**Figure-4.** Surface finish for double layer conductive ink track on (a) cotton sample (b) polyester sample (c) nylon sample.

### Thickness measurement

To calculate the resistivity, determination of the cross-sectional area of the conductive ink is essential which it is calculated by multiplying the width with the average thickness of the conductive ink track. Figure-5 shows the film thickness for the double layer conductive ink track measured by the optical microscope.

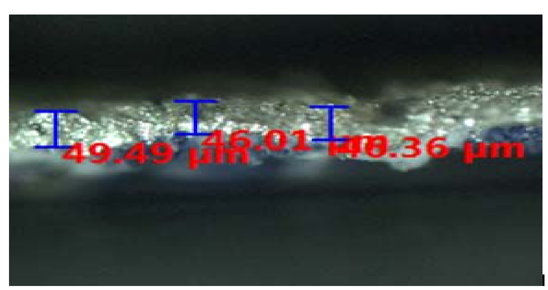



**Figure-5.** Variation of thickness of the double layer conductive ink.

### Printed ink track cured with DLP process

The results of resistance obtained for all substrates as depicted in Figure-6 were not as expected since the resistance were fluctuated according to the length of curing time. The surface of the ink track were

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rougher because of the effect of the silkscreen net hence result in uneven cross-sectional areas and bumpy surface finish. Furthermore the layer track is too thin which some voids were observed (Figure-3 (a)). It is assumed that the resistance of conductive ink track should decrease proportionally to the length of curing time. These drawbacks have led to the fluctuated resistance obtained. It is proven that the densification of the single layer track was not good enough for conduction.

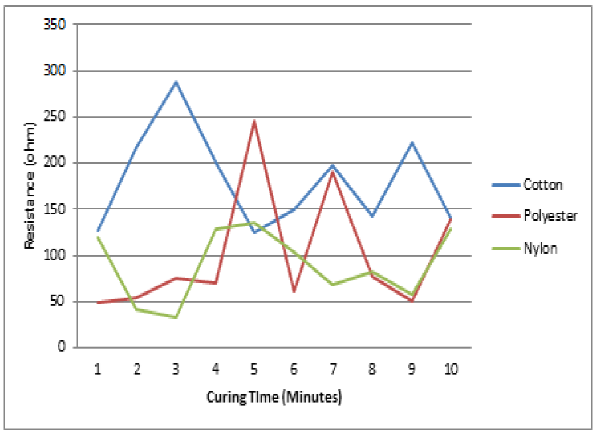


**Figure-6.** Single layer printed ink track with DLP curing process.

For the double layer ink track, the results of resistance obtained for all substrates were as expected (depicted in Figure-7) since the resistance decreased proportionally to the length of the curing time. It was proven that the thickness of the conductive ink track has some effect on the resistance and it is validated by the equation (1) previously. The thicker the conductive ink track, the lower the resistance obtained. The reduction in resistivity is due to the densification of the double layer conductive ink track and it is increase the contact area between the individual particles which will enhance the conduction through the conductive ink track. This phenomenon can be explained as more layer or thicker the cross-sectional area, the more electric current can be deliver through the conductor since the amount of the contact between particles is increased. This is similar to the concept of electric wire in which the thicker wire allows bigger electric current to flow through and the thin wire can only provide small amount of the electric current. But, there is still some drawbacks observed where the resistance results were still considered high. The resistance acquired for nylon and cotton samples were higher than 50 ohm after 30 minutes of curing. It means that the curing temperature for the DLP was too low ($35^o$-$40^o$) to remove the volatile solvents and binders inside the silver conductive ink. The removal of these volatile solvents and binders are crucial to increase the contact area between particles so that it will become more conductive. Higher temperature is needed to reduce the resistance and to increase the contact between particles to allow more current to flow through the ink track. The key to obtain a high conductive ink track is by providing more heat which is increasing the curing temperature.

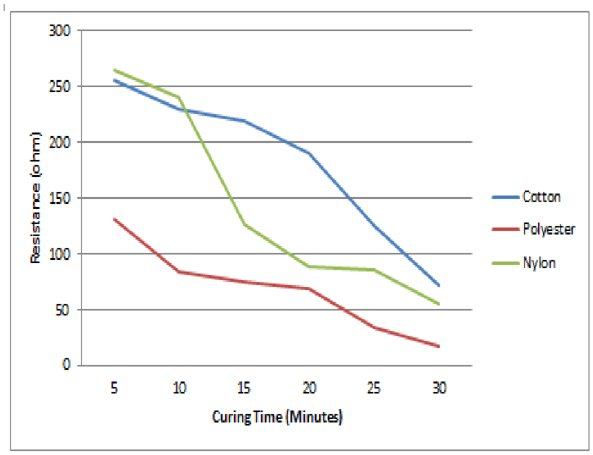


**Figure-7.** Double layer printed ink track with DLP curing process.

### Printed ink track cured with oven

The constant curing temperature of 100 $^oC$ is selected and the curing time is varied accordingly and set to a maximum of 30 minutes. This is due to the longer curing time appears to have an adverse effect on the electrical performance in term of measured resistance and this can avoid the potential result of oxidation after the substrate make contact with the oxygen in the environment.

