Laser Scribed Porous Graphene on Polyimide Film for Flexible Strain Sensor

by

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15985

Dissertation submitted in partial fulfilment of

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Universiti Teknologi PETRONAS

32610 Bandar Seri Iskandar

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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(ELECTRICAL AND ELECTRONIC)

Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR
PERAK
JANUARY 2017

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

WAN MUHAMMAD ZUBAIR BIN WAN MAT

ABSTRACT

Strain sensor is a device that is used to measure electrical resistance change from the effect of mechanical fundamental. Strain sensors are widely used in structural health monitoring, wearable electronic, soft robotic and many more. Since the uses of strain sensors are very significant nowadays, there are a lot of studies in developing strain sensor recently. However, constrained strain before break, small gauge factor, leakage of liquid, complex synthesis, time consuming, and high cost has become one of the drawback in current strain sensor. In this report, a strain sensor is fabricated using a new nanomaterial found in 2004 which is a graphene. The characteristic of graphene that have high electrical conductivity, very strong material and high flexibility characteristics can increase the ability of the graphene strain sensor as a sensing devices. Laser scribed technique will be used to grow porous graphene on polyimide film and the graphene will be transferred onto polydimethylsiloxane (PDMS) to enhance the ability for the strain sensor to be more elastic and flexible. This research will evaluate the properties of the fabricated graphene strain sensor as a sensing element using scanning electron microscope (SEM) evaluation, transmission electron evaluation (TEM) and Raman spectroscopy. The graphene strain sensor also will be analysed using electromechanical properties which are tensile, bending and IV-characteristic. The outstanding characteristics of the graphene will be able to produce a sensitive and flexible strain sensor.

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CHAPTER 1

INTRODUCTION

1.1. Background

Strain sensor is a device that is used to measure electrical resistance change due to mechanical fundamental like force, pressure and etc. The applied force on the structure can be classified either strain or stress. The changes in structure of the material due to force will affect the conductivity of electron flowing through. In this project, graphene will be used as the sensing element in strain sensor.

Strain sensor using transparent conducting electrode (TCE) have been widely used and applied in countless field of electronics. Its electrical conductive characteristic with its transparent optical characteristic has made it being used in many applications especially in the optoelectronics, medical implant, light emitting diodes and solar cells. [1] [2]

Graphene, a two dimensional carbon which packed tightly into honeycomb lattice have been explored to be the most promising TCE. The conductivity and transparency is better and more efficient than indium tin oxide which have several drawbacks. [1] Because of its exceptional mechanical and electrical properties, graphene has gained tremendous attention since its discovery by Andrew K. G. and Konstantin S. N. in 2004 [1]. It has turned into the centre of broad research inferable from its remarkable basic, electrical, thermal, optical, and mechanical properties. [2−6]

Stretchable and flexible sensors have dragged in extensive consideration for their potential applications in wearable electronics, structural health monitoring, and non-rigid robotics [5]. Preparation technique in getting graphene can influence the electrical properties obtained of that graphene. Not only the electrical properties, the strain, electric field, magnetic field, and other physical aspects that are connected to it will definitely bring about many-sided quality of the matter.

In contrast with the electric field and magnetic field, strain can be connected to graphene more effectively, and applications that identify with the strain are extremely widespread, for example, weight sensors, ultrasonic sensors, and research of oil and coal. [7] Furthermore, flexible sensors have pulled in extraordinary enthusiasm because of their delicate and rubbery properties and potential applications, for instance, in latest intervals conductive polymer composites (CPCs) with two-dimensional (2D) graphene, carbon dark, or carbon nanotubes as conductive fillers have been broadly explored and proposed to be utilised as sensors for different stimuli, for example, strain, pressure, and touch. [8-9]

In this research project, the 3D graphene will be synthesized on polyimide film by using laser scriber and then transfer to polydimethylsiloxane (PDMS) composite for better flexibility and stretch ability. Conventional metallic and semiconducting sensors are inappropriate for stretchable uses since the sensors can just endure extremely restricted strain before crack approximately less than 5%. [10]

1.2. Problem Statement

A strain sensor is often to be connected with flexibility, elasticity and reliability. Currently available strain sensors suffer from various drawbacks such as can just withstand exceptionally limited strain before break, small gauge factor, leakage of liquid, complex synthesis, time consuming, and high cost.

Liquid based strain sensor always facing problem with small strain and also suffer with leakage for example mercury strain sensors, conductive liquids strain sensors and silver nanowire strain sensors. While, solid based strain sensor like metallic foil sensors and semiconductors wafer sensors usually better in form of constraining strain but they suffer with complex process of synthesising, time consuming and high cost material. Obtaining graphene on polyimide film using laser however can solve these problems.

Up until today, various technique has been carried out in order to obtained good quality of graphene not only by laser. Different technique will produce different quality of graphene and also possess different difficulty of synthesizing level. The examples of the techniques are exfoliation, hydrothermal self-assembly, chemical vapour deposition, carbon dioxide reduction, nanotube slicing, spin coating, intercalation and many more.

This research will attempt to address the existing problems by using a simple technique to produce a porous graphene for strain sensing applications. By using laser technique, the process will be easier since it is not involving any chemical process. Compared to chemical vapour deposition technique, laser technique will consume less time and a design can be obtained in less time after undergoing the laser scribe process. Although the material of polyimide film is cheap, compared with other strain sensor materials but it is able to give high quality of graphene. By applying polydimethylsiloxane (PDMS) that has flexible properties, it can improve the quality of the strain sensor while minimize its drawbacks.

1.3. Objectives

The specific objective of research is to study the electromechanical properties of porous 3D graphene grown using laser scriber on polyimide film. The following research strategies will be undertaken in order to achieve the objective:

a. To synthesize 3D graphene on polyimide film using laser scriber
b. To transfer the 3D graphene on polyimide film to polydimethylsiloxane (PDMS)
c. To evaluate the electromechanical properties of fabricated 3D graphene/PDMS composite film

The electromechanical properties such as the resistance change during the compression, tensile, and bending will be studied in detail. The outcome of the studies will greatly benefit in developing a highly sensitive and flexible strain sensor for applications in sports and health monitoring, kinesiology, and wearable electronics.

1.4 Scope of Studies

The scope of work consisting two stages:

1. The first stage will involve the design and integration of the components namely the 3D graphene and underlying substrate that will host the graphene for flexibility and stretch ability. In this stage, graphene will be grown using laser scriber on polyimide film and then transfer to PDMS. The growth and transfer parameter will be optimized.
2. Second stage will be testing and evaluating the fabricated 3D graphene/PDMS composite film. The electromechanical properties (resistance change to compression, tensile, bending) will be studied by using a fabricated specialized holder and digital multimeter 34465A.

CHAPTER 2
LITERATURE REVIEW

In this chapter, a feasible study has been carried out to discover the possibility of graphene as strain sensor. Graphene was deeply study by referring to the publication of researcher around the world. The graphene’s basic structure and also its properties will be explained in this chapter. Several techniques are used to obtain a pure graphene are explained along with suitable integration to produce high quality graphene.

2.1 Strain Sensor

As for strain sensors, they are suffering with many drawbacks such as limited in withstand strain before fracture, small gauge factor, leakage of liquid, complex synthesis, time consuming and high cost. In order to overcoming these drawback, a lot of research has been made. With the combination of graphene in strain sensor, a lot of these drawback can be countered.

Sensors with high flexibility, stretchable and wearable can be effectively mounted on garments or straightforwardly connected onto the body. Particularly, sensitive and intensely stretchable strain sensors are required for the human gesture recognition. Extremely flexible, stretchable and sensitive strain sensors in accord to the nanocomposite of silver nanowire (AgNW) system and PDMS elastomer as the sandwich structure (AgNW thin film inserted between two layers of PDMS).

The AgNW link elastomer nanocomposite based strain sensors demonstrate robust piezo resistivity with tunable gauge factors in the scopes of 2 to 14 and a high extend capacity up to 70%. Pertinence of superior performance strain sensors is shown by creating a glove integrated with five strain sensors for the movement recognition of fingers and control of a symbol in the virtual environment. [10]

Likewise, there is also the utilization of conductive liquid as a strain sensor. As instance, sensors made out of a very flexible elastomer and mounted conductive liquid eutectic gallium indium (eGaIn) of miniaturized scale channels exhibited generally astound precision with reliable quality in evaluating extensive strain. [11] The uniform change in resistance against sensor affects the uniform change in resistance between ionic solution and eGaIn. Thus, it is proven that gauge factor is significant fluctuated (increase) by 3 times precisely 3.17 times in lieu for ionic solution sensor.

