SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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FABRICATION OF STRAIN SENSOR BASED ON SILVER CONDUCTIVE INK

By

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DECLARATION

I hereby declare that I have conducted and completed the research work and written the dissertation entitled "**Fabrication of strain sensor based on silver conductive ink**". I also declare that is has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or university.

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PDMS	Polydimethylsiloxane
Ag	Silver
Cu	Copper
Ni	Nickel
Al	Aluminum
CNT	Carbon nanotube
PCB	Printed circuit board
PEDOT	Poly(3, 4-ethylenedioxythiophene)
PSS	Poly(styrene sulfonic acid)
PA	Polyacetylene
PANI	Polyaniline
PPY	Polypyrrole
NR	Natural rubber
SBR	Styrene butadiene rubber
EPDM	Ethylene-propylene-diene monomer
PU	Polyurethane
RFID	Radio-frequency identification
FTIR	Fourier transform infrared
TGA	Thermogravimetric analysis
DSC	Differential scanning calorimetry
SEM	Scanning electron microscope

LED	Light-emitting diode
OM	Optical microscope
SiOH	Silanol

FABRIKASI SENSOR TERIKAN BERDASARKAN DAKWAT SILVER KONDUKTIF

ABSTRAK

Sensor terikan merupakan bahagian penting dalam sistem pintar. Dalam kajian ini, sensor terikan disediakan dengan menggunakan polidimetilsiloksana (PDMS) sebagai substrat dan pengisi perak sebagai dakwat konduktif. Bahan-bahan yang digunakan dalam penyediaan substrat adalah polidimetilsiloksana hidroksida (PDMS-OH), wasap silika, toluene, dibutiltin dilaurat dan glaicidilpropiltrimetoksisilina. Dakwat konduktif perak dicetak menggunakan cetakan stensil pada substrat PDMS. Pelbagai ujian dijalankan untuk menyiasat sifat-sifat elektrik pada sampel sensor terikan. Sensor terikan menunjukkan peningkatan dalam rintangan ketika terikan meningkat. Rintangan elektrik sensor terikan juga meningkat dari hari ke hari. Di samping itu, sensor terikan menunjukkan konsistensi rintangan yang baik pada terikan yang tetap selama 4 jam. Selain itu, sifat-sifat substrat dan dakwat konduktif sensor terikan juga dikenalpasti melalui ujian FTIR, TGA, DSC, SEM dan tegangan. Hasil ujian FTIR menunjukan tiada kemunculan ikatan OH, menunjukkan reaksi telah berlaku sepenuhnya. Substrat PDMS mempunyai kekuatan dan pemanjangan tegangan yang tinggi yang menunjukkan ianya sesuai untuk digunakan sebagai substrat.

FABRICATION OF STRAIN SENSOR BASED ON SILVER CONDUCTIVE INK

ABSTRACT

The strain sensor is an essential part of a smart system. In this research, a strain sensor is being prepared by using polydimethylsiloxane (PDMS) as substrate and silver filler as a conductive ink. The ingredients used for substrate preparation are polydimethylsiloxane-hydroxide (PDMS-OH), fumed silica, toluene, dibutyltin dilaurate and 3-glycidoxypropyl-3 trimethoxysilane. The silver conductive ink was printed by stencil printing on the PDMS substrate. Various testing has been conducted to investigate the electrical properties of the strain sensor sample. The strain sensor showed increasing resistance as the applied strain increased. The electrical resistance of the strain sensor also increased day by day. Besides, the strain sensor showed good consistency in resistance at constant strain for 4 hours. Moreover, the properties of the substrate and conductive ink of the strain sensor also are being identified by FTIR, TGA, DSC, SEM and tensile testing. There is no OH bond presence from FTIR result, indicated that the sample was fully cured. PDMS substrate has high tensile strength and elongation at break which means that it is suitable to be used as a substrate

CHAPTER 1

INTRODUCTION

1.1 Research Background

Since the advent of electronics, advances in fabrication techniques have driven the development of smaller, faster, and more efficient devices. The primary focus has been on rigid electronics. However, recent interest in wearable electronics, human/machine interfaces, and soft robotics, among other areas, has led to new development of electronic devices known as stretchable electronics. The importance of this stretchable electronic has increased because of various applications. One device of particular interest is strain sensors, which are both highly conformal and extensible (Muth et al., 2014).

In recent years, stretchable electronics have been mostly studied in two different methods. The first method is 'wavy structural configuration' which use rigid semiconductor nanowires, nanoribbons and nanomembranes configured into 'wavy' shapes. This 'wavy' shape can withstand large applied strain without fracture. The fabrication of stretchable wavy ribbons is illustrated in Figure 1.1. The flat ribbon chemically bonded to a prestrained compliant substrate. The ribbon is compressed to generate the wavy layout through a nonlinear buckling response when prestrain is released. These wavy layouts can accommodate external deformations through changes in wavelength and amplitude (Gao, 2011).

The second method is 'stretchable interconnects'. This method involve the uses of stretchable electrodes to interconnect rigid active device islands on elastomeric substrate. A various types of conductive materials such as metal wires, conducting polymer, carbon nanotubes or graphene film have been applied for this stretchable composite interconnects.

There are many techniques such as vacuum evaporation, photolithographic patterning, transfer printing and screen printing that can be used to fabricate stretchable electronics. However, this approach is limited only to two-dimensional (2D) structure and low aspect ratio features that should be supported by substrates (Ahn and Je, 2012).