There were six samples created for each substrate and the curing time is varied from 5, 10, 15, 20, 25 and 30 minutes. The resistance obtained for all substrates were almost two times smaller after 30 minutes of curing when using oven as illustrated in Figure-8. The conductivity is increased when curing at higher temperature. The loss of conductance was reduced and the stable resistance is obtained. The resistance became lower due to the temperature stability of the oven provides a good curing environment to the specimens. Furthermore, the surface of the ink track become more flatten and the thickness for each substrate are more even. It can be explained by the higher temperature successfully removed the volatile solvents and at the same time breaks the binders which allowing more particles to bond with each other hence increase the contact area between particles..

### Functional test

A functional test via bending test is employed to evaluate the performance of the ink track in changing the resistance when deforms with continuous strains. It is also performed to measure the elastic behavior of the conductive inks track and to determine the relationship between the resistance obtained to the applied strains.

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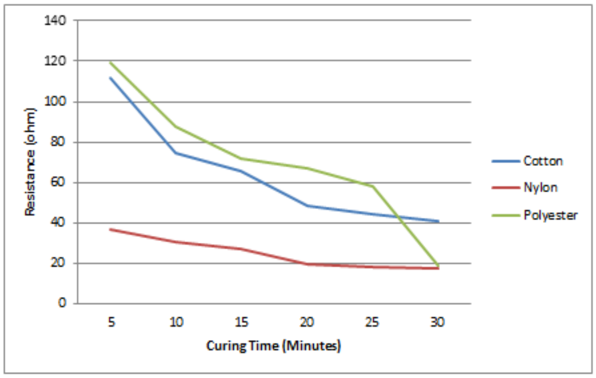


**Figure-8.** Double layer printed conductor with oven curing process.

The bend angle is increased incrementally from minimum 10 degrees to a maximum of 160 degrees with a 10 degrees interval for each test and the resistances are recorded using a two point probe method via Source Meter model 2400.

It was found that the performance of the strain sensor is as expected when the change in resistance was observed accordingly (Figure-9). The resistance measured is continuously increased when the strain gauge is bent incrementally to its maximum strain. It is observed that nylon samples produced the lowest resistance for all bending test despite of the bend angle is at its maximum angle (160 degrees) compared to cotton and polyester. The potential errors during measurement of resistance were considered including the probes have to be in contact properly with the substrate and the static current has to be avoided during the testing. In general, the better the conductor, the more easily the current spreads, and hence the less error is measured. To enhance the conductivity for conductive ink track, the key is to observe the threshold of the curing temperature.

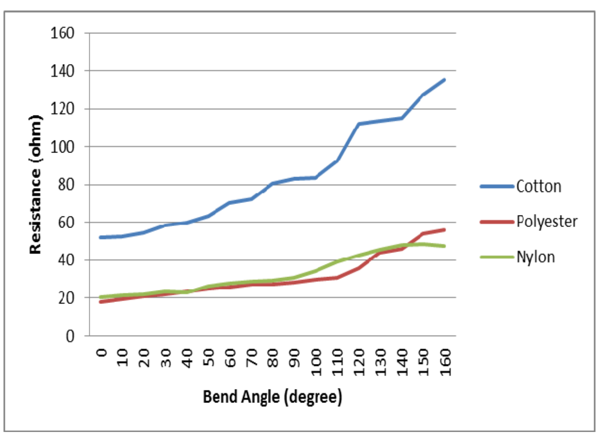


**Figure-9.** Change in resistance against bend angles.

## CONCLUSIONS

It was concluded that the silver conductive ink used (silver conductive paint RS186-3600) is proven to be appropriate for the study. To realize a good conductive ink track, a proper control of the curing process is significant especially in determining the right temperature and curing time. The oven curing process is suitable to produce a more stable and required temperature compared to DLP curing process. The DLP is sufficient enough to be used for curing process but it will need some assistances by integrating it with other curing method especially in providing more variation of curing temperature needed. In addition, the relationship between curing time and temperature to the resistance was successfully determined which is the resistance of conductive ink track is in proportional to the length of curing time and temperature. Another factor which is significant in reducing the resistance is the film layer where a bigger cross-sectional area of the film layer conveys more electric current to flow through the ink track. The bending test results were as expected since increasing the strains causing the electronics structure to change the resistance incrementally thus proving the functionality of the electronics structure printed. The used of conductive ink is proven suitable to provide some elastic character (stretchable) and it is highly potential for wearable electronics application in the future.

In future, to improve the conductivity of the printed conductors, a non-contact type of deposition method via filament of fluid dispensing system is suggested. The system can provide a multilayer printed conductor and capable of exhibiting a good surface finish since it is a non-contact process and fast as well. With high speed printing, the oxidization can be prevented before the samples are proceed to curing process. The deposition of the inks can be properly control and spread evenly on the sample substrate to provide a good surface finish. The different type of conductive inks can be investigated to determine the best conductivity of conductive inks. Currently the conductive inks still needs a high curing temperature but certain textile materials could not withstand high temperature during curing. A conductive ink which can be cured at a relative low temperature is required. A localized type of heating process via laser curing technique could be employed without damaging the substrates since oven could burn some of the low temperature substrates such as textiles and polymers.

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