PRINTING CONDUCTIVE INK TRACKS ON TEXTILE MATERIALS

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ABSTRACT

Textile materials with integrated electrical features are capable of creating intelligent articles with wide range of applications such as sports, work wear, health care, safety and others. Traditionally the techniques used to create conductive textiles are conductive fibers, treated conductive fibers, conductive woven fabrics and conductive ink. The technologies to print conductive ink on textile materials are still under progress of development thus this study is to investigate the feasibility of printing conductive ink using manual, silk screen printing and on-shelf modified ink jet printer. In this study, the two points probe resistance test (IV Resistance Test) is employed to measure the resistance for all substrates. The surface finish and the thickness of the conductive inks track were measured using the optical microscope. The functionality of the electronics structure printed was tested by introducing strain via bending test to determine its performance in changing resistance when bent. It was found that the resistance obtained from manual method and single layer conductive ink track by silkscreen process were as expected. But this is a different case for the double layer conductive ink tracks by silkscreen where the resistance acquired shows a satisfactory result as expected. A micro-structure analysis shows the surface finish for the single layer conductive inks tracks were not good enough compared to the double conductive ink track. Furthermore, the bending tests provide expected result if increasing of the bend angle will decrease the level of conductivity. The silver conductive paint RS186-3600 could provide low resistance which was below 40 ohm after printed on fabrics material.

ABSTRAK

Bahan-bahan tekstil dengan elektrik bersepadu boleh dibuat jadi artikel pintar dengan pelbagai aplikasi seperti pakaian sukan, pakaian kerja, barang penjagaan kesihatan, keselamatan dan lain-lain. Secara tradisional teknik yang digunakan untuk membuat tekstil konduktif trek ialah kain tenun yang disalut, konduktif kain tenun dan konduktif dakwat. Teknologi untuk mencetak dakwat konduktif pada bahan-bahan tekstil masih di dalam peringkat kajian, tujuan ini adalah memcari kemungkinan percetakan dakwat konduktif dengan menggunakan pencetak jet dakwat yang diubahsuaikan, manual bercetak dengan plat spatula dan skrin sutera percetakan. Dalam kajian ini, Two Point Probe Resistance Test (IV Resistanve Test) telah digunakan untuk mengukur kerintangan dan kekonduksian untuk semua substrat. Permukaan dan ketebalan trek dakwat konduktif diukur dan dilihat menggunakan mikroskop optik. Fungsi struktur elektronik yang dicetak telah diperhatikan dengan melalui ujian bengkok untuk menentukan kerintangan and kekonduksian dalam berubah apabila sampel dibengkok. Keputusan dapat dari kaedah manual dan satu lapis trek dakwat kondutif seperti yang dijankakan. Tetapi ini berbeza dengan dua lapis trek dakwat konduktif oleh silkscreen di mana rintangan yang diperolehi menunjukkan keputusan memuaskan seperti yang dijankakan. Analisis bagi mikro-struktur menunjukkan kemasan permukaan untuk satu lapisan dakwat konduktif trek tidak cukup baik berbanding dengan dua lapisan dakwat konduktif berganda. Pengujian bengkok memberikan keputusan yang dijangkakan jika peningkatan sudut bengkok akan mengurangkan tahap kekonduksian. Dakwat konduktif RS186-3600 boleh menyediakan rintangan yang rendah iaitu di bawah 40 ohm selepas dicetak atas material kain.

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LIST OF SYMBOLS AND ABBREVIATIONS

A	-	Cross-section area (m^2)
Ω	-	Resistance (ohm)
σ	-	Conductivity (S/m)
^0C	-	Celsius
H_2O	-	Water
I	-	Electric Current
L	-	Length (m)
ρ	-	Volume Resistivity (Ω.m)
µm	-	Micrometer
V	-	Voltage

AC	- Alternating current
BOM	- Bill of Material
CMOS	- Complementary Metal–Oxide–Semiconductor
C	- Cotton
DPI	- Drop per Inch
DLP	- Digital Light Process
DOP	- Drop-on-Demand
DTG	- Direct to Garment
DC	- Direct current
HP	- Hewlett-Packard
LCD	- Liquid Crystal Display
N	- Nylon
P	- Polyester
IV Test	- Two Points Probe Measurement

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CHAPTER 1

INTRODUCTION

1.1 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 material which is inkjet printing and silk screen. The inkjet printing technique is suitable for mass production and it is hypothetically more efficient, easy and capable of achieving high accuracy of printing with small tolerance. Inkjet printing is able in printing lower resolution in the region of 50 micron (Kadian and Kumar, 2004). Silk screen printing is suitable for fabricate electrical and electronics structure because it can produce a pattern for thick layers of paste-like materials (Sauer and Meilchen, 2004). This technique gives benefits such as low cost, easy to set up and more flexible compared to other method.

1.2 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 generally, 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 for determining heart rate, respiration movement and pressure blood (Pacelli and Taccini, 2006). The pressure sensors are commonly used either as switches and interfaces with electronic devices or to monitor vital signs of the users (Rothmaier and Luong, 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 electronic parameter (Grupta and Sankaralingam, 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.

Several fabrication techniques have been found for conductive textile in the past decade. The techniques introduced here are conductive fabrics, silkscreen printing technology and inkjet printing. There are currently three methods in fabricating the conductive fabrics - by twisted metal wire, metal coating and metal fibers. The first method is to twist the metal wire around the polymer yarn as shown in Figure 1.1. Second method is to use the chemical coat thin metal layer on the polymer yarn which is shown in Figure 1.2. The third method is used the conductive yarn consists of metal multifilament directly (Figure 1.3). The fabrication techniques of the conductive fabric were present several years ago. However, the integration of conductive yarns in a structure is complex and seldom a uniform process as it needs to be ensured that the electrically conductive fabric is comfortable to wear or soft in touch rather than hard and rigid (Locher, 2006). Additionally, due to the woven fabric structures was complicated; it is not suitable to form a conductive track on the fabric.