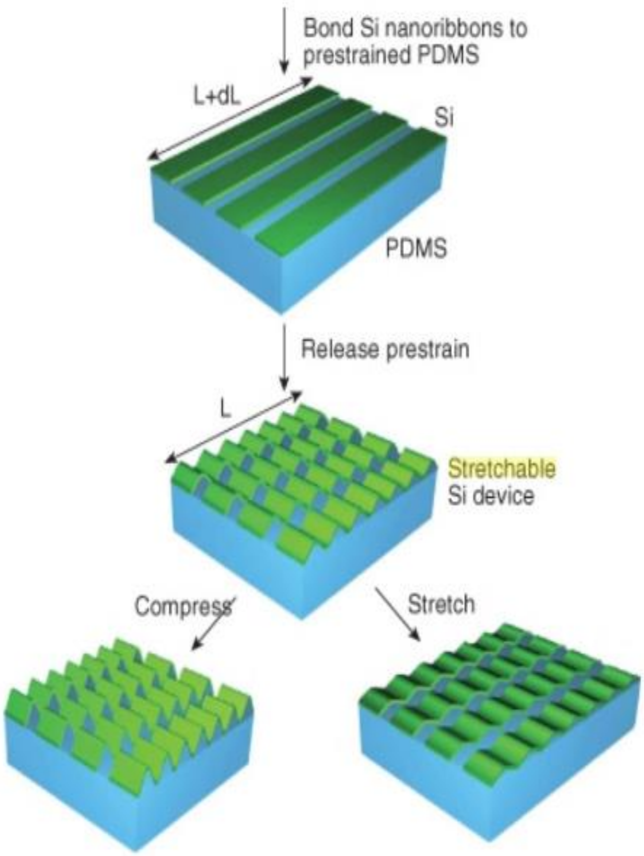

Figure 1.1: Schematic illustration of the process for fabricating buckled, or 'wavy,' single crystal Si ribbons on a PDMS substrate (Gao, 2011).

Recently, development of strain sensors have attracted much interests among the researchers. According to Bae et al. (2012), strain sensor can be used to detect any deformations or structural changes in our surrounding infrastructure and also the internal activities in human bodies. Typically, strain sensor is fabricated by printing the conductive ink onto the stretchable substrate.

Electronic materials can be classified into two major groups. The first group is structural electronic materials. This group relatively stable to pressure and weight. Besides, they also have good mechanical properties and can be used as frames, casings, substrates, sealing materials and packaging. The next group is functional electronic materials which can be used to realize chemical, magnetic, electrical, thermal functions and optical. This group can be divided into two groups as well, which are inorganic electronic materials and organic electronic materials (Gao, 2011).

The combinations of conductive ink, which have high electrical conductivity, with substrate with high elasticity, results in strain sensor with excellent conductivity, flexibility and even stretchability. However, there is drawback of this combination which is increase in content of conductive ink will reduce the elasticity of the substrate. Increase in conductive ink content will increases the rigidness of the strain sensor. This is due to the different in elastic properties between conductive ink and substrate. Conductive ink are rigid while substrate are flexible and stretchable.

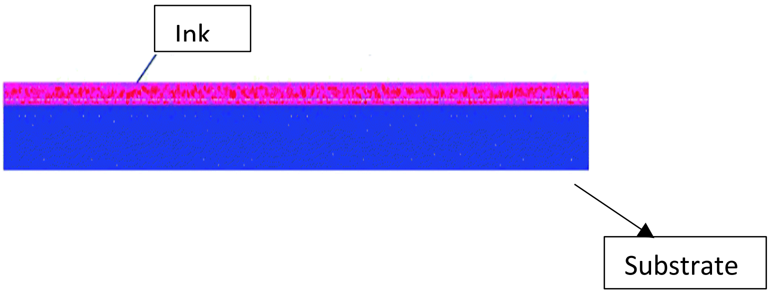

Figure 1.2: Printed conductive ink on substrate.

Polydimethylsiloxane (PDMS) is widely used to fabricate stretchable electronics. PDMS is physically and chemically stable silicone rubber. It has unique properties such as good flexibility and has the lowest glass transition temperature compared to other polymers. In addition, PDMS also has low curing temperature, high compressability and very low change in elasticity versus temperature and time (Deepalekshimi et. al., 2015).

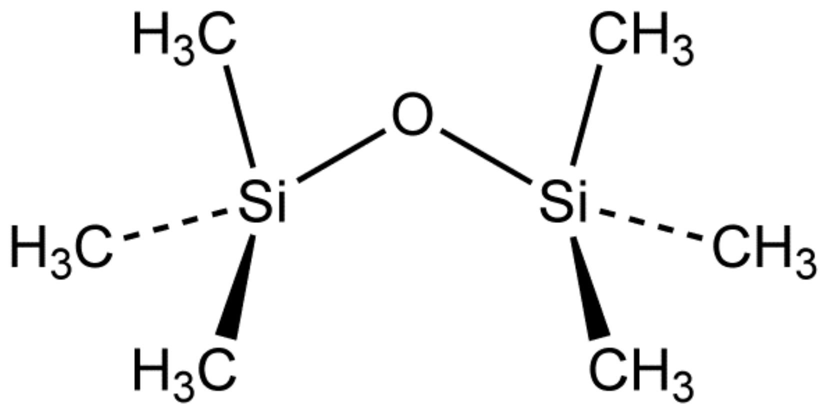

Figure 1.3: PDMS chemical structure.

Because of its transparency, flexibility and good biocompatibility, PDMS has play an important role in patterning functional materials and fabricating devices such as transfer printing, microfluids and implantable medical devices. The combination of conductive patterns with PDMS result in high-performance devices, such as stretchable conductors, wearable devices and electronic skins (Sun et al., 2016).

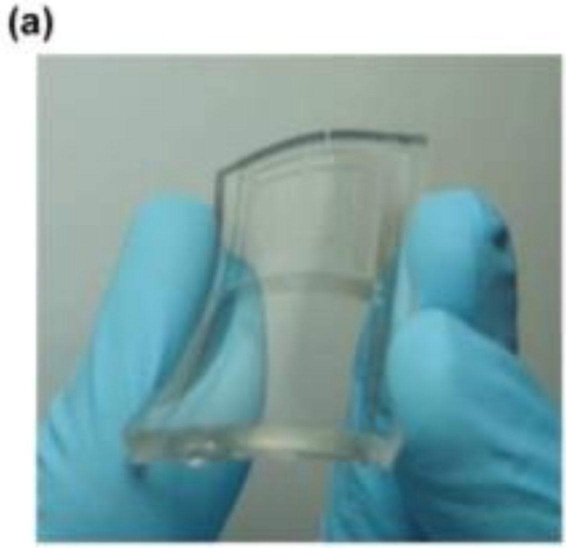

Figure 1.4: Transparent and flexible graphene films on PDMS substrate (Ahn and Je, 2012).