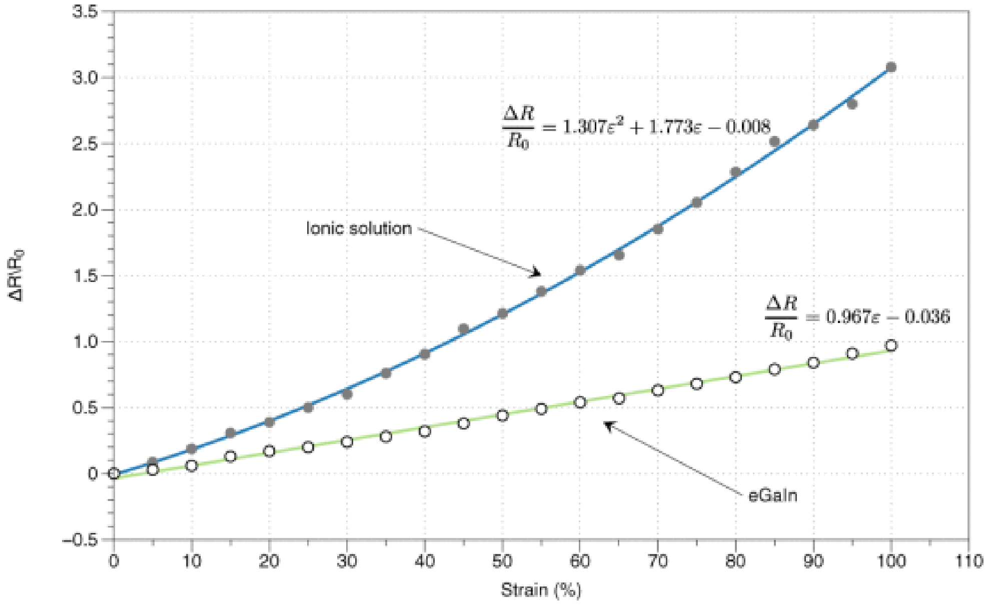

Figure 1: Resistance change against strain

Hence, it conceivable that the viable range of the liquid is in the steady state, when it is approaching the limit of a specific critical stress and channel cross-sectional area. The study made at higher strains than displayed in these diagrams bolster this clarification. After exceeding the strain of 130%, the bend loses its linearity and obtains the characteristic for a quadratic framework in which the channel length and the cross-sectional zone both change.

Next, glycerol in water (H2O) containing sodium chloride (NaC1) acting as an ionic liquid which part of strain sensor sensitive component in the sensor. In order to gain high viscosity solution, glycerol has been utilized in ratio of 1:1 of water and glycerol in volume. Sodium chloride was broken up utilizing a planetary blender, which delivers a radial drive which is almost reach 400g to guarantee the perfect dissolution. The dissolvability of NaCl in 1:1 water/glycerol is 21.8 g for every 100 ml at room temperature. With this fixation, no accelerate shaped in the sensor even with weight or temperature changes.

The utilization of ionic solution in detecting or recognizing had already been proposed. Cheung et al. has proposed a tube shaped strain sensor utilizing a saline solution and reported the study of the impedance of the solution over an extensive variety of recurrence and strain. [12] Nonetheless, the sensor was impressively bigger than in the present study and included the utilization of stiff metal electrodes.

These two features would make this sensor extremely hard to be coordinated into a minimal, versatile and delicate application, for example, a proprioceptive glove. Ionic liquid (IL) have additionally been utilized for observing fluid pressure as a part of a microfluidic system with a specific end goal to illustrate the flow conditions and fluid properties. [11]

Other than that, the second solution utilized as a part of current sensor is a eutectic metal composite comprising of gallium (75%) and indium (25%) (eGaIn, Sigma-Aldrich). Keeping up its liquid state at room temperature (15.7°C melting point), this alloy and Galinstan [13], a comparable combination, are considered non-dangerous substitution to mercury. [11] With a resistivity of just a couple mΩ/cm (29.4 x 10^{-6} Ω/cm), eGaIn has a conductivity near to that copper. Lately, eGaIn and Galinstan have been utilized as a part of flexible and stretchable hardware. [11]

Strain-sensitive part of the sensor is getting electric current supply from microchannel that is loaded with eGaIn. By utilizing this method, the sensor signal can be transmitted. As beforehand showed, the resistivity of the saline solution is much more prominent than that of eGaIn. [11] In fact, the conduction instrument of saline arrangement is on a very basic level not quite the same as that of eGaIn, since it is the development of hydrated ions particles that makes a saline solution electrically conductive.

2.2 Graphene

As mentioned in Chapter 1, graphene conductivity and transparency is better and more efficient than ITO. Among its many advantageous features include thin material (0.34 nm thick), entirely transparent (with 97.7% transmittance), and good electrical conductor at 10^{-6} W.cm compare to ITO which the thickness material 1.14nm, 90.2% transparency, and 7.2×10^{-4} Ω·cm.

2.2.1 2D Single Layer Graphene

The monolayer 2D graphene was discovered to be very useful in producing high frequency in electronic device. It is contained on a single layer structure like in figure 1.

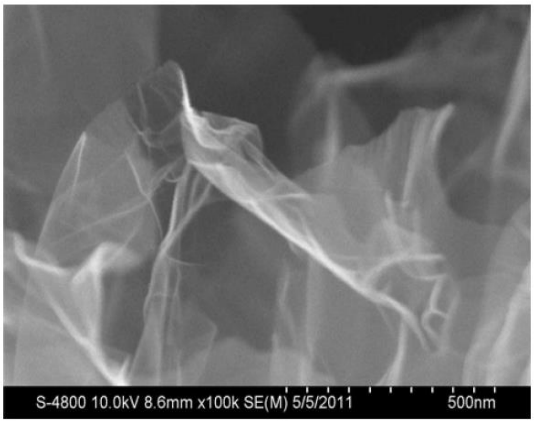

Figure 2: SEM image of 2D monolayer graphene

2.2.2 2D Multilayer Graphene

A few layers of graphene are considered as multilayer of graphene. Multilayer of graphene contain band gap between layer, this feature gives the advantage for graphene to act as transistor.

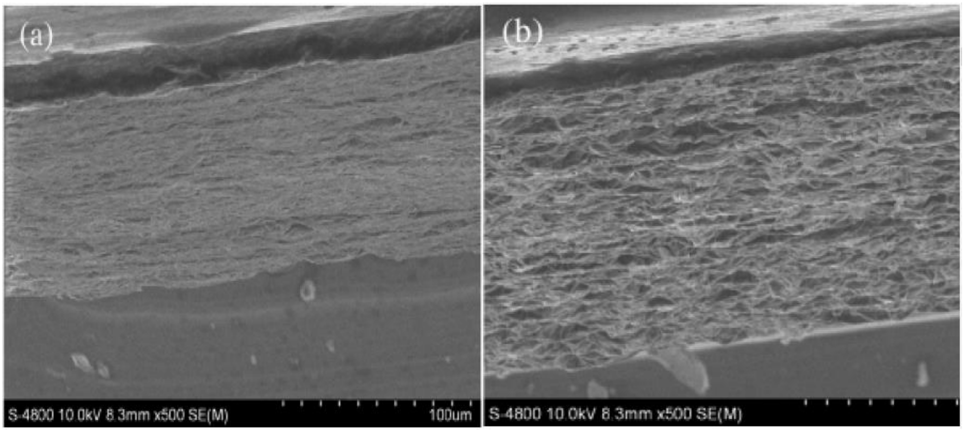

Figure 3 (a) Structure of multilayer of graphene in 100micrometer scale, (b) SEM images of multilayer 2D graphene

2.2.3 3D Graphene

3D graphene on the other hand contains hole either with arbitrary or high normality. Permeable graphene is a changed graphene sheet, where the nonattendance of carbon particles inside the plane make some holes or pores. The scanning electron microscopy (SEM) was utilized to describe the morphology of the test utilizing accelerating voltage [8]. Accelerating speed voltage permits electrons to infiltrate the sample, the higher the accelerating voltage the more entrance into specimen will happen. Subsequently, ultrastructural data from more profound layers will meddle with the genuine surface morphology that is seen [6].

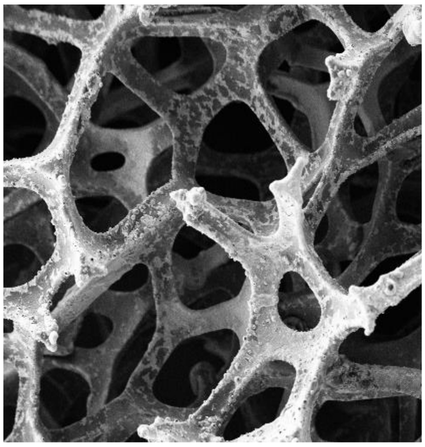

Figure 4: Structure of 3D graphene

2.3 Growth of Graphene

From 2004 until today, the impact of graphene discovery as new nanomaterial to the current technology is very big. A lot of study and research has been carried out in order to improve the production and also the quality of the graphene. Different methods and techniques will give different outcome in term of graphene quality and quantity. There are a lot of techniques that have been discovered for example:

2.3.1 Exfoliation

Exfoliation is the process of removal or separating the outermost layer of the surface. It produces the lowest number of defected graphene with high electron mobility. This technique can be separated into several methods which are

2.3.1.1 Adhesive Tape

In 2004 Andre Geim and Konstantin Novoselov first founder of graphene has invented this technique. This technique can produce a single layer of graphene. The process requires multiple exfoliation steps by using adhesive tape to achieve a single layer of graphene.

