Development of Flexible 3D Graphene/PDMS Composite Film for Strain Sensing

by

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15484

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CERTIFICATION OF APPROVAL

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Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
JANUARY 2016

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.

SAFUAN BIN YAHAYA

ABSTRACT

Piezoresistive strain sensor has been studied for real-time monitoring of human body motion detections. However, the traditionally available strain sensor suffer from various drawbacks such as can only withstand limited strain (< 5%) before fracture, small gauge factor, leakage of liquid, complex synthesis, time consuming and high cost. Recently, 2D graphene has started to be developed as the sensing element for the strain sensor due to its extraordinary electrical, mechanical, optical, thermal, and chemical properties. The objective of this research is to develop a flexible and stretchable 3D graphene/poly(dimethlysiloxane) (PDMS) composite film. The 3D graphene is another variant of graphene, in which it is mechanically robust and stable. The 3D graphene was synthesized on nickel foam as the template using chemical vapor deposition technique. Then, the 3D graphene was incorporated with PDMS and the nickel was etched to obtained free standing 3D graphene/PDMS composite film. The composite film shows low sheet resistance with electron mobility and conductivity of 500 cm^2/Vs. The electromechanical measurement shows excellent properties of the fabricated 3D graphene/PDMS composite film. Here, we has done do the electromechanical testing such as, torsion, tensile, compress and bending test. For bending and torsion testing, the degree for the testing is starting from 0 degree until 180 degree and it need to return back to zero degree to prove that the resistance can back to normal resistance. From this testing, for the bending test, the average maximum value of the sample is 0.037$\Delta R/R$ and for the torsion test is 0.1$\Delta R/R$. For the tensile test, the tensile percentage that we get from the sample is about 12.5 % from the actual sample and the maximum resistance value is 0.19$\Delta R/R$. For the last test, the compress that we give to the sample is about 6.25% from the actual sample and the maximum resistance value that we get is 0.122$\Delta R/R$. The outcome of this research opens up path for the integration of 3D graphene in strain sensor for better performance with added advantage of flexibility and stretch ability.

ACKNOWLEDGEMENTS

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CHAPTER 1 - INTRODUCTION

1.1 Background of Study

1.1.1 Graphene

Graphene is as an atomic scale honeycomb lattice made of carbon atoms. It was a structure of element allotropes, including graphite, charcoal, carbon nanotubes and fullerenes. The properties of graphene is very extraordinary, such as graphene is very good to conduct heat and the electricity, it is also stronger than steel, and it also nearly transparent. The name of graphene is from the combination of graphite and suffix-ene, the name has been coined by Hanns-Peter Boehm. The term graphene is to describe a single sheets of graphite and also to describe the carbon nanotubes which was discovered earlier.

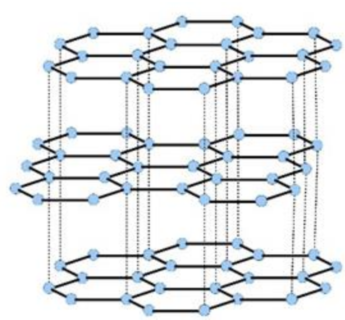

Figure 1: Graphite atoms structure [1].

Each atom in graphene is available for chemical reaction, it is because graphene is the only form of carbon. There are some special chemical reactivity at the edges of the atoms and edge atoms of the graphene has the highest ratio for any allotrope. Graphene is commonly modified with oxygen- and nitrogen-containing functional groups. The analyzed of the graphene is by infrared spectroscopy and X-ray photoelectron spectroscopy [2].

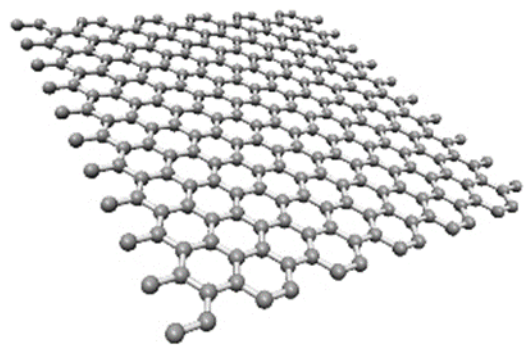

Figure 2: Graphene honeycomb atomic structure [3].