Conductive fillers are important in producing high performance stretchable electronics. The electrical properties of the stretchable electronic such as electrical resistance are influenced by the type of conductive fillers used. The conductive materials for stretchable electronics have more diversity compared to the elastomeric materials. They vary from inorganic materials, solids to liquids and bulk films to nano-scale percolation systems (Yu et al., 2016).

The choice of conductive ranges from carbon to precious metals. Graphite is used for radio frequency interference screening. However, metals are much better in conductivity. It is usually used in fine powder or flake form. Base metals such as nickel (Ni), copper (Cu) and aluminum (Al) oxidize in air while silver (Ag) oxidizes very slowly. Because of this, silver is the favored metal compared to other metals to be used as conductive filler for stretchable electronics (Minges, 1989).

Silver ink is mostly used as conductive materials in the fabrication of strain sensor due to its stability and higher conductivity compared to other conductive materials. Besides, the conductivity of silver will not reduce even as an oxide. Due to its good properties, silver usually used to replaces Cu and Al metals since Cu and Al have low conductivity.

However, Tao et al. (2013) in their research stated that metallic nanoparticle inks usually require high annealing temperatures (>150^{o}C) in order to decompose the stabilizing agents and other polymeric additives that inhibit electrical conductivity. This will limit the choice of substrate. Besides, after a long-term storage, it will result in condensation and agglomeration of nanoparticles.

1.2 Problem Statement

The problems that need to be faced in this research is how to improve the conductivity property of the substrate and conductive ink. In the fabrication of stretchable strain sensor, good conductivity as well as reproducibility of strain sensor should be obtained since excellent conductivity in a sample will make it becomes easier for a current to flow through the sample and reduce the resistivity.

Another problem in this research is to identify the right amount of composition of formulation for substrate and conductive ink. In order to get a sample with good conductivity, stretchability and reproducibility, the right amount of ingredients for substrate and conductive ink need to be determined. Choosing the right formulation is a critical success factor for the excellent performance of strain sensor. Factors such as conductive materials and substrate used need to be considered in creating a good formulation. Thus, right formulation needs to be determined in order to fabricate strain sensor with good conductivity and stretchability.

Besides, it is also difficult to control the consistency of the resistance in a fabricated strain sensor. Strain sensor produced must have constant resistance with not much change even after several cyclic deformation and strain.

1.3 Objectives

- To prepare the conductive ink based on PDMS substrate and silver ink.
- To formulate and design consistency in the device in terms of cyclic deformation and strain.
- To design strain sensor with good conductivity and consistency.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Strain Sensor

Researchers from all over the world have done so many researches on strain sensor. Sensor are an essential part of a smart system. In many applications, it would be especially used as the sensing element that could be embedded as part of the structure that is monitored. Printing is used to fabricate the sensors, and the strain sensitivity of the prototype sensor is based on the materials used.

Strain sensors can detect strain of various conditions and surfaces. For example, if strain information about infrastructure (e.g., gas or water pipe-lines) or vehicles (e.g., airplane) can be monitored in real-time, and therefore, severe accidents due to breaks or cracks might be prevented. Flexible and/or stretchable strain sensors have been widely demonstrated, especially using nanomaterials, piezo materials, and transistor structures. As an example of a printable strain sensor, Ag nanoparticles and CNTs is the most popular conductive fillers used to form a strain sensor on a flexible substrate using a screen printing or painting method. Many strain sensors using nanomaterials, involve a mechanism where the distance between nanomaterials increases (decreases), resulting in an increase (decrease) in electrical resistance due to tunneling current between nanoparticles upon applying a tensile (compressive) strain (Shen & Fan, 2016).

Amjadi et al. (2014) and Neella et al. (2015) in their research stated that strain sensors respond to mechanical deformations or structural changes occurring in the surrounding infrastructure as well as internal activities of moving objects by the change of electrical characteristics such as resistance or capacitance. Countless effort has been done to develop highly sensitive and stretchable strain sensors to detect the process of body motions and work at high strains to monitor large scale deformations (Zhang et al., 2015).

There are some requirement need to be considered to fabricate a high performance strain sensor. Amjadi et al. (2014), Lee et al. (2014) and Alaferdov et al. (2016) in their research found that sensitivity, stretchability, response speed, stability, fabrication cost, and simplicity is the important factors to be considered in order to produce high-performance strain sensors. Due to these requirements, researchers are looking for the efficient materials which can exhibit large structural changes due to applied strain and are focused on materials at low cost.

There are many ways can be done to fabricate the strain sensor with a high performance. Zhang et al. (2015) in their research found that, a highly flexible, stretchable, sensitive, and reliable strain sensors can be fabricated by designing a special nano-structure using one-dimensional (1D) nanomaterial (carbon nanotubes) and zero-dimensional nanomaterial (silver nanoparticles). The Ag NPs can modify the surface of CNT and reduce the interfacial resistance between CNTs, which plays an important role in achieving the superb performance of the sensor.

While Morteza et al. (2014) in their research found that highly flexible, stretchable and sensitive strain sensors can be obtained by fabricating it in the form of sandwich structure (AgNW thin film embedded between two layers of PDMS). This form of sandwich structure has excellent flexibility, stretchability and bendability compared to conventional strain sensors which are easily damaged even by mild touching.