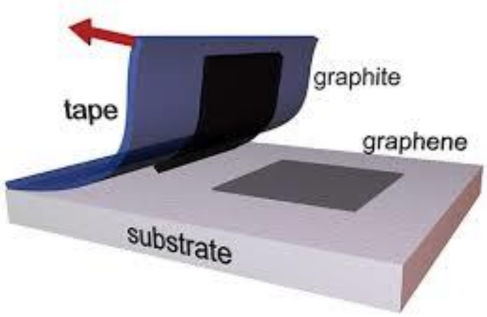

Figure 5: Adhesive tape process of producing graphene

2.3.1.2 Graphite Oxide Reduction

Graphite oxide reduction process are divide into 3 stages to obtain graphene [10] which are oxidation of graphite to form graphite oxide, sonication and stirring process to turn graphite oxide to graphene oxide and lastly electrochemical reduction of graphene oxide to form reduction graphene oxide.

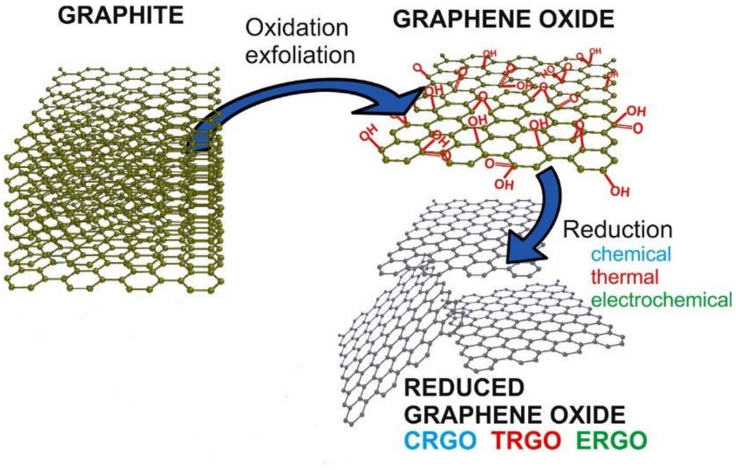

Figure 6: The process of graphite oxide reduction from graphite to reduce graphene oxide

The first process of graphite oxide reduction is treating graphite with strong oxidizing agent like oxygen, ozone, hydrogen peroxide, fluorine, chlorine, peroxydisulfuric acid and nitric acid.

This reaction is known as redox reaction as the oxidizing agent is reducing to oxidise the reactance. When the process is complete, the oxidized compound will disperse into water to form graphite oxide which consist of carbon, hydrogen and oxygen molecules.

After that, the graphite oxide will be turn into graphene oxide by using the sonication process and stirring process. However, this process can damage the structure of individual layer of graphene oxide.

Next, the process of removing oxygen from graphene oxide. There are many ways to perform this reduction process however, electrochemical reduction is the best method to remove the oxygen since the structure of graphene oxide will not be damaged. In this process, the oxygen is reduced from graphene oxide to form reduced graphene oxide.

2.3.1.3 Wedge-Based

In this method, an ultra-sharp single crystal diamond wedge is used as a tool to cleave the bulk of graphite normally use highly ordered pyrolytic graphite (HOPG). The graphite will be cut in square shape dimension by using sharp knife. The square shape dimension graphite will be mount into epofix to give a strong hold on graphite. Then, ultra-sharp single crystal diamond will penetrate the bulk of graphite and in very small thickness which contain a few layer of graphene.

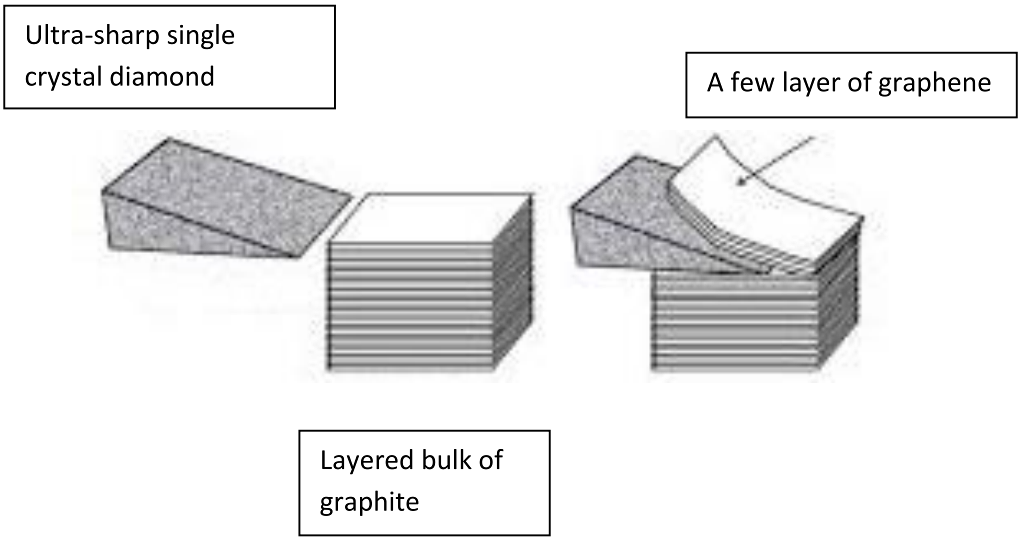

Figure 7: A layer of graphene being cleave from graphite using ultra sharp single crystal diamond

2.3.2 Molten Salts

Molten salt is a process that producing graphene in response of heat energy. Molten salts in normal temperature and environment temperature is in a formed of solid which is known as salt. If high temperature is applied to the molten salt, the solid state of the salt will be melting after a certain degree and pressure.

In liquid state, the molten salt can produce graphene after it erode the graphite particle into nanostructure [7]. The process of chemical reaction between hydrogen and molten lithium chloride will produce graphene nanosheets in a single crystalline structure.

2.3.3 Chemical Vapor Deposition

Chemical vapor deposition (CVD) is a chemical process that consist of several type of chemical process in form of gases. In order to obtain graphene, a metal substrate like nickel or copper is used to grow graphene in a chamber that have very high temperature. There are 2 type of gases that involve in CVD process which act as carbon source and carrier gases. Methane is most popular carbon source that usually used in producing graphene.

CHAPTER 3
METHODOLOGY

3.1. Research Methodology

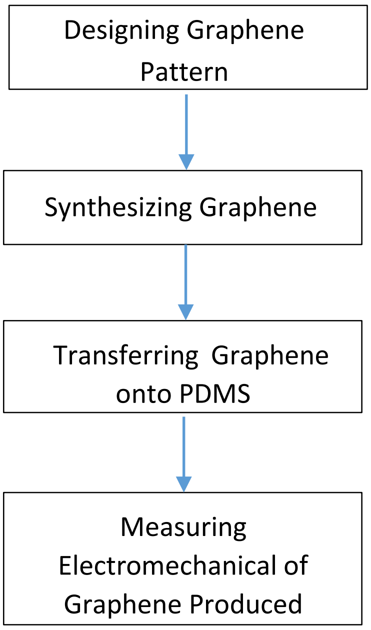

Figure 8: Procedure of patterning monolayer graphene using laser scribe.

Figure above shows the procedure needed in this project. The first part is designing the pattern of graphene by using CorelDraw software and synthesizing graphene using laser scribing method. Then transferring the porous graphene onto the PDMS. Last but not least observer and record the data during measuring electromechanical properties of produced graphene.

The electromechanical properties will be evaluated by applying tensile and bending to the strain sensor. Each strain applied to the sensor is in term of 0.02 centimeter movement of testing prototype.

3.1.1 Design of Graphene Pattern

Before the graphene being transfer to PDMS, the graphene need to synthesis in certain pattern on the polyimide film. To achieve a specific pattern, the mask has to be design using a Corel draw software. Below are the design masks. The dimension of each design mask is by 3cm x 3cm.