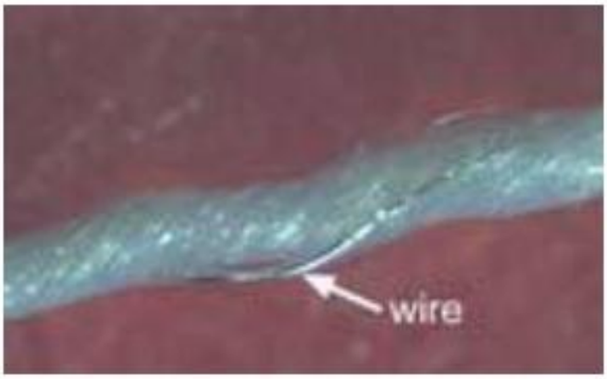


Figure 1.1 Twisted metal wire (Locher, 2006)

Figure 1.2 Metal Coating (Locher, 2006)

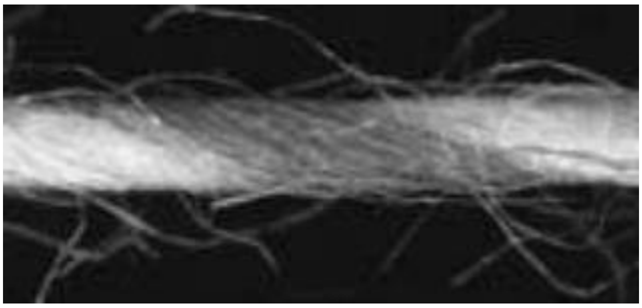


Figure 1.3 Metal Fibers (Locher, 2006)

Before proceeding to the printing process, the conductive inks have to be introduced first. The conductive inks must contain an appropriate highly conductive metal such as copper, gold and silver. The types of conductive inks can be separated into two different types; one is particle and another one is nano-particle. In general, the nano-particle type of conductive inks was preferred to be used in ink- jet printing due to the small particle inside the inks. 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). As the high cost of the gold and the high corrosion of the copper, the silver conductive inks were selected to be used to print the conductive track on different materials.

1.3 Problem Statement

It is a challenge to investigate the method to print the conductive ink track on textile material as this technology is still in development. Inkjet printing and silk screen printings are the method to print conductive ink track on textile material. However, the right material and technique used are still not being established yet especially on textile materials. Most of them are still under development. The main challenge of silk screen printing is how to adjust the accuracy and parameter to create a right ink trace to print. Silk screen printing is appropriate for fabricating electrics and electronics due to its ability to produce patterned, thick layers from paste-like materials (Sauer and Meilchen, 2004). The main challenge for inkjet printing is the inks used has to meet certain requirements including high electrical conductivity, resistance to oxidation, dry out without clogging the nozzle during printing, good adhesion to the substrate, lower particle aggregation and suitable viscosity and surface tension (Pourdeyhimi and Grant, 2006). Inks may also contain additives which are used to tune ink properties or to add specific properties thus increasing its performance. In this study a normal on-shelf paper printer will be modified to allow it print the conductive inks on textile material. The selection of the printer is important where some factors need to be considered for example cost, method of modifications, applicability in working with conductive inks, DTG inks and resolution Drop per inch (DPI). The challenge is whether the outcome of this modification suitable to be applied on textile materials, since the normal printer only permits papers. Besides, the print head has to be freed from clogging, and the roller has to move smoothly when using textile materials. In addition, the printer cartridge only allows non-conductive material with specific viscosity and conductive inks will probably clog the print head. Furthermore, to enhance the conductivity of the inks, a proper control of curing process is important to prevent under-cure and over-cure phenomenon which reducing the conductivity of the tracks. Therefore, there is a need to do this research in which it will focus on finding the right materials (inks) and technique to be used for printing and curing a pre-defined geometry structures on textile materials.

1.4 Objective

This research is aim:

i) 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.

ii) To evaluate the performance of the electronics structure printed

iii) The variations of curing parameters used to the conductivity obtained are also determined.

1.5 Scope of Study

i) The type of the printer used is an EPSON printer because it is cost effective as and suitable to be modified.

ii) Silk screen printing method is used if the printer modification unsuccessful.

iii) The type of conductive ink used is a particulate type of conductive ink (silver conductive paint RS186-3600).

iv) The curing process is done using a Digital Light Process (DLP) and oven to cure the conductive ink.

v) The surface of the conductive ink track is investigated using optical microscope

vi) The functional test is done to observe the maximum bend angle of the electronics structure printed.

vii) A two point probes method is used to measure the resistance of the ink tracks.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review is focus on the method for printing conductive ink on the textile material, the type of conductive ink, the method of resistance measurement and also the type of textile material.

2.2 Printing Techniques on Textile Material

There are many types of the printing techniques on textile materials like heat printing method, silkscreen method, inkjet printing and brush printing. But not all the printing techniques can be applied for printing the conductive ink.

2.2.1 Silkscreen Printing

Silk screen printing is appropriate for fabrication electrics and 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 method. The screen printing procedure, a stencil process comprised the printing of a viscous paste through a patterned fabric screen and is usually followed by a drying process (Sauer and Meilchen, 2004).

Silkscreen block have to be prepared before the printing process. Normally the silkscreen block is made from wooden frame and stapled with mesh or silk. The pattern or picture to be printed on textile materials is printed on the stencil and the pattern is cut from the stencil. After cutting out the pattern, the stencil is placed between the silkscreen and the textile material before start the printing process. The ink or rubber dye is force to penetrate the textile material by the squeegee to form the pattern on the textile material (Figure 2.1).

Figure 2.1 Silkscreen process

2.2.2 Inkjet Printing

Inkjet printing has been widely used in office and home in the past decade. The inkjet printer can be used for printing text, pictures, or panel onto various types of paper. Nowadays, due to the improvement of invention, the capability of printer is no longer to only print text and pictures, it can also print the high-resolution photos with relatively inexpensive process. There are many different types and brand of the printers available in the market today, but the most commonly used printer was inkjet printer. The inkjet printer was invented in 1976, and in 1988 the inkjet printer was manufactured by Hewlett-Packard (HP) and became to sell to the public, at over $1000 (Aaron and Daniel, 2011). The inkjet printing technologies is the non-contact and no-mask patterning with low temperature processing, due to the invention of these technologies it can be used with difference medium or substrate such as plastic, fabric, acrylic, wood, metal and textile material not only the paper. The philosophy for the non-contact inkjet printing is micro-droplets of liquid are sprayed through one or more inkjet print head to impact on the target substrate with high accuracy and precise location to create an image (Savita and Sushil, 2004). The ink for used in the inkjet printing is usually in liquid form, although it is hot-melt inks but that need to be liquefied before start to print (Perelaer, 2008). The principle of inkjet printing is to transfer the pattern or draft to the digital signal or model to the control board of the printer from the computer or scanner to form the image on the substrate via an inkjet printer (Kazani, 2012). The software has to be installed in the computer as the driver to convert computer-based design or image into the digital signals to control the print head and the machine in the printer through the control board in the printer.