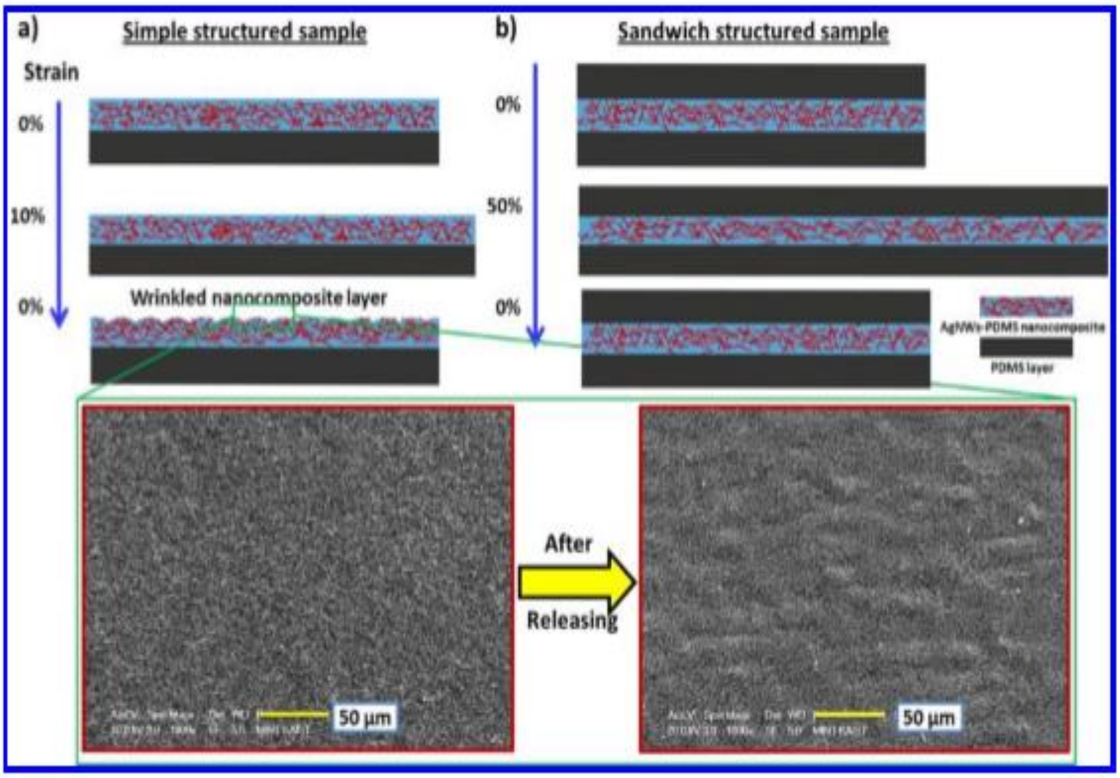

Figure 2.1: Schematics for the behavior of the simple (a) and sandwich (b) structured under cyclic stretch/release cycles (Morteza et al., 2014).

2.2 Printed Circuit Board (PCB)

The purpose of the printed circuit board is to provide both the physical structure for mounting and holding electrical components. Besides, it also provide the physical structure for the electrical interconnection between components (Khandpur, 2005).

According to Merilampi et al. (2009), printed circuit consist of conductive ink and a flexible substrate as a printed circuit board (PCB). When using flexible PCB (FPCB) materials the conductive patterns as well as the substrate has to tolerate bending, vibration, thermal shock and stretching. Because of this, the microstructure of the printed pattern has to be defect free. Defects such as porosity and cracks shall be avoided and there must be good adhesion between the substrate and the pattern. In addition, changes in the cross section area of the printed pattern also should be minimized. The polymer matrix of the ink is an important factor of the mechanical properties. Electrical conductivity also has to fulfill the demands of the applications.

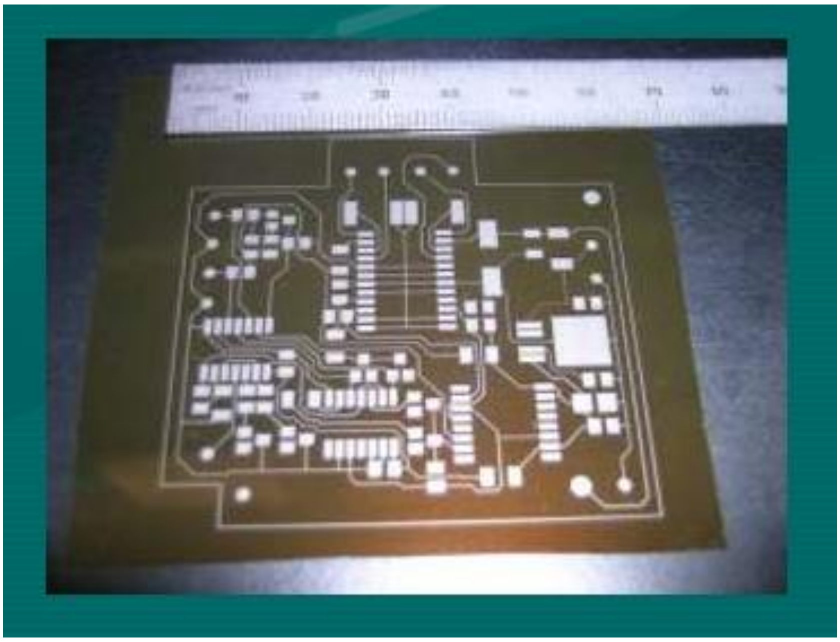

Figure 2.2: Printed flex circuit on polyimide

On the other hand, Vieroth et al. (2009) on their research stated that even FPCB technology already gave the designer a new degree of freedom, however, it is still not stretchable. FPCB still a plastic foil which can only conform to simple surface topographies (2D comformability). This is the reason why researchers worldwide are seeking for the next degree of freedom, the stretchable circuit board (SCB). Wearable systems that are really follow the shape and movements of the body are possible (3D conformability).

Larmagnac et al. (2014) has fabricated a stretchable printed circuit board which is the mixture of Ag and PDMS that can be stretched at high strains while maintaining high conductivity.

2.3 Polydimethylsiloxane (PDMS) as Substrate

Various conducting polymers, such as poly(3,4-ethylene dioxythiophene) (PEDOT), polyaniline (PANI), polyacetylene (PA) and polypyrrole (PPY) have been developed for wide range of applications, however they have poor mechanical properties. For example, a poly(3,4-ethylene dioxythiophene):poly(styrene sulfonic acid) (PEDOT:PSS) film, which is widely employed in plastic electronics and organics-based optoelectronic devices, shows high electrical conductivity up to 1000 S/cm, but its breaking strain is below 10%. This level of tolerance to strain is not acceptable for the above-mentioned applications (Noh, 2016).