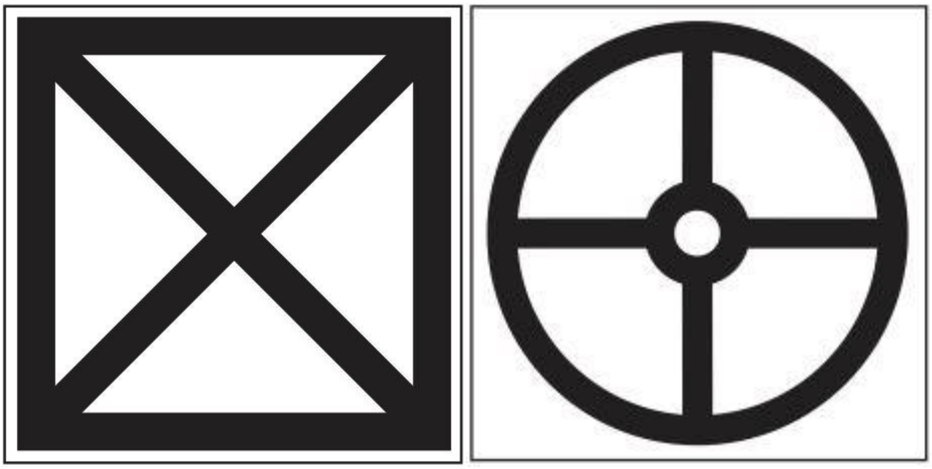

Figure 9: (a) Pattern of graphene masks cover outer space (b) Pattern of graphene masks cover inner space

3.1.2 Synthesis Graphene Using Laser Scriber

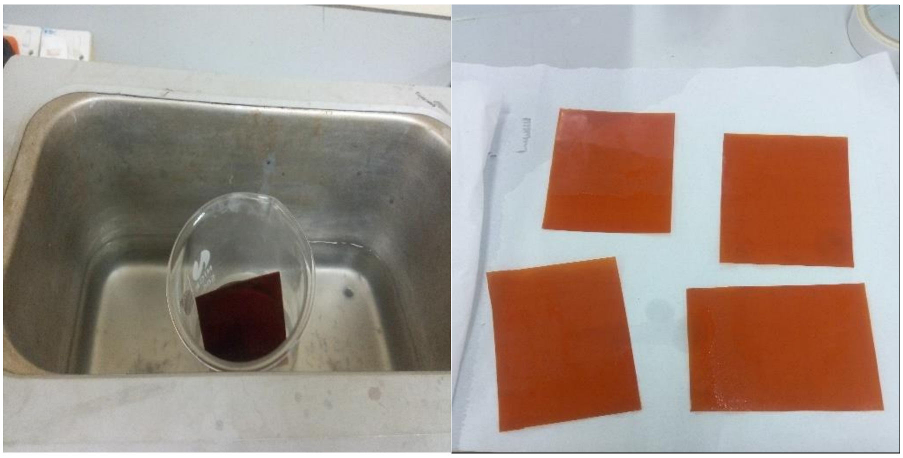

Figure 10: (a) Ultrasonication of polyimide film in acetone, (b) Cleaned polyimide film is then dried in room temperature.

A polyimide film with a size of 5cm x 3cm will be cleaned using acetone or isopropyl alcohol (IPA) in order to remove any contamination on the polyimide film. Then the film will be dried in room temperature.

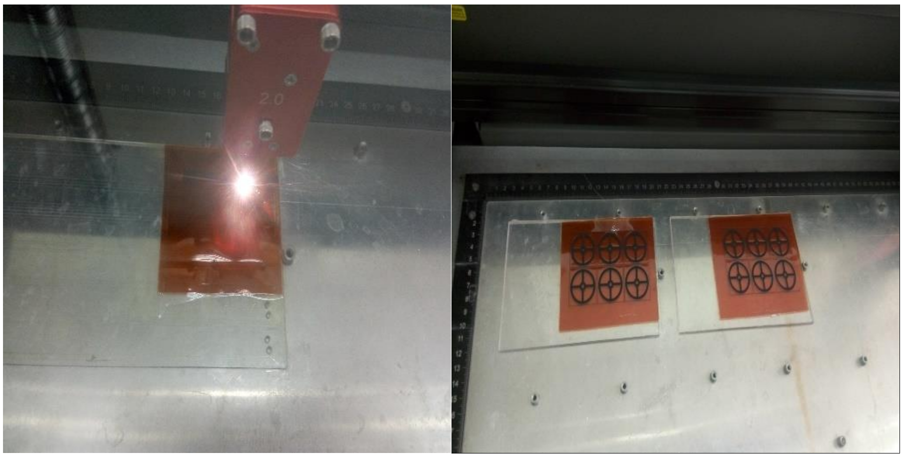

Figure 11: (a) Scribing of polyimide film using CO_2 laser, (b) Graphene on top of polyimide film

When the polyimide film ready, the film will be placed under laser scriber. The laser will be set 10W with a scan rate of 500 inches per second. The speed of the laser is set to 0.5% of its original speed. The porous graphene is completely being synthesis base on the design.

3.1.3 Transferring Process of Graphene

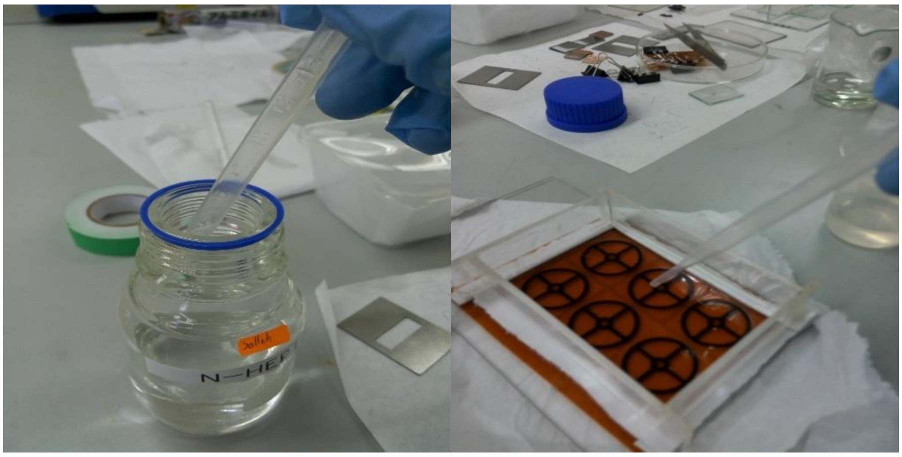

Figure 12: (a) Adding N-heptane to make graphene stickier (b) Graphene cover with N-haptene

The porous graphene is sweep with N-heptane solution in order to let the porous graphene become stickier. Leave the graphene and N-heptane dry before coated or cover the porous graphene with PDMS. The reason in transferring onto PDMS is to produce a stretchable sensor. In order to make the PDMS become in solid state, the PDMS will be heated at 80°C. When the PDMS is ready, the polyimide film will be removed from PDMS by peeling it off then will leaving the porous graphene sticking on the PDMS.

3.1.4 Preparation of PDMS

Polydimethylsiloxane (PDMS) is a polymer that turn from liquid to solid form on certain degree. PDMS will provide an elasticity to graphene as a strain sensor.

Figure 13: Elastomer and curing agent

Mix elastomer (silicon)with the curing agent (Silgard 184) at (10:1) ratio. Example 10ml of elastomer with 1ml curing agent. After mixing, stirred the mixture (PDMS) for about 30 minutes to ensure the mixture is well mixed. Leave the PDMS in room temperature for 2 hours in order to remove the bubbles from the PDMS.

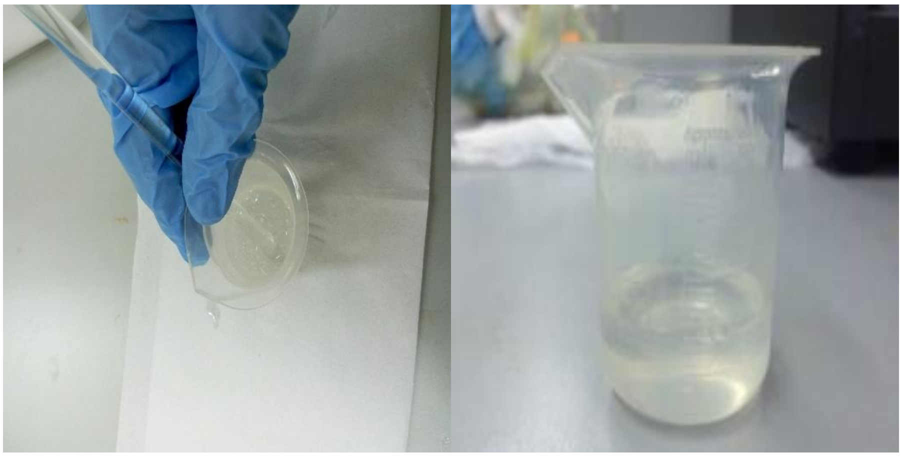

Figure 14: (a) Elastomer and curing agent is stir together, (b) Complete preparation of PDMS

The PDMS is applied to the desired mold and heat it up. It is very important to not create bubble during applying PDMS into mold. The temperature is slowly increased with starting temperature of 40°C up to 80°C in 1 hour 30minutes intervals.

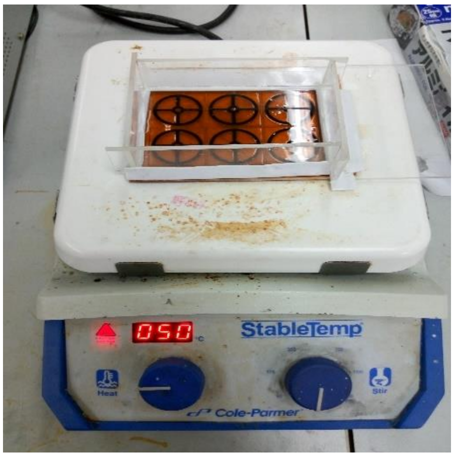

Figure 15: Heating process to harden the PDMS

The PDMS will be left to harden for 1.5 hours by the process of heating. The PDMS will then be let cool down before being removed from the mold.