2.2.3 Inkjet Printing Techniques

The inkjet printing techniques can be classified into two categories, first is continuous inkjet printing and second is the drop-on-demand inkjet printing. The different between continuous inkjet printing and the drop-on-demand inkjet printing is continuous method can continuous stream system more than on drop can be directed at any pixel location (Kazani, 2012), and when it is nothing to be printed, the ink is deflected into a gutter for recirculation depending upon the imposed electric field. For the drop-on-demand method it is the only one drops per pixel was formed only when the printing process required (Sumerel and Lewis, 2006).

2.2.4 Continuous ink jet technology

The continuous ink jet technology provides a continuous and constant spray of tiny ink droplets, which are charged and controlled electronically according to the image. The charged droplets are deflected by a subsequent electric field, while the uncharged ones flow onto the paper. This means that the imaging signal for charging the droplets corresponds to a negative print image (as was also the case with the example described above for electrophotographic technologies is accordance with Figure 2.2). Continuous ink jet printing usually feeds only a small proportion of the stream of droplets to the substrate. With continuous ink jet generally only a small part of the drop volume covering the sheet in accordance with the print information is applied to the substrate. The large part is fed back into the system (Kipphen, 2008).

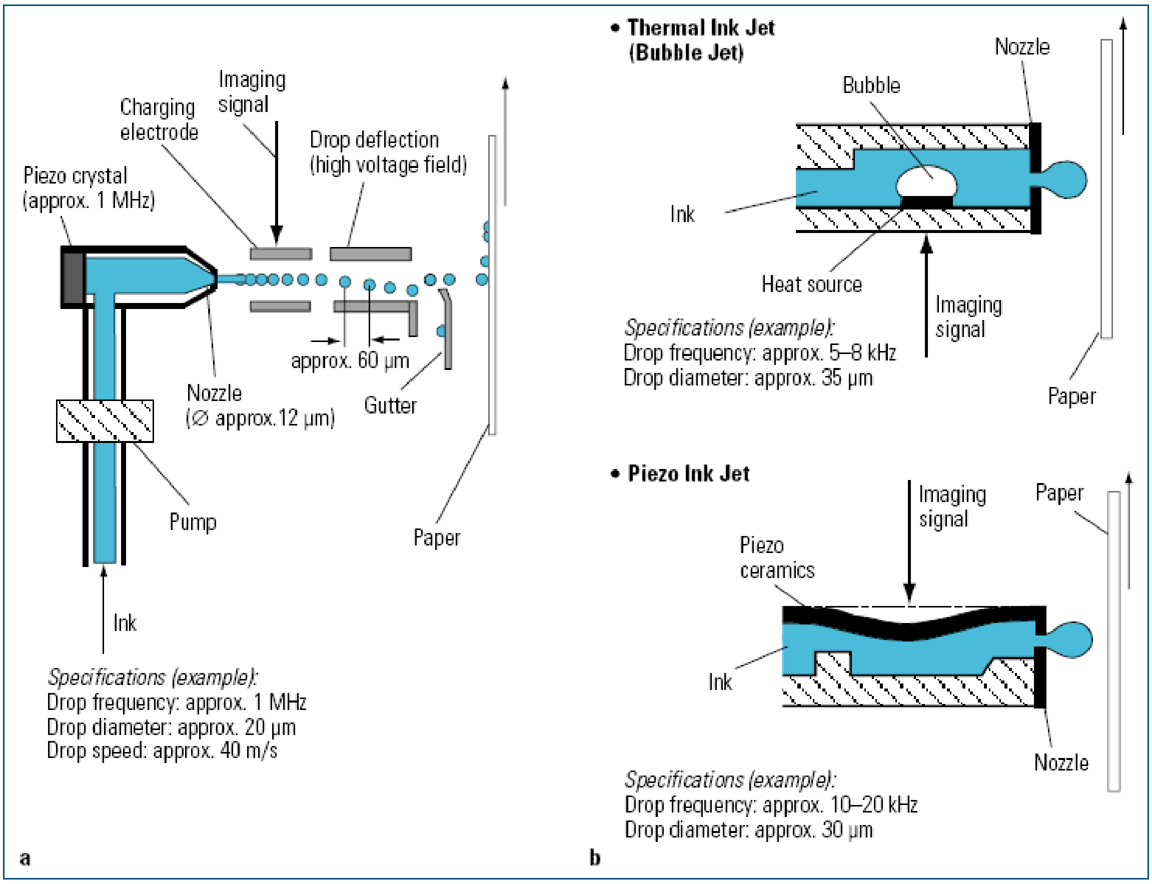


Figure 2.2 Ink jet Technology (a. continue ink jet; b. Drop on demand) (Kipphen, 2008)

2.2.5 Drop-on-Demand technology

The Drop-on-Demand usually can be further classified in to two main technologies there are either thermal inkjet or piezo-electrically inkjet, based on the actuation methods deployed for droplet formation from the print head of an inkjet printer (Ashok, 2010). The drop-on-demand can provide high placement accuracy, high speed, and smaller drops which can achieve up to 30μm per drops.

2.2.6 Thermal Inkjet Method

The thermal inkjet method can be considered as thermal bubble method. In the thermal inkjet print head, it is around 600 tiny resistors inside and heated by current to achieve very high temperature to 350^{0}c controlled by computer signal (Sankir, 2005). The ink will feed into the pressure chamber and heated by the resistors. This will creates a vapour bubble in a volatile component in the ink (Ashok, 2010). Due to the expansion process by the bubble, the vapour bubble can causes a drop of ink to be pushed to eject from the nozzle of the print head. The vapour bubble then collapse and vacuum formed, this allowing to pull the new ink feed into the pressure chamber in the print head and the process is ready to begin again refer to Figure 2.3 (Aeron and Daniel, 2010). The whole process of bubble formation and collapse only take place in less than 10μm (Ashok, 2010). The nozzle of thermal inkjet can deliver approximately 0.1ml of ink per minute.