While, an elastomer such as natural rubber (NR), polyurethane (PU), ethylene-propylene-diene monomer (EPDM), poly(dimethylsiloxane) (PDMS) and styrene butadiene rubber (SBR) can withstand high strain but have poor conductivity. Thus, various studied have been done in order to increase both stretchability and conductivity.

To achieve both stretchability and conductivity, PDMS were used in order to develop stretchable electronic due to its transparency, flexibility and good biocompatibility. PDMS belongs to silicone elastomer family. PDMS comes in various form such as thin films, tubes and rods, foams or particles packed into sorbent tube are applied mainly in the areas of sampling of organic compounds from air, water and soil gas matrices, as well as manufacturing of laboratory-on-a-chip devices (Deepalekshimi et al., 2015).

PDMS is a commonly used silicon-based organic polymer. PDMS is widely used in various application due to its unique mechanical, chemical and optical properties. The primary field of application for PDMS, a silicone elastomer, is the embedding of electronic components through casting, which prolongs chip lifespan. Due to its very good contour accuracy (< 10 nm), it has been increasingly used in the micro- and nanotechnologies. It is often found in fluidics, optical system and sensors (Schneider, 2008).

Generally, it is obtained by combining a pre-polymer (vinyl terminated PDMS) and a cross-linker (dimethyl, methyl hydrogen siloxane) in specific ratio and subsequently curing them at specified conditions (Deepalekshimi et al., 2015). The chemical formula for PDMS is $(H_3C)_3SiO[Si(CH_3)_2O]nSi(CH_3)_3$, where n is the number of repeating monomer $[SiO(CH_3)_2]$ units.

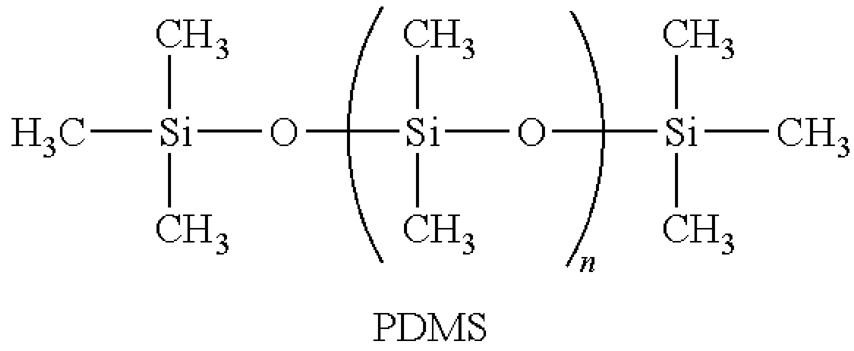

Figure 2.3: PDMS chemical formula.

Due to its desirable properties, make it attractive for the development of stretchable conductive ink. Their own unique properties, such as, low glass transition temperature (T_g), low surface tension and surface energy, low solubility, low dielectric constant, transparent to visible and UV light, very resistant to ozone, and stable against atomic oxygen plasmas (Hopper, 2007). Apart from used in electronic application, PDMS also used as a food additive, in shampoo, and as anti-foaming agent in beverages or in lubricating oils.

2.4 Conductive Ink

The conductive ink is a mixture of metallic particles contained within a solvent. The non-Newtonian rheology of this mixture allows the ink to be screen printable. The common conductive materials used in the fabrication of strain sensor is carbon nanotubes (CNTs), graphene and metal particles. Formation of network between conductive filler provides an electrical pathway for the conduction of electron in the strain sensor. Thus, electrical properties of the sensor can be achieved by the filler-filler network within the matrix. According to Wang et al. (2016) in their research, they stated that among all the conductive materials, carbon and graphene have poorer conductivity compared with metal.

Silver is one of the metal particles and it is commonly used as conductive filler compared to other metals. This is due to its unique properties which is it have high conductivity and there is almost no change in the conductivity as the silver particles oxidize. Silver particles are very easy to form and to fabricate into ideal shapes. Silver can be precipitated into a wide range of controllable sizes and shapes. This means that just the right sizes of particles can be produced for use "as is" or for milling into fine flake. It is even possible to precipitate silver into particles so thin that they are translucent (Gilleo, 1995).

Xu and Zhu (2012) found that their Ag nanowires (AgNWs)-PDMS composite achieved a high conductivity of 5285 S/cm in a tensile strain range of 0%–50%. Lee et al. (2014) have proposed a new type of AgNWs/PDMS stretchable strain sensor that can detect both tensile and compressive strain. Amjadi et al. (2014) has fabricated a sandwich structure of silver nanowire and PDMS (Figure 2.4). This strain sensor showed strong piezoresistivity and high stretchability up to 70%.

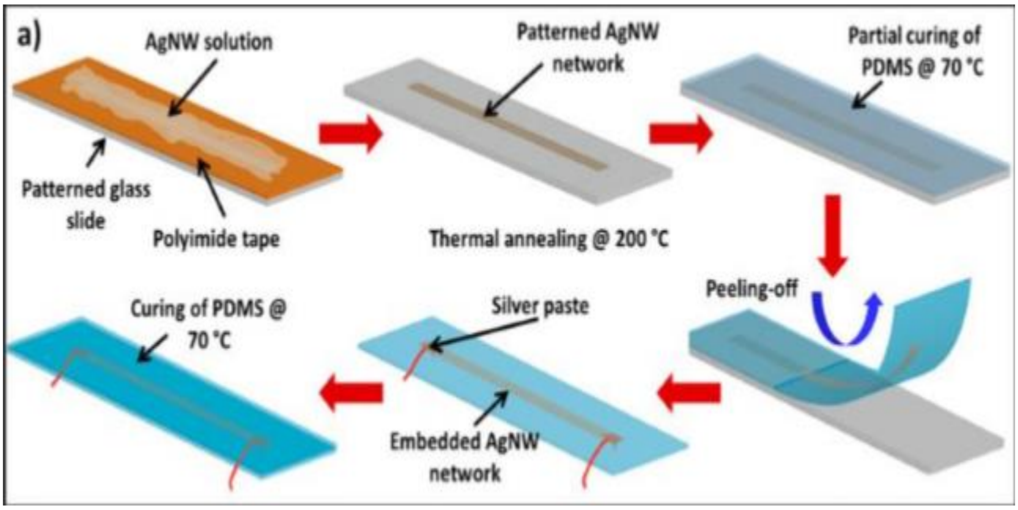

Figure 2.4: Fabrication process of sandwich structure of silver nanowire and PDMS strain sensor.