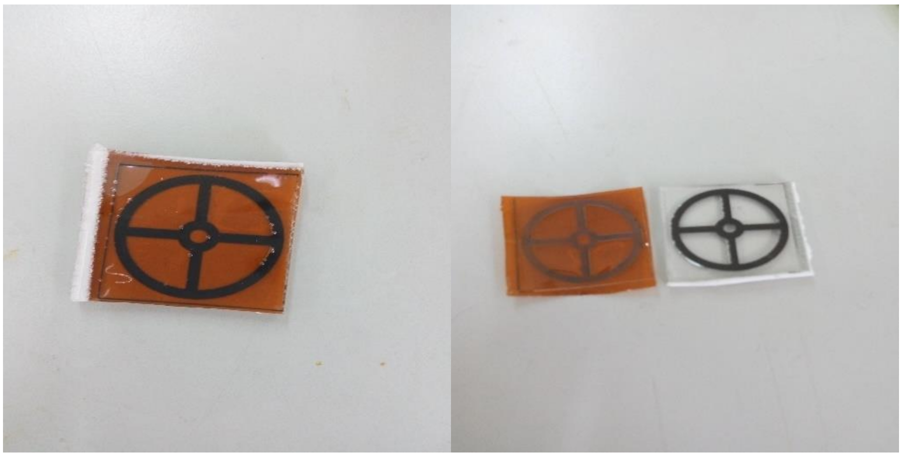

Figure 16: (a) PDMS with polyimide film, (b) complete transferring process

CHAPTER 4

RESULT AND DISCUSSION

4.1 Graphene Growth using Laser Scriber

After the synthesis of graphene using laser scriber, the graphene will be analysed using scanned using scanning electron microscopy (SEM) and transmission electron microscopy (TEM) to understand its morphology, crystallinity, number of layers and structural integrity of the synthesized graphene.

As depicted in Figure 17, the irradiation of commercial PI film by a CO_2 laser under ambient conditions converts the film into an interconnected porous graphene. The synthesized graphene indicates appearance of foam with porous structures due to rapid liberation of gaseous products.

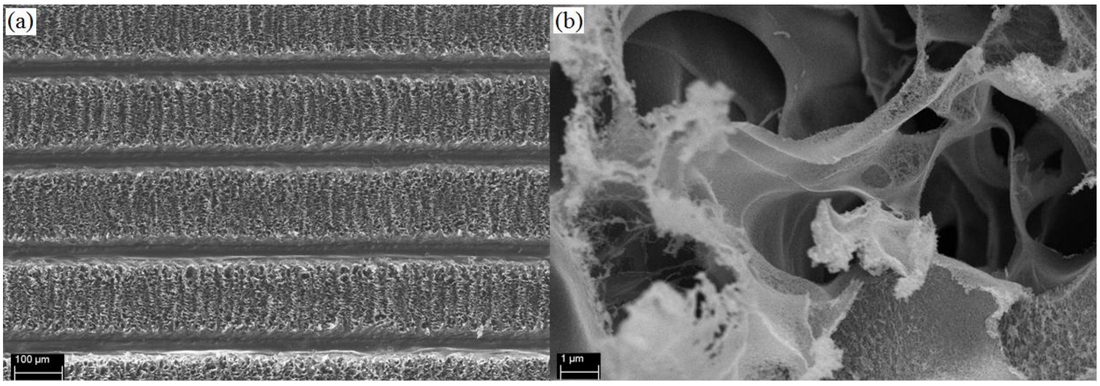

Figure 17: SEM image of (a) laser scribed 3D graphene, (b) close-up image of the graphene porous structure.

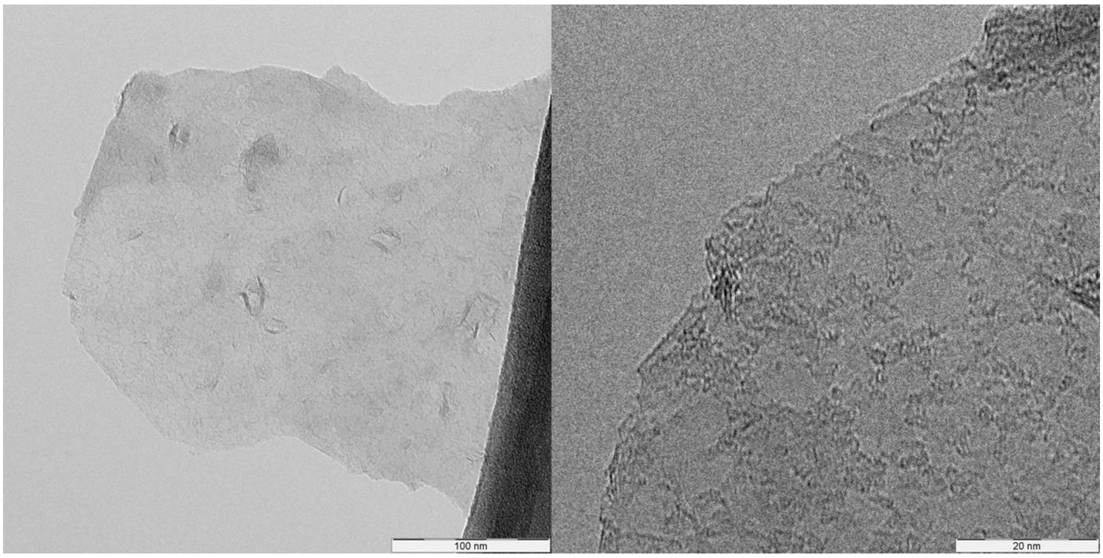

Figure 18: High resolution TEM image of 3D graphene

The micro-flakes of graphene are then analyzed using TEM. The flakes show few-layers features as indicated in Figure 18. Moreover, ripple-like wrinkled structures can be observed, which is due to thermal expansion caused by laser irradiation.

Raman analysis of the graphene shows three prominent peaks, D-peak at 1374 cm^{-1} induced by defects or bent sp^2 carbon bonds, G-peak at 1617 cm^{-1} which indicates formation of graphitic structure and 2D-peak at 2723 cm^{-1} originating from second order zone-boundary phonons. The 2D profile is typical of that found in 2D graphite consisting of randomly stacked graphene layers along the *c*-axis.

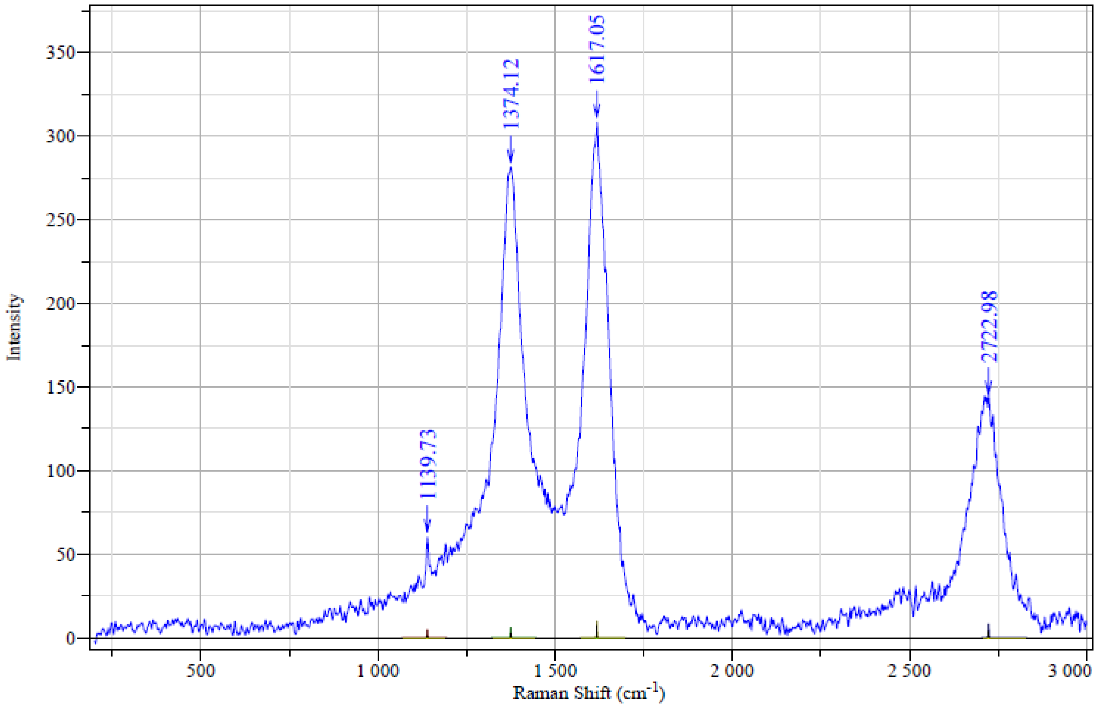

Figure 19: Raman spectrum of graphene grown on PI film.