1.2 Problem Statement

Flexible and stretchable sensors have been investigated extensively for their potential applications in wearable electronics for human body detections and kinesiology, smart textiles, and structural health monitoring. Piezoresistive strain sensors are the most investigated among the various type of transducers available for these applications. Traditional semiconducting and metallic strain sensors can only withstand limited strain (<5 %) before facture, rendering it unsuitable for stretchable applications. Conductive-liquid-filled elastomeric tubes or micro-channels are examples of highly stretchable pizeoresistive strain sensors. The liquids such as mercury, carbon grease and eutectic gallium-indium will be filled in the elastomeric tubes to measure blood volume in the limbs. When strained, the tube will be stretched and narrowed, leading to increase in resistance. Although the technique is quite simple, it suffers from various disadvantages such as small gauge factor, leakage of liquid and the issues in filling a highly viscous fluid into micro-channels. Another variety is the printing of conductive nanomaterials such as carbon nanotubes, graphene, silver nanowires and so forth on the surface of stretchable substrate. Various printing techniques are being employed such as contact transfer printing, screen printing, and inkjet printing. Despite their promising performances, these techniques pose various practical fabrication challenges such as these processes requires complex synthesis and time-consuming. The experimental setup often has to be in clean room facility thereby increasing cost and limits the scalability of the process. Additionally, the nanoparticles tend to aggregate thereby requiring additional processing steps to ensure uniform dispersal before being utilized for screen and inkjet printings.

1.3 Objectives and Scope of Study

The specific objective of research is to fabricate strain sensor by using 3D graphene/poly(dimethylsiloxane) (PDMS) composite film. The research elements undertaken in order to achieve the objective are:

- to synthesize 3D graphene with a porous structure, large surface area, good electrical conductivity and high mechanical strength
- to fabricate 3D graphene/PDMS composite film that is flexible and stretchable
- to evaluate the performance of the fabricated composite film in terms of electrical conductivity when under bending, tensile, compression and torsion

The scope of study for this research consists of two stages:

- In this first stage, it involves the synthesis, characterization, and optimization of 3D graphene grown on nickel foam using chemical vapor deposition technique. The nickel foam is then etched using iron (III) chloride to obtain free-standing 3D graphene network. The graphene is then analyzed and studied to understand its morphology, quality, crystallinity, and internal structure.
- In the second stage, the 3D graphene is then integrated with PDMS to obtained flexible and stretchable conductive graphene-based composite. The composite is then subjected to electromechanical evaluation to study its mechanical integrity and electronic properties using bending, compression, tensile, and torsion.

CHAPTER 2 - LITERATURE REVIEW

A single layer of graphite is call graphene and and it can be declare as a thinnest material ever. The saiz of the graphene by the thin is one atom layer. Graphene is impermeable and it was very flexible in characteristic and it also is the strongest meterial if compare to iron. From the graphene characteristic and the thermal of conductor, we can declare that the graphene is one of the best electrical conductor. Figure 3 shows the relations between the graphite and the graphene that can be obtained from graphite. The structure of graphene is from crystalline allotrope of carbon with the two dimension of properties. The stabilities of graphene is due to its tightly packed of carbon atoms and the combination of orbitals. There are some special about graphene that is it can repair holes in its sheets by itself when it reveal to others molecules that contained carbon.

The only form of carbon that has atoms that available for chemical reaction is graphene. The numbers of edge atom in graphene is the highest in any allotrope. Graphene can be burn at the lowest temperature as low as 350°C. Graphene chemical properties is commonly altered with oxygen and nitrogen containing functional group. Its analyzed by x-tray photoelectron and infrared spectroscopy. Graphene have a potential in electronic field. It has an unic electronic properties that is zero-gap semiconductors. It occurs because the conduction and valence band meet the dirac point [6-7].

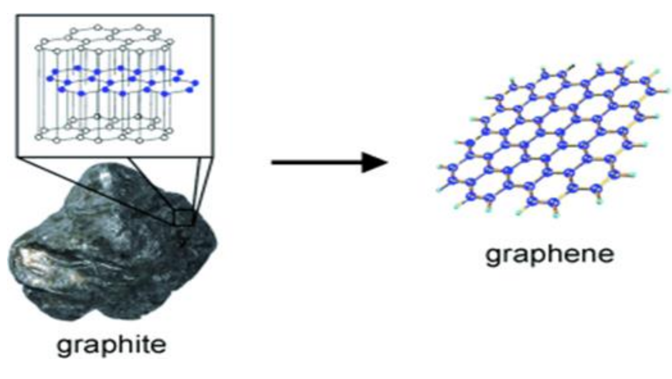

Figure 3: Structure atom of graphene from the graphite [8].

Because of the unique structure and the superior physical properties of the graphene foams, the three-dimensional (3D) interconnected graphene networks had gained a great attention. It was high overall electrical conductivity, mechanical flexibility, chemical stability, good conductor, high thermal and others. To collect the applications of graphene foams some approaches has been develop. It developed for the fabrication of graphene foams, mainly including hydrothermal reduction of graphene oxides (GOs), chemical reduction of GO, and chemical vapor deposition (CVD) growth on nickel foam skeletons.

Starting from 2004, the researchers are interested in graphene-based technologies because of the superior characteristics and the potential applications that can be derived using graphene. From that year until now, there are so many new things that has been found about the benefits of graphene. With the two-dimensionality physically, it was very flexible, good in conductivity and also transparent make graphene is a very perfect candidate for the best flexible electronic title.