On the other hand, graphene also has widely used as conductive filler due to its good electrical properties, unique physical properties and high mechanical properties. Graphene is a nanocarbon material. Graphene exhibit good physical, chemical and electrical properties due to its unique two-dimensional honeycomb lattice structure (Aliofkhazraei et al., 2016).

Liu et al. (2016) reported that a layered graphene based strain sensor which could sustain large tensile deformation (25% strain) demonstrated high sensitivity to mechanical strain with gauge factor of 6 – 35. Jing et al. (2013) also reported graphene based strain sensor with high sensitivity. Further, Li et al. (2016) showed that graphene can be stretched as high as 30% of its original length and the gauge factor of this sensor is as high as 98.66 under 5% of applied strain.

Carbon nanotubes (CNTs) are nanometer sized fibers with extremely high aspect ratio, Young's modulus and tensile strength, current carrying ability, and thermal conductivity (Cai et al., 2013). Various research has been done on carbon nanotube based strain sensors. Yamada et al. (2011) reported that their carbon nanotube based strain sensor can measure and stand strain up to 280% with high durability (10,000 cycles at 150% strain) and fast response. Tadakaluru et al. (2013) also reported that carbon nanotube strain sensor could measure high strains of up to 620%, with high sensitivity of 5-43. Further, Song et al. (2016) also fabricated the carbon nanotube strain sensor with high strain and sensitivity.

Copper is a good alternative material for silver because of its high electrical conductivity and low price. Therefore, the uses of copper as conductive fillers can reduce the manufacturing cost. However, the problem occur when using copper as conductive filler is, it is easily oxidize in an atmospheric environment. Thus, the prevention of oxidation in copper inks is very important (Tsai et al., 2015).

Due to this problem, most copper nanoparticles are covered with an oxide shell and cannot be sintered by thermal sintering under ambient conditions. Besides, the use of laser process and plasma process have been developed in order to sinter copper nanoparticles without oxide shells. However, these approaches are complex process and it is very expensive equipment (Joo et al., 2014).

2.5 Printing Method

The requirement in developing electronic device with low manufacturing costs, long-time endurance, environmentally sustainable production methods, lower energy consumption and higher efficiency and the integration of electronics as part of other structures, have become more important. Thus, new manufacturing technique such as printing, have to be developed and new advanced materials have to be taken in use. Printing is an additive method which can be used to prepare conductive patterns directly on flat or even differently shaped and curved surfaces (Merilampi et al., 2009).

The use of printing techniques in electronic industries is well established and this has allowed for the creation of printed circuit boards on various substrate (Ryan & Lewis, 2007). In addition, components such as transistors, sensors, RFID tags and diode also can be produced by printing techniques (Ryan & Lewis, 2010). The big advantages of printing technique is, it is low cost methods and suitable for mass production.

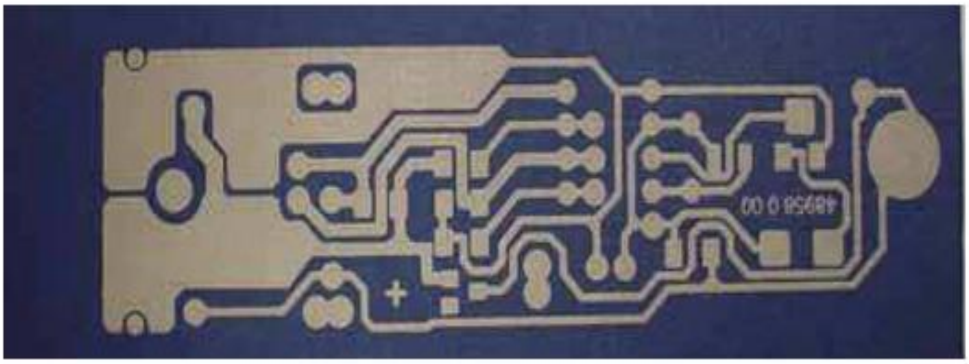

Figure 2.5: Successful printing of conductive ink (Ryan & Lewis, 2010).

There are many different printing techniques that can be done. For example, inkjet printing, microtransfer printing, screen printing and stencil printing. Printing methods can be developed by using soluble materials such as carbon nanotubes (CNTs), graphene, conducting polymers like poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) (PEDOT:PSS), metal nanowires, and metal nanoparticle ink. (Park et al., 2016).

2.5.1 Inkjet Printing

According to Kang et al. (2010), direct inkjet printing method has attracted much researcher interest. This because, this method does not require any additional etching and metal deposition process likes photolithography method. Besides, direct inkjet printing method only require one-step printing procedure in creation of conductive pattern on various substrates. In addition, by using this method, the cost and material can be reduced, flexibility of changing patterns and capability of printing on a large area.