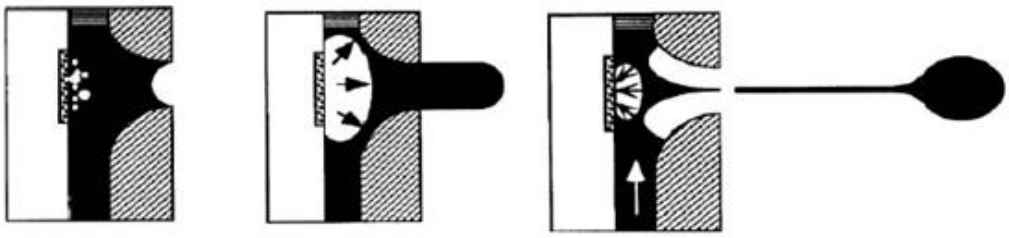


Figure 2.3 Drop formation by a thermal ink jet Printer (Continue ink jet Printing) (Aeron and Daniel, 2010)

2.2.7 The Piezo-electrical Inkjet Method

The principle of operation for piezo-electrical inkjet method was similar to the solenoid valve. This technology was invented by Epson. In piezoelectric printers, the computer imposes an electrical potential across a piezoelectric actuator element (ceramics material), which causes shear action of the piezoelectric material (Ashok, 2010). The contraction in the direction of electric field and expansion in the perpendicular direction will affect the ink volume change in the pressure chamber. The change of the pressure wave and volume will push the ink toward the nozzle for ejection so an ink drop begins to form at the nozzle and spray out. In order to spray out the ink drop, the pressure at the print head must be sufficient to expel the droplet toward the substrate or contact medium. After the ink drop was spray out, the piezoelectric actuator will returns to its normal dimensions and pulls a small amount of ink into the pressure chamber refilled from an ink reservoir due to the capillary process (Ashok, 2010). The whole process cycle time for piezo-electrical inkjet method was very fast (14,000 cycles/s), so the vibration frequency for piezoelectric ceramics was very high. The volume of the drop size was smaller than the thermal inkjet, so the piezo-based printers can produce very high resolution prints. The durability for the piezo-based print head is higher than the thermal inkjet print head. The technology can be classified to four different types, there are squeeze, bend, push and shear. A squeeze-mode inkjet was designed as a glass nozzle surrounding by a piezo-ceramic. The bend-mode designed by bonded the piezo-ceramic plates bonded to the diaphragm to form an array of bilaminar electromechanical transducers used to spray the ink droplets. For a push-mode, the piezo-ceramic rods expand to push against the ink to eject the droplets. In shear mode, the electric field was designed to be perpendicular to the polarization of the piezo-driver and the vibration of the piezo-plates against ink to eject the droplets (Malik and Kumar, 2004).

2.3 Printing Ink

The printing inks used in home or office printers generally are water-based and can be classified either dye-like or pigment like. It is basically four process colours used in home or office printers (C Cyan, M magenta, Y yellow and K black) (Momin, 2008). Dye-based is colorant, which is dissolved in the carrier medium, usually the carrier media can be classified to several types which are water (H_2O), mixture of H_2O and organic co-solvents and organic solvents such as hydrocarbons, esters, ketones. A pigment is colorant that is insoluble in carrier medium but can be dispersed or suspended the form of small particles, often stabilized against flocculation and settled by the use of dispersing agents (Mei, 2004). The solvent plays an important role to make sure the ink can be flow through the print head and spray via the nozzle without clog. More solvent added to the printing ink will result low viscosity of the ink, if the ink contain is high in solid and little solvent, it will be result high viscous of the ink. The viscosity of the printing inks also very much affect the printing quality and efficiency. The low viscosity ink can cause the printing quality become low, unclear for the image on the substrate that printed and event it does not work on the printer. If using high viscosity ink to print, the print head may clog (Sagar, 2011). So, before start printing, the viscosity has to be measure and adjust. Surface tension plays an important role during the formation of a droplet. The surface tension of commercial inks varies between 21 mN/m and 48 mN/m. These values do not show whether high or low surface tension is necessary for best printing result (Mei, 2004).

2.3.1 Characteristics of Dye-Based Inks

Dye-based inks provide bright, rich colours and reduce the likelihood smudged of the images printed on the paper. Those dry almost immediately in room ambient which allow immediate paper absorption due to the small molecular structure of dyes. However, because of the small molecules of the dye-based inks, it is water soluble and they easily smear upon contact with water. The durability of image colours produce by dye-based inks are usually not long due to the small molecular makeup is highly susceptible to oxidation. The quick absorption qualities of dye inks can lead to some unintended overlapping of separate colours, slightly changing the intended colour in a printed graphic.

2.3.2 Characteristic of Pigment-based inks.

The pigment-based inks generally more expensive than the dye-based inks, but it was become more popular in inkjet printing due to the long durability time. The pigment inks can maintain much of their original colour as many as 100 year depending on the type of paper that's used. Addition, the particles in the pigment based inks aren't organic and don't break down to mix with the liquid. Pigment based inks also provide a good resistant to the potentially damaging forces such as sunlight and moisture. The quality of the pigment-based inks was not that good as the dye-based inks due to the colour is not in liquid form its mean it cannot absorbed properly by traditional paper immediately, so, the smudge will occur before it dry to handling.

2.3.3 Ink use to print on the textile material (DTG printing)

Difference textile substrates have different colourant requirements due to the difference in the mode of colour-substrate interaction. In generally, the dye-based inks were not suitable to use on the textile material, in this case, pigment base inks were selected. Refer to Table 2.1 shown below the selection of colourant for textile substrates and their mode of interaction with fibres (Momin, 2008)

Table 2.1 The selection of colourant for textile substrates and their mode of interaction with fibres.(Momin, 2008)

Colourant	Fibre	Colour-Fibre Interaction
Pigment	All Fibres	No interaction- complex surface polymer bonding mechanism
Reactive dye	Cotton, Silk and Wool	Covalent fibre bonding
Disperse dye	Poluester	Hydrophobic-Solid State Mechanism
Disperse dye	Polyester	Hydrophobic-Solid State Mechanism
Acid dye	Silk, Wool and Nylon	Electrostatic and hydrogen bonding with fibre

2.3.4 Conductive Inks

Before proceeding to the printing process, the conductive inks have to be introduced first. The conductive inks must contain an appropriate highly conductive metal such as copper, gold and silver. The types of conductive inks can be separated into two different types; one is particle and another one is nano-particle. In general, the nano-particle type of conductive inks was preferred to be used in ink- jet printing due to the small particle inside the inks. 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). As the high cost of the gold and the high corrosion of the copper, the silver conductive inks were selected to be used to print the conductive track on different materials.

In order to apply conductive inks into an office printer, the major challenge is the formulation of inks must be with suitable physicochemical properties. It is difference with the screen printing as the screen printing technic requires high viscosity of the conductive inks to prevent the ink simply passing through the net of the screen onto the substrates. For inkjet printing, due to the conductive inks have to pass through the print head with very tiny drop, the low viscosity of the conductive inks have selected to prevent clog of the print head while printing. The surface tension and viscosity not only influence the droplets size pass through the print head but it is also affected the ejected droplet velocity, stability and the shape of the droplets impact on the substrate. 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 (Hue, 1998).The contains of the conductive inks are based on expensive metal because of the high conductivity. There are basically three types of the metal used as contain of the conductive inks there are copper, silver and gold. The copper conductive ink is the cheaper compared to other but the problem is copper easy to oxidize in air and oxidized copper the conductivity will reduce or event not conduct. So, the silver conductive inks become the first choice of end-users and another benefit is the silver can easily formulated into inks and the adhesion to substrates is better than other. The conductive inks can be classified to several categories as the ingredients of conductive inks including micro-particles, nanoparticles and metal organic decompositions refer to Table 2.2 (Daniel and Frank, 2003).