4.2 Analyzing Electromechanical Properties of the Design

Data from the electromechanical will be analyse in order to make sure that the performance of the strain sensor is excellence. In order to access the dynamic performance of the graphene strain sensor, the test is conducted with different level of strain and the resistance value is measured and recorded. The expected response of the sensor should be that the behaviour of the resistance value should be return to normal value every time the strain is released. In order to gain the comparison between other stretchable strain sensors, the data gain from the test will be calculated by using gauge factor:

$$GF = \frac{\frac{\Delta R}{R}}{\frac{\Delta L}{\mathrm{L}}}$$

Where:
GF = gauge factor
R = electrical resistance
L = length of strain

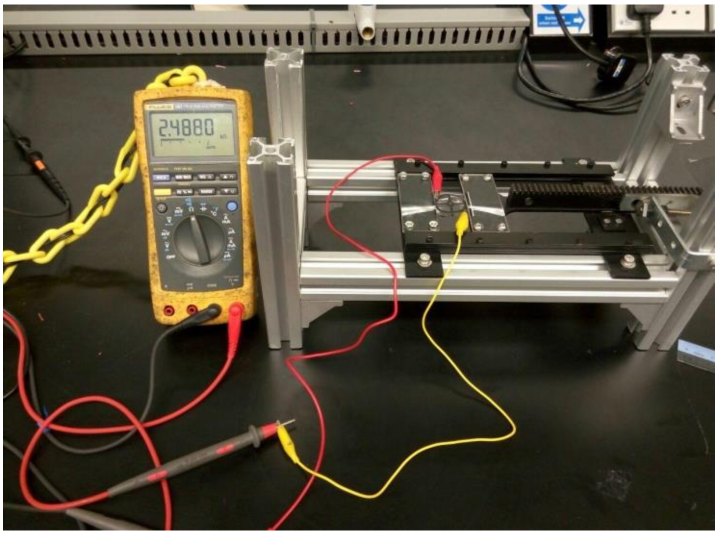

Figure 20: Electromechanical testing

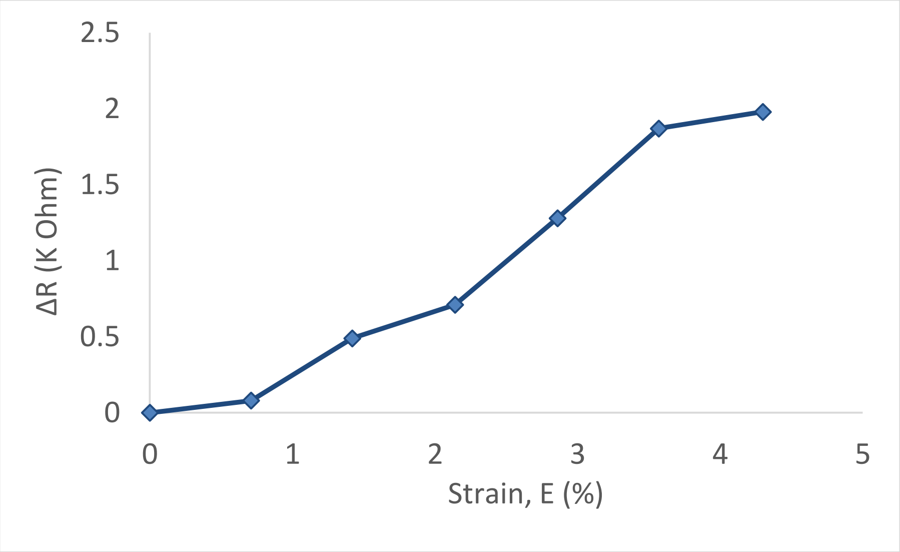

Figure 21: Changes of resistance across a variation of applied strain

Figure above show the value of resistance change correspond to strain apply. The strain starts from 0.02 cm up to 0.12 cm in increasing strain of 0.02cm.

4.2.1 Tensile

A few sample of strain sensor produced is used in tensile testing. Strain is applied to the strain sensor and the changes in resistance due to different strain applied is observed and recorded. In this testing, 3D graphene strain sensor will be clamped at both end of the sensor using a holder prototype. The prototype will execute tensile by pulling the second holder away from the first holder. The prototype is controlled by using Arduino and a stepper motor where the applied force is constant 0.02 centimeter.

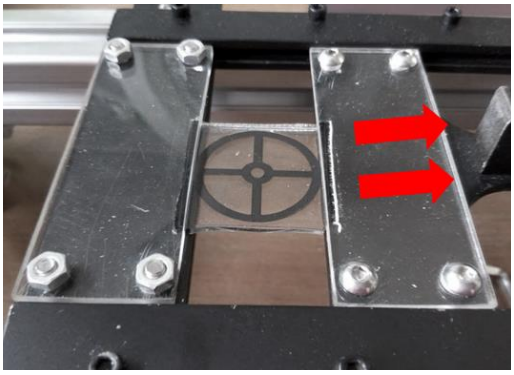

Figure 22: illustrate the bending testing being done on 3D graphene strain sensor

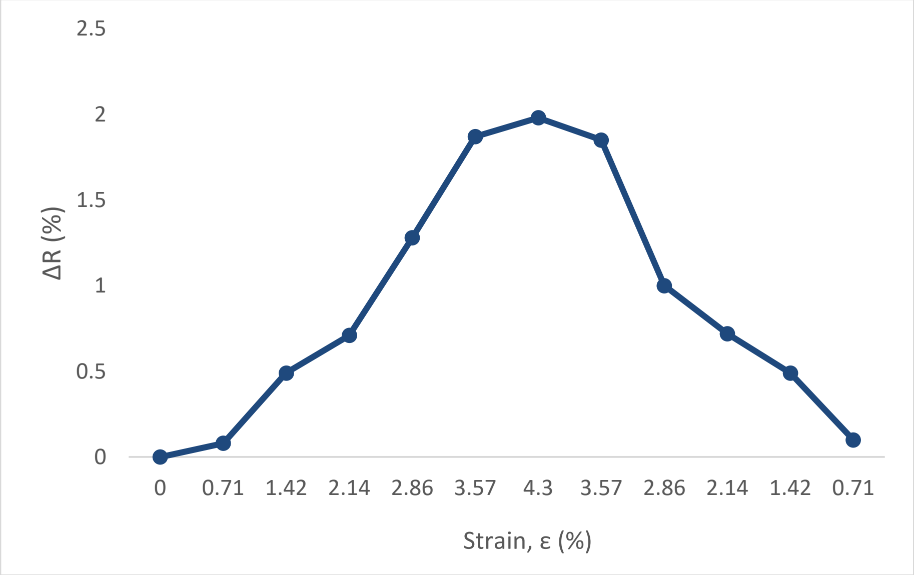

Figure 23: Average reading of tensile

The value strain is calculated by dividing the changes of length being extended with the original length of 3D graphene strain sensor. The strain is moving in length of 0.02

centimetre. Based on the figures above, the average result of graphene strain sensor can achieve the strain up to 48% or 0.48 at 36 kilo ohm resistance before the graphene structure start to crack.

For the strain applied from 0 to 1, the 3D graphene strain sensor shows small change in resistance which are good for small detection. When the 3D graphene strain sensor reaching value of 1 strain, the changes of the resistance are rapidly increase until its maximum change 36k ohm. Then the 3D graphene strain sensor is undergoing the reverse process which from maximum point to 0 strain or no force applied. The rapid drop in resistivity is observed from maximum point until it reaches 1 strain. The strain sensor slowly decreases in resistivity until the resistance become zero where no force is applied.