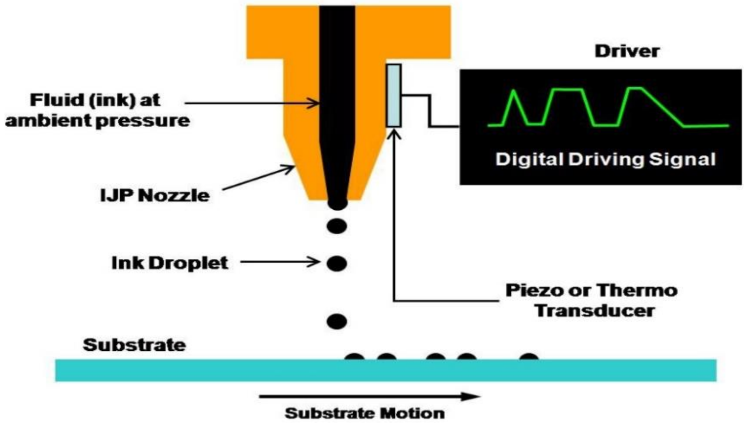

Figure 2.6: Inkjet printing technique (Kang et al., 2010).

The process involves in the inkjet printing is the ejection of a specific amount of ink in the chamber, through a nozzle. The ejection of liquid drop from a nozzle is resulted from the sudden quasi-adiabatic reduction of chamber volume via piezoelectric action which causes a shockwave in the liquid (Singh et al., 2010).

2.5.2 Transfer Printing Method

Transfer printing method is a printing method which can solve the limitation of substrate types. This method can be conducted on a glass or a wafer surface used as a donor substrate. Then, the printed pattern layer can be transferred to a film substrate (Park et al., 2016).

Generally, the donor surface is modified into a hydrophobic layer before the printing process. However, it is hard for metal nanoparticle-dispersed ink to be applied to this microtransfer printing method. This is due to the printed electrode pattern cannot be process by the conventional interfacial surface treatments after sintering process because of the binding materials mixed into inks. The binding materials should be mixed with the inks for good printability and mechanical stability of the printed electrode.

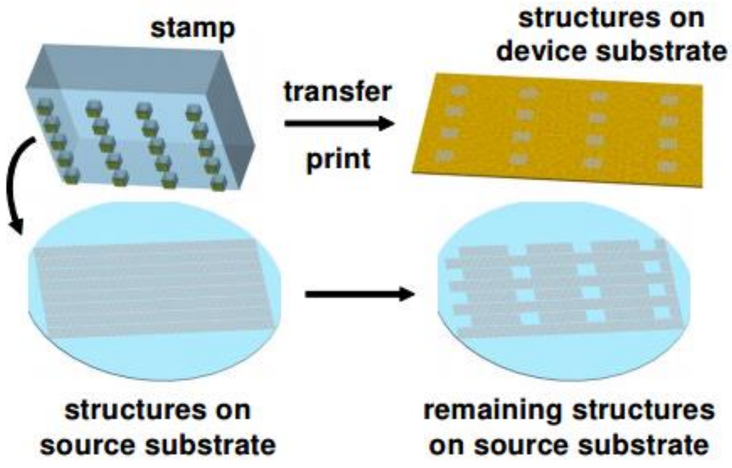

Figure 2.7: Transfer printing technique.

2.5.3 Screen Printing

Screen printing is a simple and efficient method of reproducing patterns on a various substrates. A printing screen consist of a frame on which a screen is stretched taut, typically consisting of a woven mesh with a patterned stencil attached to the mesh (Kosloff, 1980). The squeegee will be used to press the ink on the screen mask. The ink will pass through the portions of the mesh that are not covered by stencil material and therefore the ink will be transferred onto the substrate (Hyun et al., 2015).

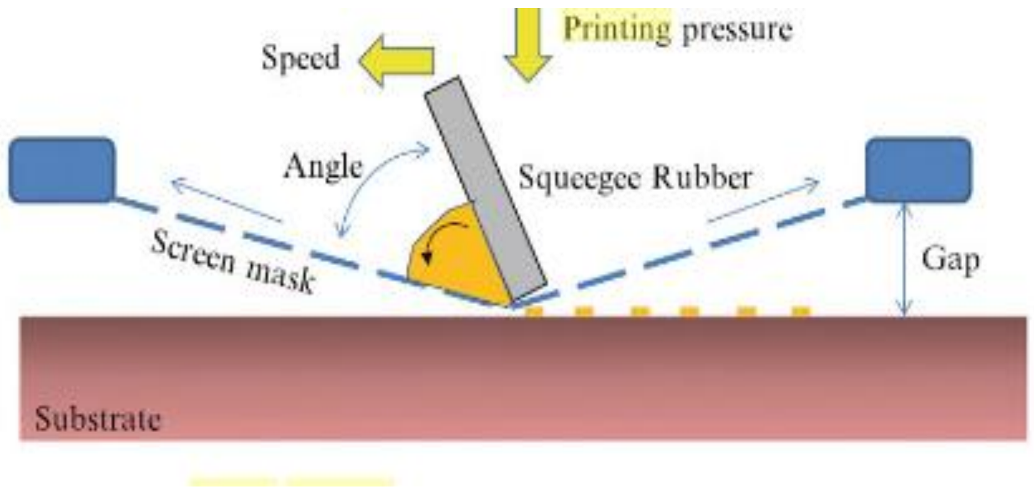

Figure 2.8: Screen printing method.

2.5.4 Stencil Printing

This printing technique is a simple and efficient method in producing conductive material onto the substrate. Stencil printing uses a squeegee to press a viscous material through a thin metal sheet with patterned opening (stencil), onto the substrate. Conductive material then will passed through the stencil opening and is transferred onto substrate, producing printed pattern (Kay and Desmulliez, 2012). Printing could be repeated several times using the same stencil without losing quality.

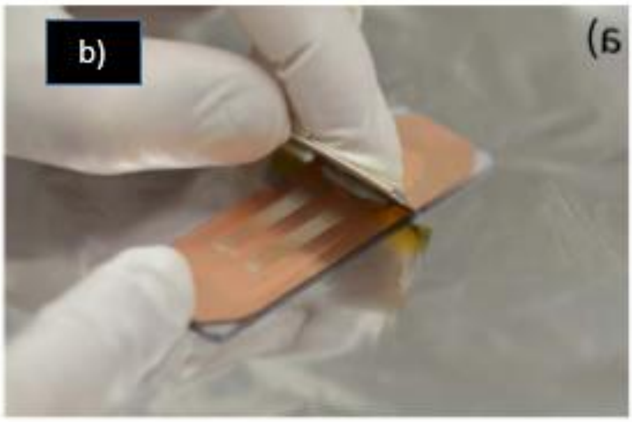

Figure 2.9: Stencil printing method (Larmagnac et al., 2014).