Table 2.2 Typical ink properties for a continuous ink-printer(Daniel and Frank, 2003)

Viscosity (CPS)	1-10µm
Surface tension (dynes/cm)	25-70mN/m
Particle size	Micrometer, no agglomerate

2.4 Conductivity and Resistivity

Before understanding the concept of conductivity and resistivity, the Ohm's law has to be explained first. From the Ohm's law, if physical conditions (like mechanical stress, temperature) remains unchanged and then the potential difference across two ends of a conductor is proportional to current flowing through a conductor. The formula as shown below:

$$V = IR \tag{2.1}$$

Where,
V= Voltage
I= Electric Current
R = Resistance (Ω)

Voltage is the electric potential different or electric pressure to move the charge between two points. Electric current is a flow of electric charge carried out by moving electron in conductor. To understand the resistance, the relationship between resistance and resistivity is important to be understood when describing the printable conductor (Wathiq and Ryan, 2009).

Resistance is a measurement for an object which resist or opposes an electric current flow through it the unit for measurement is ohm. This can explain why the metal is a better conductor compared with wood. The thicker wire have less resistance compare to the thin wire and also the longer wire have more resistance than a shorter wire. 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 (Wathiq and Ryan, 2009). The relationship between resistance and resistivity is shown in below formula:-

$$\rho = \frac{A}{L}R \qquad (2.2)$$

Where,

ρ = Volume Resistivity, Ω.m

A = Cross-section area , m^2

L = Length, m

R = Resistance, Ω

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. It is commonly represented by the Greek letter σ (sigma) and the formula for conductivity show as below:

$$\sigma = \frac{1}{\rho} \qquad (2.3)$$

Where,

σ = conductivity

ρ = Volume Resistivity, Ω.m

2.5 Curing Process

There curing process can be achieved by exposure of the printed pattern to heat, intense light (photonic curing), oven curing process and electrical curing process. To avoid destructive heating of textile material, the suitable curing methods have to be found. Besides that, the economic, low cost and time consume were considerate.

2.5.1 Oven Curing process

To sinter the particles of conductive ink to become close to each other and evaporate the solvent contain in the conductive ink, oven curing process was used to heat and cure the printed conductive patterns. To achieve high conductivity of the conductive ink track, heating to a high temperature (100^{o}C and above) were required to burn-out all organic contaminants (solvent). The heating coil on the top and bottom inside the oven can provide heat supply and maintain or fix the temperature in certain level. However, the defect was found by using the oven curing process which is the substrate will be deformed.

2.5.2 Photonic Curing process

Digital Light Process (DLP) via DLP projector is one of the process for photonic curing process and it 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. It is advantageous by using the photonic curing process due to more effective and light energy transfer and absorbs by the substrate without damage the microstructure of the substrate (Kamyshny and Steinke, 2011).

2.5.3 Electrical curing process

The method of electrical curing process is to applying a voltage over the printed structure that causes current flow through the structure, leading to a local heating by energy dissipation. The advantages for this process are the short curing time (within 10 seconds) and reduced substrate heating (Kamyshny and Steinke, 2011).

2.6 Woven materials

The woven cotton has braid texture, unique strength and comfortable soft as shown in Figure 2.4. The woven polyester had the criss-cross pattern as shown in Figure 2.5 where it has wrinkle resistance and stiffer compared to the woven cotton. Nylon was the synthetic woven (Figure 2.6) in which they are stiffer, stronger and had wrinkle resistance compared to the other woven materials.

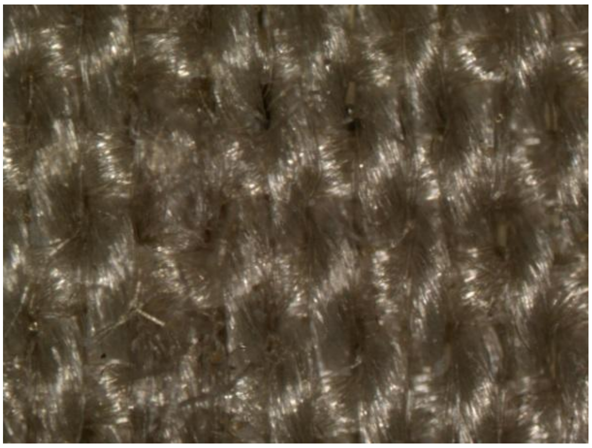


Figure 2.4 Cotton

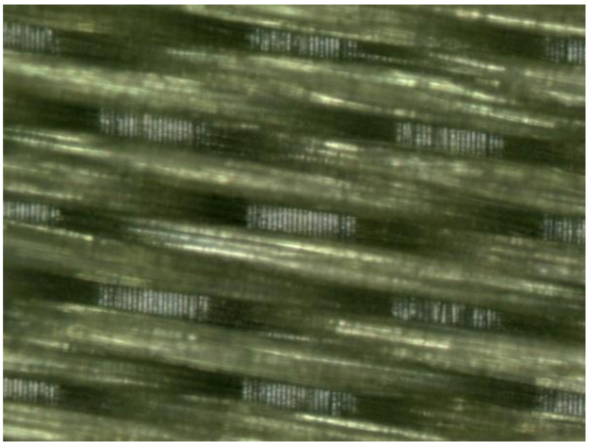


Figure 2.5 Polyester

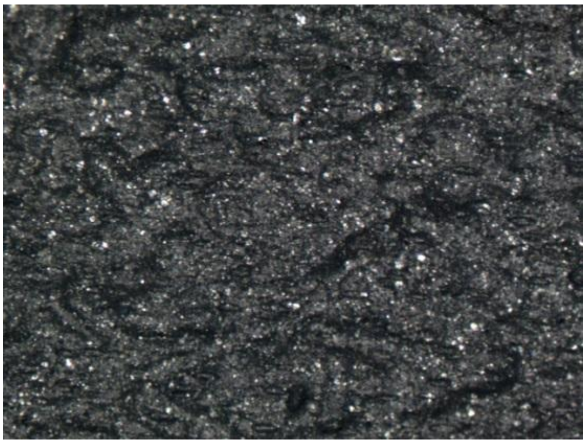


Figure 2.6 Nylon

2.7 Summary

There a lot of methods to print the conductive ink track on textile material used in previous research. The printing techniques on textile materials like heat printing method, silkscreen method, inkjet printing and brush printing. But not all the printing techniques can be applied for printing the conductive ink. For the conductive inks, it must contain an appropriate highly conductive metal such as copper, gold and silver. In general, the types of conductive inks can be separated into two different types; one is particle and another one is nano-particle. The curing process can be achieved by exposure of the printed pattern to heat, intense light (photonic curing), oven curing process and electrical curing process.