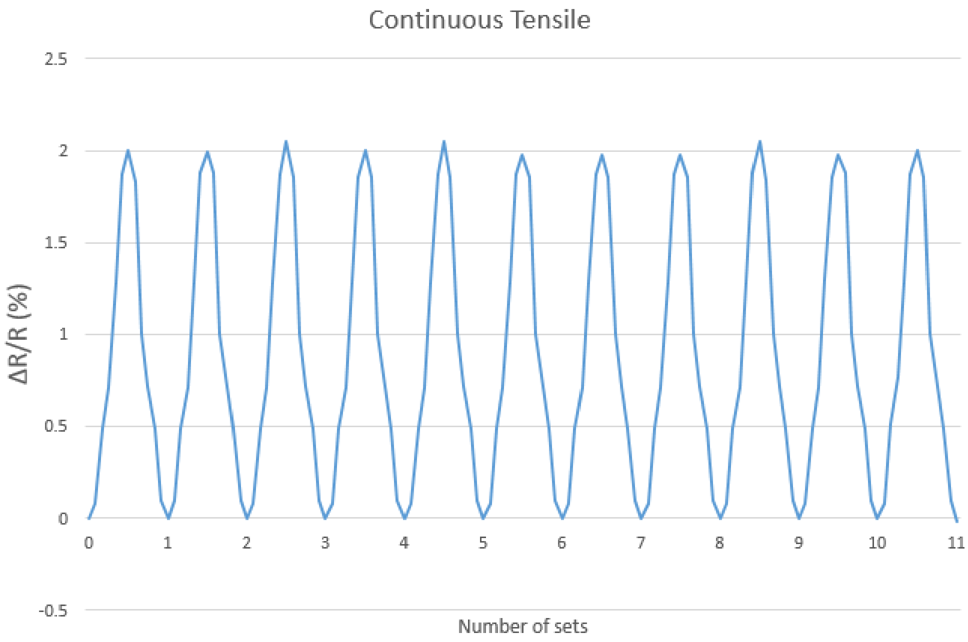

Figure 24: Continuous reading of tensile

Based on the figure above, the 11 reading of tensile test was done continuously to observed its reversible strength. The result shows a good 3D strain sensor data since the strain sensor are able to return to its original value of resistivity. This shows that 3D graphene strain sensor has the ability to be a good strain sensor.

4.2.2 Bending

Another few sample of strain sensor produced is used in bending testing. Strain is applied to the strain sensor and the changes in resistance due to different strain applied is observed and recorded. In this testing, 3D graphene strain sensor will be clamped at both end of the sensor using a holder prototype. The prototype will execute the bending by pushing the second holder towards the first holder. The applied force is also constant at 0.02 centimeter.

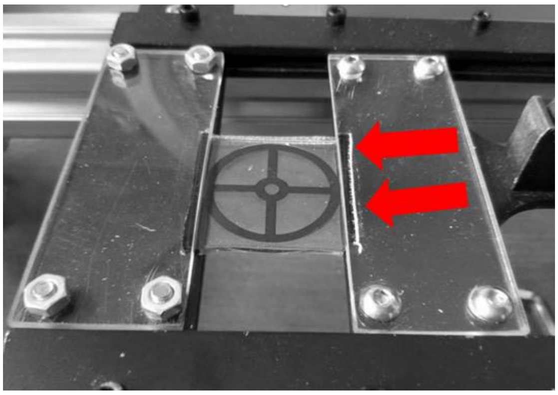

Figure 25: illustrate the bending testing being done on 3D graphene strain sensor

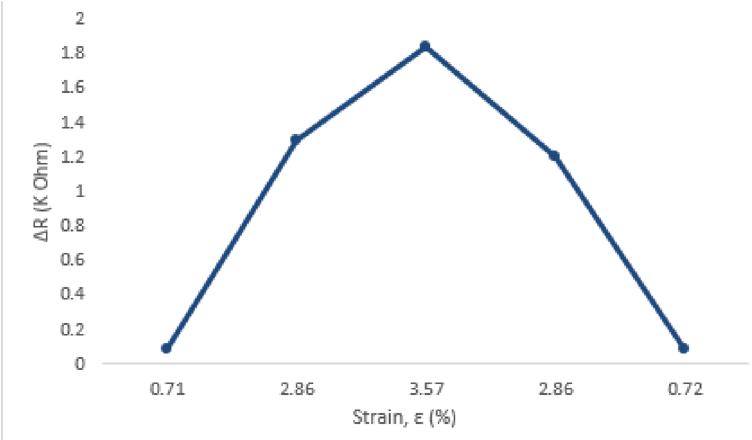

Figure 26: Average reading of bending

Based on the figures above, the average result of graphene strain sensor can achieve the strain up to 44% or 0.44 at 11.5 kilo ohm resistance before the graphene structure start to deplete.

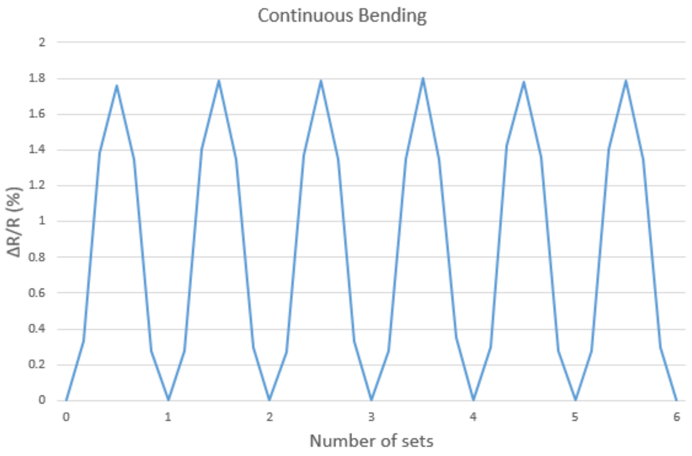

Figure 27: Continuous reading of bending

Based on the figure above, the 6 reading of bending test was done continuously to observed its reversible strength. The result shows a good 3D strain sensor data since the strain sensor are able to return to its original value of resistivity. This shows that 3D graphene strain sensor has the ability to be a good strain sensor.

4.2.3 IV Characteristic

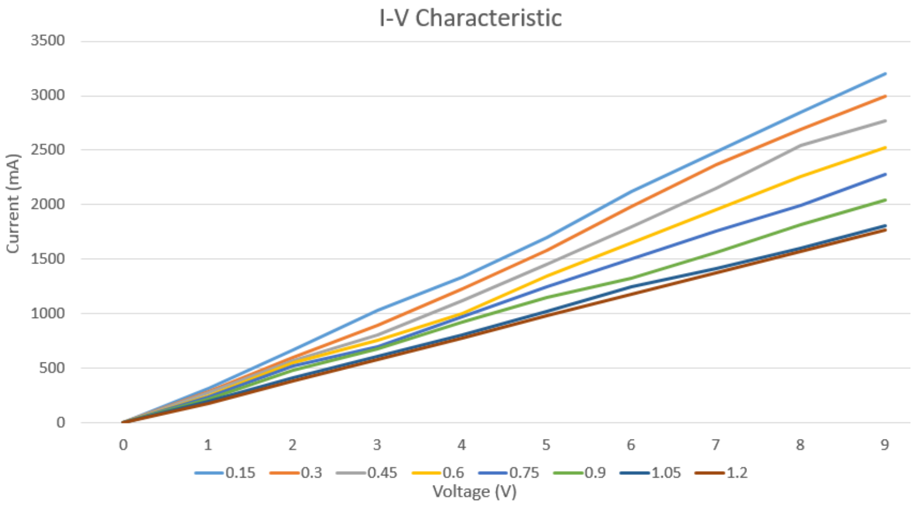

Figure 28: IV characteristic

For IV characteristic, the test has been carried out based on tensile test. The strain used are 0.15, 0.3, 0.45, 0.6, 0.75, 0.9, 1.05 and 1.2. Then the voltage is applied from 1v to 9v and the reading of current flow through strain sensor is measured when the bias voltage is applied.

Based on the graph, the 0.15 of strain slope produce the highest result compared to others. The slope of the IV characteristic is the resistance of strain sensor when the strain is applied.

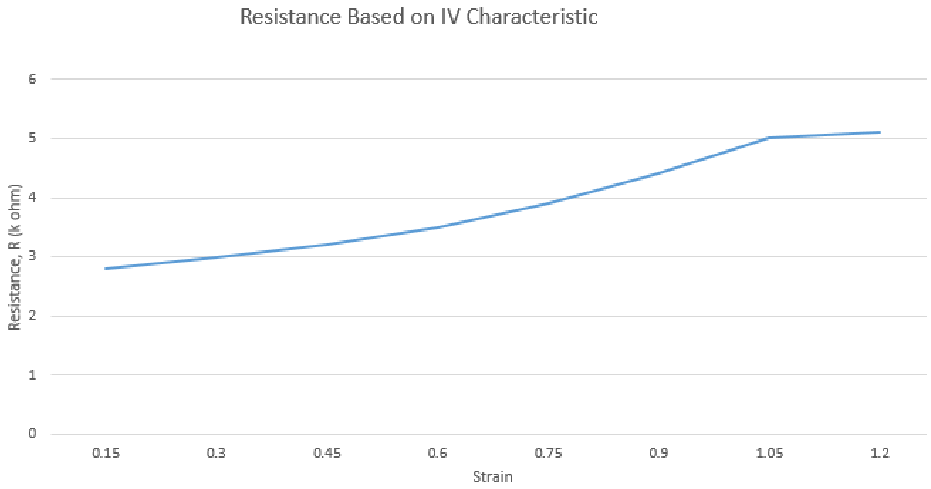

Figure 29: Resistance of strain sensor based on IV characteristic

In this evaluation, the graph shows the tensile testing by using IV characteristic. The strains which has the highest peak about 36k ohms. This graph explained the changes of resistance value from 0.15 strain up to 1.2 strain which is very small. The graph shows the ability to detect strain in small change of strain.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

From this research work, a flexible and stretchable 3D porous graphene strain sensor was successfully fabricated. The sensor shows excellent strain properties for bending (44%) and tensile (48%), higher than reported by others. For gauge factor of the sensor, it shows a good result of 7.1 for bending and 30.86 for tensile respectively. It is showing a good linearity and reversibility. The demonstrated flexible and stretchable porous graphene strain sensor has good potential to be utilize for small and large strain detection.