In general the frames of the screen and stencils are similar, the differences lie in the construction of the individual openings used for depositing the printing medium. A screen will contain open wire mesh around which the conductive material must flow to reach the substrate surface, a stencil aperture is fully etched and therefore does not obstruct the flow of the conductive material (Ryan & Lewis, 2010). The main advantage of stencil printing over screen printing occurs in applications where very small areas of paste have to be deposited. For components with pitches equal to or smaller than 0.65 mm, the stencil printing process is the only viable way for printing solder paste. Therefore, stencil printing has replaced screen printing in most cases (Salvendy, 2001).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter reported preparation process of the stretchable strain sensor. In producing stretchable strain sensor, substrate and conductive ink need to be prepared. There are specific amounts and ingredients used in the preparation of substrate and conductive ink. The conductive ink needs to be printed on the substrate.

3.2 Substrate Preparation

The substrate needs to be prepared first before conductive ink. The ingredients used for substrate preparation are polydimethylsiloxane (PDMS), fume silica, toluene and dibutyltin dilaurate. Table 3.1 shows the formulation used in preparation of substrate.

Table 3.1: Formulation of PDMS substrate.

Reagent	Amount
PDMS	7 g
Fumed silica	0.14 g
Toluene	13.86 µl
Dibutyltin dilaurate	70 µl

Firstly, PDMS were weighed in a beaker using weight balance. After that, fume silica was weighed with a specific amount. At the same time, the toluene was poured into another beaker. The weighed fume silica is then added into a beaker containing toluene. The mixture of toluene and fume silica was stirred until homogeneous. After the mixture achieves homogeneity, the mixture is then poured into a beaker containing PDMS and was stirred until mix well. Next, dibutyltin dilaurate was added and stirred for 10 seconds. Lastly, the mixture will be poured into a mould and was left at room temperature for 1 hour. Substrate preparation process was showed in Figure 3.1.

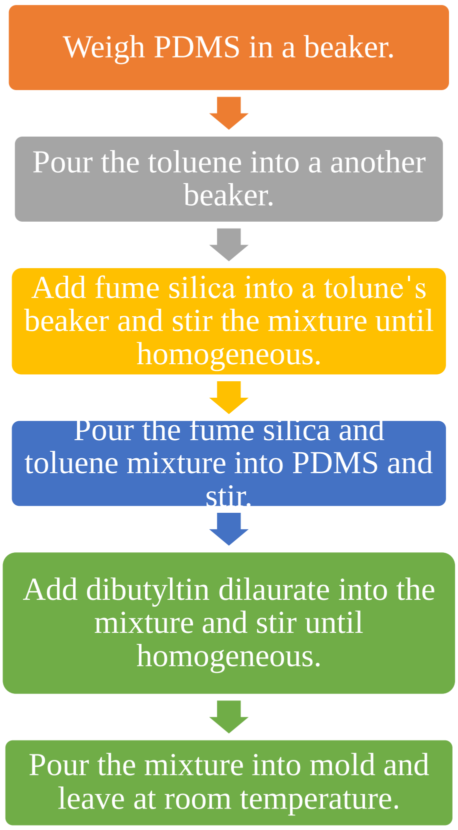

Figure 3.1: Process flow of substrate preparation.

3.3 Conductive Ink Preparation

The ingredients used in the preparation of conductive ink are octamethyl-cyclotetrasiloxane, silver powder, polydimethylsiloxane (PDMS) and acetic acid as shown in Table 3.2

Table 3.2: Formulation of conductive ink.

Reagent	Amount
Octamethyl-cyclotetrasiloxane	450µl
Silver powder	1.5g
Polydimetylsiloxane (PDMS)	0.2g
Acetic acid	2µl

Firstly, octamethyl-cyclotetrasiloxane was poured into a beaker with a specific amount. Then, silver powder was added into that beaker with needed amount. The mixture was stirred until homogeneous. After that, PDMS-OH was added to the mixture and stirred until homogeneous. Next, vinyl trimetoxysilane was added and stirred. Lastly, acetic acid was added and stirred until homogeneous. After that, the conductive ink prepared was printed on the substrate and cured at 80°C for overnight.

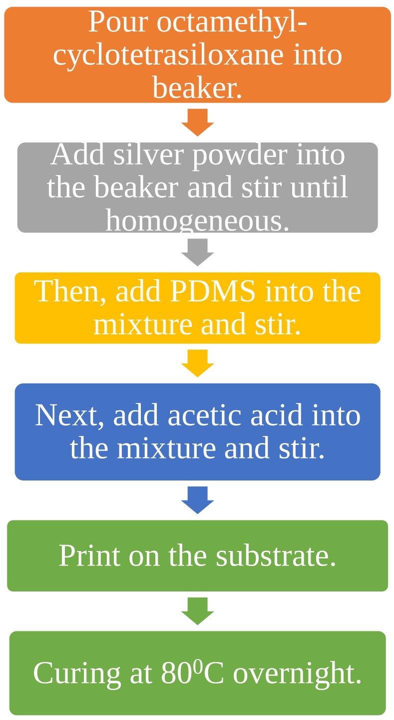

Figure 3.2: Process flow of conductive ink preparation.

3.4 Testing and Characterization

3.4.1 Fourier Transform Infrared Spectroscopy (FTIR)

FTIR is a commonly used technique to identify the functional groups in organic compounds. This equipment is an effective method to investigate the chemical composition of the materials. FTIR can provide the information about unknown materials, quality or consistency of a sample and it can determine a number of components in a mixture.

Figure 3.3: FTIR machine.

The internal energy of a molecule consists of the sum of rational, vibrational, and electronic energy. The internal energy of a molecule can absorb the energy of infrared light since infrared radiation has a strong connection with this internal energy. Thus, the molecular vibrational energy can bound to upper level especially when the frequency of