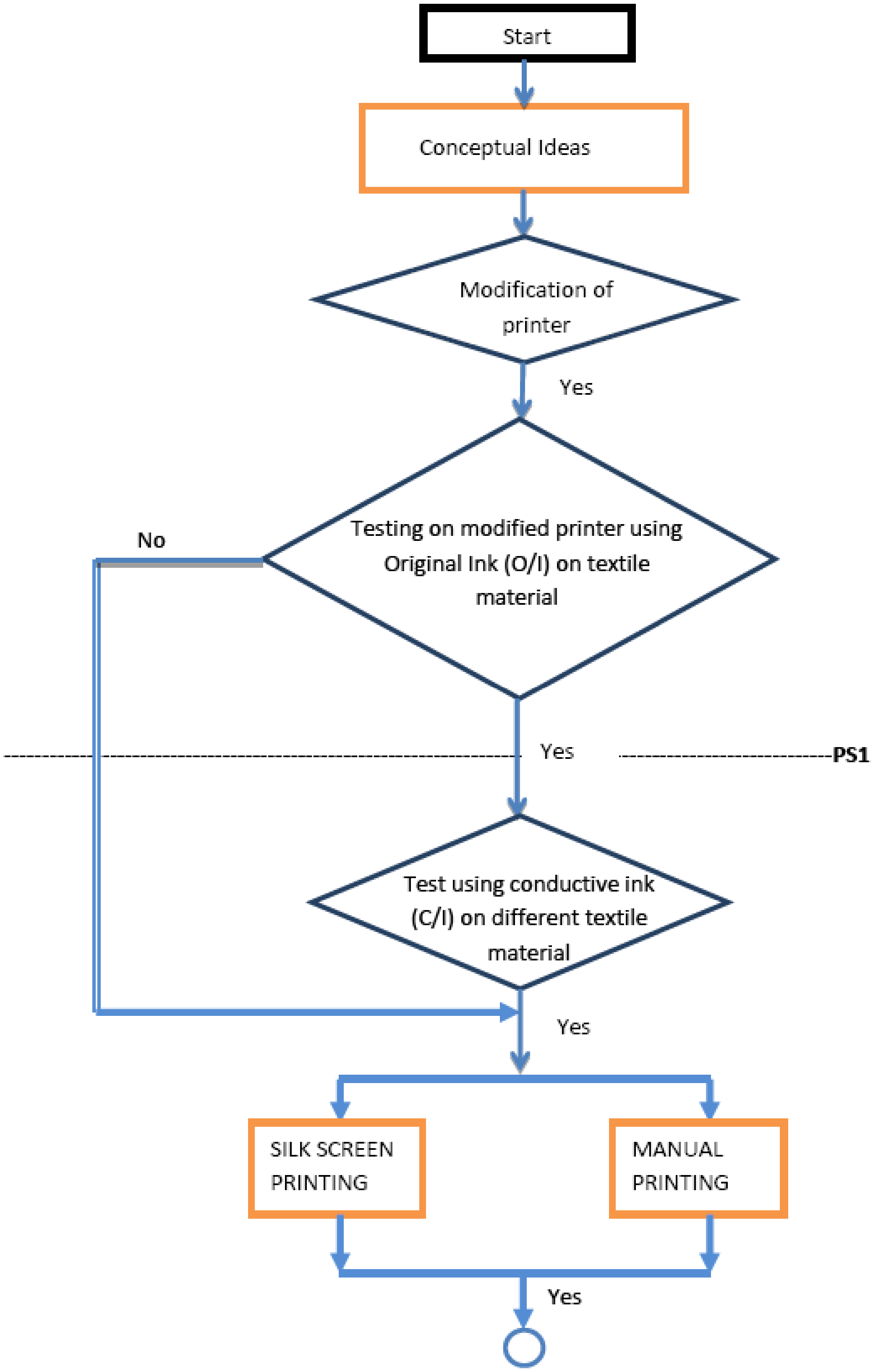
CHAPTER 3

METHODOLOGY

3.1 Introduction

In this study, a few methods such as the printing method, curing process, optical microscope test and 2-probe measurement was performed progressively. Conductive inks was used as the main material for the printing of textile material in printing methods such as spatula plate printing, silkscreen printing and modified printer printing. After the printing process, curing process had been carried out for the drying of the inks on the substrate. Then, micro-structure analysis was done in order to observe the finish surface of the conductive ink track and measure the thickness. Lastly, the measurement on the resistance of the printed conductive inks track was performed two points probes probe test.