Based on this research work, graphene as strain sensor is a good research to develop in order to improving a better future. Graphene can be clarified as a strain sensor by discovering the electric resistivity when a force is applied.

In order to improve the performance of this graphene strain sensor, several action are recommended. For testing part of the evaluation of electromechanical properties of the sensor, the jig prototype needs to be modified where the sensitivity of the prototype on moving the second holder need to be increase by increasing the ratio number of the gear, so that the result can be obtained accurately.

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Material	**Author**	**Advantage**	**Disadvantages**

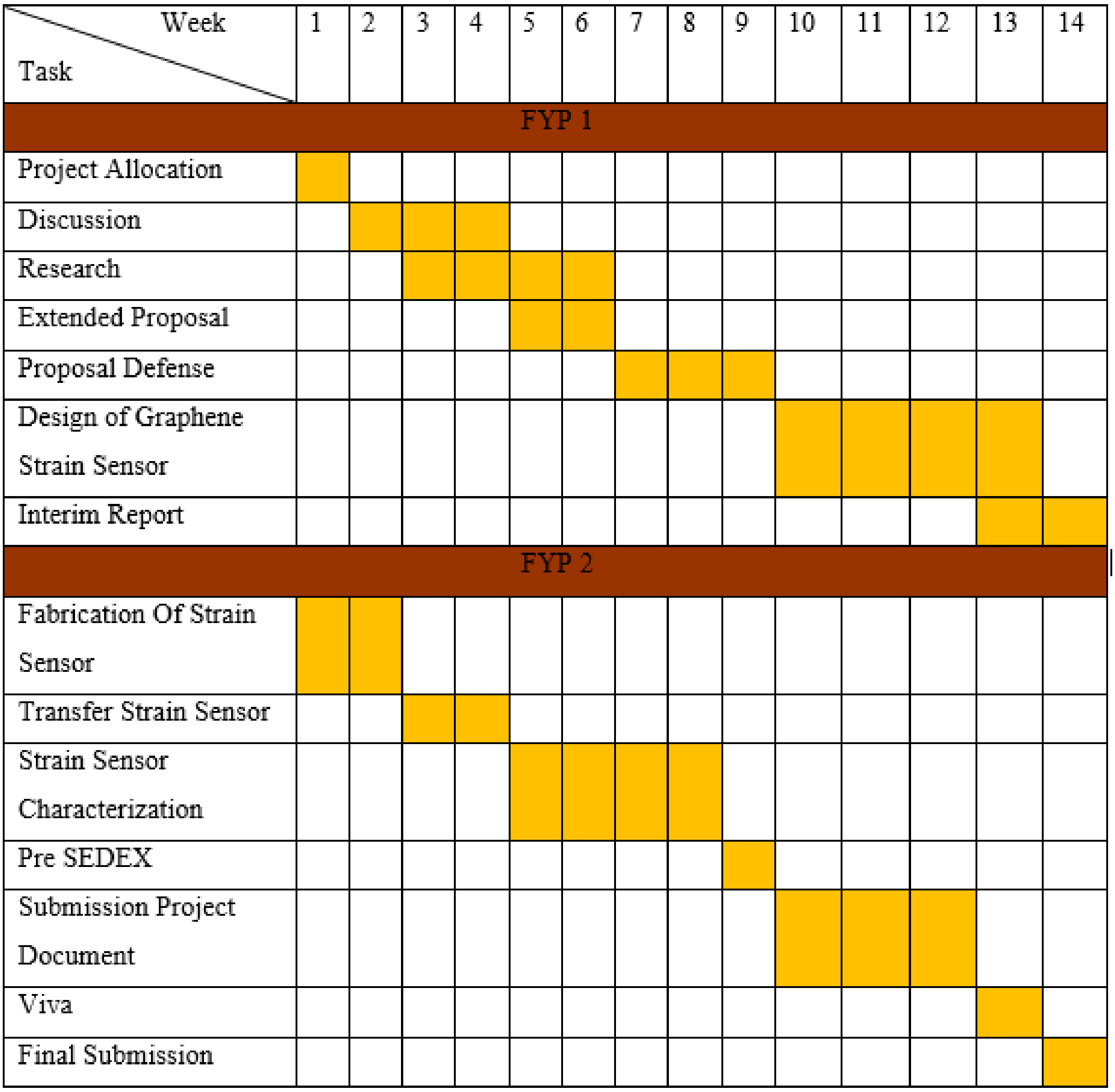
• Silver Nanowire (AgNW)	• Amjadi, Morteza et al (2014)	• Flexible, • Stretchable • sensitive strain sensors • tunable gauge factors	• silver nanowires are oxidized during the coating process • hydrogen chloride (HCl) vapor can eliminate oxidized surface, and consequently, reduce largely the resistivity of silver nanowire
• Saline solution Glycerol in water containing sodium chloride (NaC1)	• Won, Kim, Lu et al (2011)	• impressively bigger than in the present study and included the utilization of stiff metal electrodes.	• extremely hard to be coordinated into a minimal, versatile and delicate application • resistivity this solution is higher than eGaIn

APPENDICES

• Conductive Liquid	• Cheung ,Zhu ,	• astound precision	• resistivity of eGaIn is

Eutectic Gallium-Indium (eGaIn)	Cheng et al (2008) • Chossat, Park, Wood (2013)	with reliable quality in evaluating extensive strain. • gauge factor is significant fluctuated (increase) by 3 times precisely 3.17 times	lower than saline solution • expensive
• Graphene Strain Sensor by Using CVD process	• Dong, Wei, Chao et al (2011)	• Flexible • Best conductor of electricity • Strongest Compound	• Process is complex • Time taken is long

Gantt Chart



Week / Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FYP 1														
Project Allocation	🟨													
Discussion		🟨	🟨	🟨										
Research			🟨	🟨	🟨	🟨								
Extended Proposal					🟨	🟨								
Proposal Defense							🟨	🟨	🟨					
Design of Graphene Strain Sensor										🟨	🟨	🟨	🟨	
Interim Report													🟨	🟨
FYP 2														
Fabrication Of Strain Sensor	🟨	🟨												
Transfer Strain Sensor			🟨	🟨										
Strain Sensor Characterization					🟨	🟨	🟨	🟨						
Pre SEDEX									🟨					
Submission Project Document										🟨	🟨	🟨		
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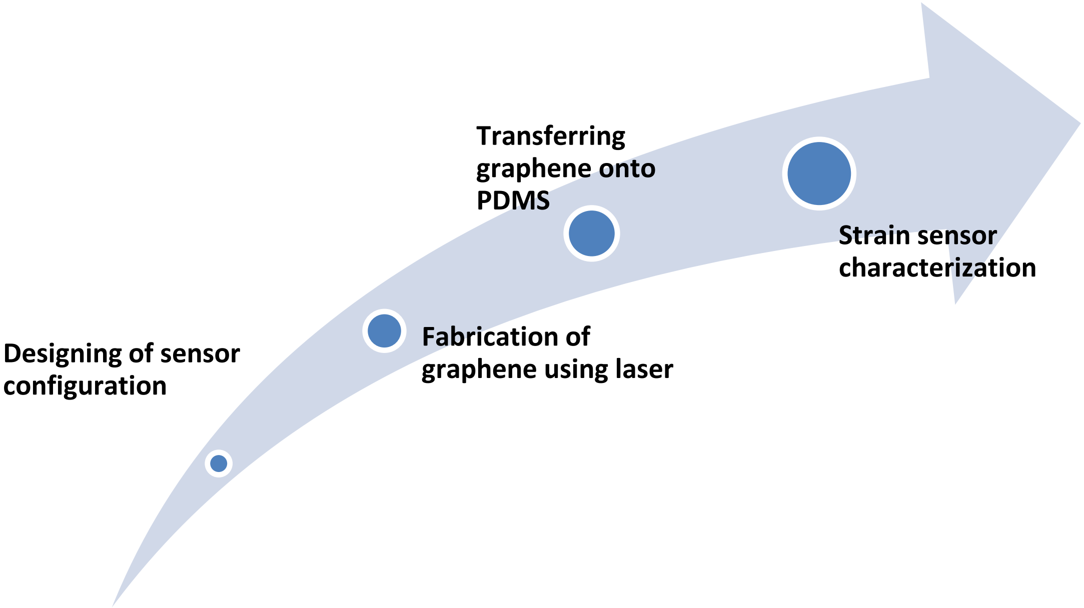
Final Submission														🟨

Key Milestone FYP II


Transferring graphene onto PDMS
Strain sensor characterization
Fabrication of graphene using laser
Designing of sensor configuration