3.2 Flow Chart



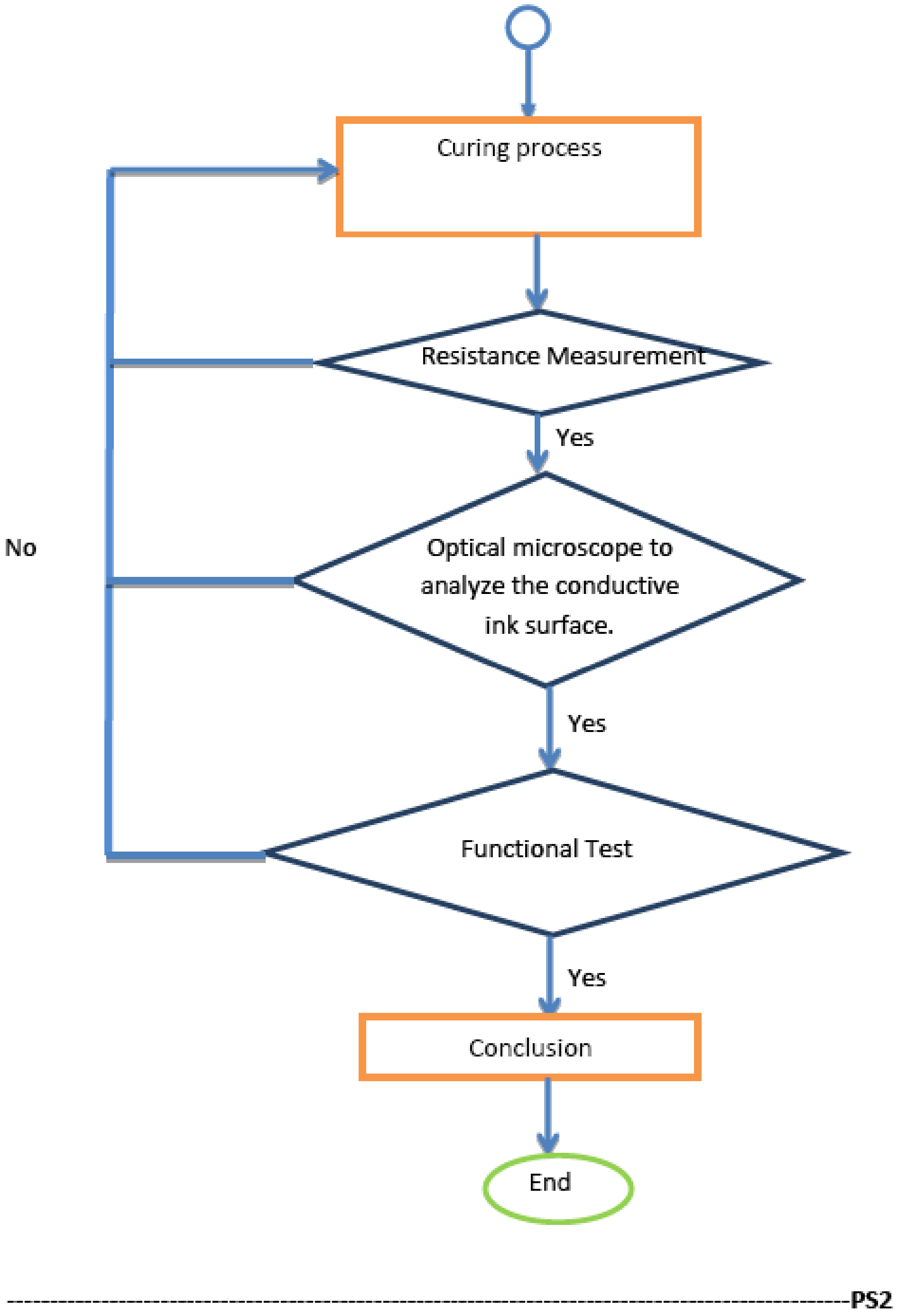


Figure 3.1 Flow Chart

3.3 Printing of conductive inks track

Before introducing the methods to print the conductive inks, the design and pattern of the electronics structure has to be developed via a strange gauge sensor as shown in Figure 3.2. A serpentine pattern was designed with conductor length 221.42mm with the width of track was 2 mm. 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.

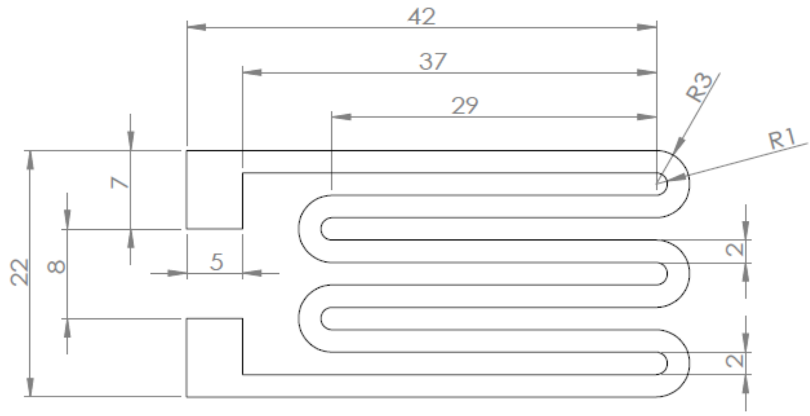


Figure 3.2 Serpentine pattern conductor

3.3.1 Manual deposition method (Brush or spatula)

Brush and spatula was used in the manual deposition method as shown in Figure 3.3 below. The metal plate of the serpentines pattern was made to cover the unpainted area on the substrate. The brush or spatula was applied to deposit the conductive inks on the uncovered area to form a serpentines pattern conductor.

Figure 3.3 Brush or spatula plate printed method.

3.3.2 Silkscreen printing

Before proceed to silkscreen oriented method, the screen have to be customized. A wooden frame with A3 size (420mm x297mm) was fabricated as depicted in Figure 3.4. The function of the wooden frame was to attach and fix the silk. The staple gun was used to fix the silk on the wooden frame as shown in Figure 3.5. The silk has to be attached gently and tightly to ensure the silk from torn apart.

Figure 3.4 Wooden frame.

Figure 3.5 Silk attached to the wooden frame.

The next step was applying the emulsion coating on the silk. The emulsion was sensitive to lights. The process was began by Laid the thin layer emulsion on the silkscreen block and later on dried with hair dryer (Figure 3.6).

(a) Fotecoat Emulsion

(b) Laying the Fotecoat emulsion.

(C) Drying process with the hair dryer.

Figure 3.6 (a) Fotecoat Emulsion (b) Lay the Fotecoatemulsion (c) Drying process with the hair dryer.

REFERENCES

Aaron, C. and Daniel, D. (2010). *Multilayer Polymer Inkjet Printing*. Degree of Bachelor Thesis. Worcester Polytechnic Institute.

Ashok, S. (2010). An *Inkjet Printing-Based Process Chain For Conductive Structures on Printed Circuit*. PhD. Thesis. University of Twente.

Atalay, O. and Kennon, W. (2014). Knitted strain sensors: Impact of design parameters on sensing properties. *Sensors (Basel, Switzerland)*, 14(3), 4712-4730.

Brinksma, H. (2010). *An Inkjet Printing-Based Process Chain For Conductive Structures on Printed Circuit*. Ph.D.Thesis. University of Twente.

Cochrane, C. et al. (2007). Design and Development of a Flexible Strain Sensor for Textile Structures Based on Conductive Polymer Composite. *Sensor,* 7(4), 473-492.

Cochrane, C., Lewandowski, M. and Koncar, V. (2010). A flexible strain sensor based on a conductive Polymer Composite for in situ measurement of parachute canopy deformation. *Sensor (Basel, Switzerland)*, 10(9), 8291-8303.

Daniel, H. and Frank, L. (2003). *Plastic compatible low resistance printable gold nanoparticle conductors for flexible electronics*. Journal of the Electrochemical Society, 150(7), 412-417.

Grupta, B., Sankaralingam, S. and Dhar, S. (2011). *Development of Wearable and implantable antennas in the last decade*. IEEE Microwave Symposium (MMS) 2010, 251-267.

Hue, P. (1998). Progress and trends ink-Jet Printing Technology. *Journal of Imaging Science and Technology*, 42(1), 49-62.

Ida, K. et al. (2012). Behavior of Cu Nanoparticles ink under reductive calcination for fabrication of Cu Conductive film. *Thin Solid Films*, 520(7), 2789-2793.

Julia, R. and Robert, A. (2007) *Thermal Cure Effects On Electrical performance of Nanoparticle Silver Inks*. Science Direct.

Kamyshny, A. and Steinke, J. (2011). Metal Based Inkjet Inks For Printed Electronics. *The Open Applied Physics Journal*, 4, 19-36.

Karwa. and Anupama. (2006). *Printing Studies with conductive inks and Exploration of new*. Master Thesis. Rochester Institute of Technology.

Kazani, I. (2012). *Study of Screen-Printed Electroconductive Textile Materials*. Ghent University, 20-43.

Kazani, I. and Hertleer, C. (2012). *Eletrical Conductive Textiles Obtained by Screen Printing*. Fibers & Textile in Eastern Europe 2012, 20(1), 57-63.

Khairi, N. et al., (2012). Diameter Stem Changes Detection Sensor Evaluation Using Different Size of Strain Gauge on Dendrobium Stem. *Sciverse Science Direct*, 41(Iris 2012), 1421-1425.

Kipphen, H. (2008). Handbook *of Printing media*. 3rd ed. Springer Berlin Heidelberg.

Lee, J. H., Kim, N. R. and Kim, B. J. (2011). *Improved Mechanical Performance of Solution-Processed MWCNR/AG nanoparticle Composite Films with Oxygen-Pressure-Controlled Annealing.* SciVerse Science Direct.

Locher, I. (2006). *Technologies for system-on-textile integration*. ETH Institutional Repository.

Malik, S., Kadian, S. and Kumar, S. (2004). Advances in ink-Jet Printing Techonlogy of textiles. *Indian Journal of Fibre & Textile Research*, 36, 99-113.

Mattmann, C., Clemens, F. and Troster, G. (2008). Sensor for Measuring Strain in Textile. *Sensor*, 8(6), 3719-3732.

Mei, J. F. (2004). *Formulation and Processing of Conductive Inks For Inkjet Printing Of Electrical Component*. Ph.D. Thesis. University of Pittsburgh.

Merilampi, S. et al., (2010). Analysis of electrically conductive silver ink on stretchable substrates under tensile load. *Microelectronic Reliability*, 50(12), 2001-2011.

Momin, N. H. (2008). *Chitosan and Improved Pigment Ink Jet Printing on Textiles*. PhD. Thesis. RMIT University.

Nishide, H. and Oyaizu, K. (2008). Toward Flexible batteries. *Science Magazine*, 319 (5864), 737-738.

Pacelli, M. G. and Taccini, N. (2006). *Sensing Fabrics for monitoring Physiologica and Biomechanical Variables: E-textile solutions*. *IEEE Journal*, 1-4.

Parashkov. and Becker, E. (2005). Large Area electronics using printing methods. *IEEE Journal*, 93(7), 1321-1329.

Park, B.K. et al. (2007). Direct writing of copper conductive patterns by ink jet printing. *Thin Solid Films*, 515(19),7706-7711.

Perelaer, J. (2008). *Inkjet printing of narrow conductive tracks on untreated polymeric substrates*. Wiley, 343-345.

Pourdeyhimi, B. and Grant, E. (2006). *Printing Electric Circuits onto Nonwoven Conformal Fabrics Using Conductive Inks and Intelligent Control*. National Textile Center.

Rothmaier, M., Luong, M. P. and Clemens, F. (2010). Textile pressure sensor made of flexible plastic optical fibers. *Sensors 2008*, 8(7), 4318-4329.

Sagar, S. (2011). *Evaluation of Silver and Graphite Ink Blend for use in Printed Electronics*. Master Thesis. Western Michigan University.

Samarasinghe, S. et al. (2009). Electric-Jet Assisted Layer by Layer Deposition of Gold Nanoparticles to prepare conducting tracks. *Natural Science*, 1(2),142-150.

Sankir, N. D. (2005). *Flexible Electronics: Materials and Device Fabrication*. PhD. Thesis. Faculty of Virginia Polytechnic Institute and State University.

Sauer, M. and Meilchen, S. (2004). *Screen Printing in Sol-Gel Technologies for Glass Producers and User.* Springer Science & Business Media, 117-120.

Schwarz, A. and Langenhove, L. V. (2013). *Types and processing of electro-conductive and semiconducting materials for smart textiles*. Woodhead publishing limited.

Shi, M. (2012). *Organic Logic Circuits: Fabrication Process and Device Optimisation*. PhD. Thesis.University of Manchester.

Siden, J. et al. (2007). Printed antennas with variable conductive ink layer thickness. IET Microwaves, Antennas & Propagation, 1(2),

Stoppa, M. and Chiolerio, A. (2014). Wearable Electronics and Smart Textiles: A Critical Review. *Sensors 2014*, 14(7), 11957-11992.

Sumerel, J. and Lewis, J. (2006). Piezoelectric ink jet processing of materials for medical and biological applications. *Biotechnology Journal 2006*, 1(8), 976-987.

Tiberto, P., Barrera, G. and Gelegato, F. (2013). *Magnetic properties of jet-printer inks containing dispersed magnetite nanoparticles*. European physical journal B, 86(173), 1-6.

Vatansever, D. (2011). *Smart Woven Fabrics in Renewable Energy Generation*, Institute for Materials Research and Innovation, 1-6.

Walker, B. S. and Lewis, J. A. (2011). Reactive Silver Inks For Patterning High-Conductivity Features at Mild Temperature. *Journal of the American Chemical Society*, 134(3), 419- 421

Wathiq, N. and Ryan, K. (2009). The DNA of Materials. *Journal of College Teaching & Learnin*g 6(4), 39-44

Woo, K. H., Daeh, W. J. and Young, W. K. (2013). Relationship between printability and rheological behavior of ink-jet conductive ink. *Ceramics International*, 39(6), 7015-7021.

Wu, H. C., Lin, H. J., and Hwang, W. S. (2005). A numerical study of the effect of operating Parameters on drop formation in a squeeze mode inkjet device. *Modelling and Simulation in Materials Science and Engineering*, 13(1), 8-25.

Zhou, X. Q., Li, W. and Wu, M. L. (2013). Enhanced dispersibility and dispersion stability of dodecylamine-protected silver nanoparticles by dodecanethiol for ink-jet conductive Inks. *Applied Surface Science*, 252(2), 537-543.