Because of its large surface area, high strength and Young's modulus, as well as extraordinary electronic properties and thermal conductivity, graphene become headline in semiconductor industry. As a precursor for graphene, graphene oxide (GO) enjoys an abundance of oxygenated functional groups on its surface which over high process ability. Reduced graphene oxide (rGO) have been fused together into a wide range of polymer material, including epoxy, polyurethane, polycarbonate, polystyrene, and poly(methyl methacrylate) (PMMA) to form composites that possess special unique properties and capabilities [12-13].

2.1 Flexible Thin Film using Graphene

The unique electronic property of a flexible thin film by using graphene provides potential applications in synthesizing nanocomposites and to be implement in various use in future. Several effective techniques have been developed for preparing graphene flexible thin film. This flexible film will vastly use especially in semiconductor product [9].

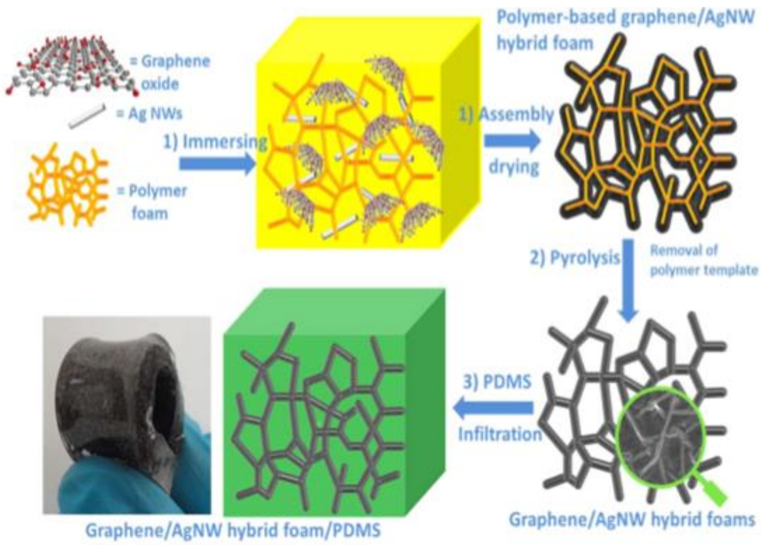

Figure 4: The fabrication process of graphene hybrid foam [10].

2.2 Graphene Strain Sensor

The graphene technologies can be used in many ways. One of it is, it can be a sensors. An idea to create a sensors by using the graphene is come because the change of resistivity when the graphene is bend. The resistivity of graphene will trigger and become the sensors if it detect the changed. Through this project, there are few test measurements such as torsion, tensile, compress and bending that prove resistivity change on graphene sample thus strengthen the theory that graphene is suitable to be developed as sensor. Differ with other strain sensor, graphene usage as strain sensor is more effective because it is thinner, transparent and flexible. In addition, graphene is more durable and strong than other material. By combination of graphene and PDMS, it will create the new era of sensor that can be used widely [11].

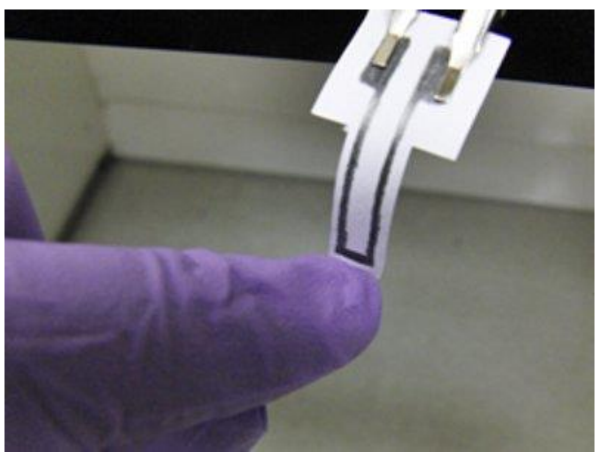

Figure 5: Strain sensor

2.3 Graphene with PDMS

Polydimethylsiloxane or also known as PDMS is a silicon-based organic polymer and widely used in elastomers industry. PDMS is visibly clear and almost zero harm when handling. The usage of PDMS are widely used in optical device where it was utilized to create contact lenses and medical instruments. It was also used to create consumable product such as shampoo and antifoaming agent [3].

Graphene caught many researchers due to its properties in term of mechanical, electrical and optical. Thus it was used to react with CVD to create high-end film. Many substrates have been successfully transferred on CVD-grown graphene films but for device development, it has limitation where the PDMS have very low surface energy. By introducing SU-8 adhesion layer, PDMS substrate can be successfully bond with graphene and gave out better achievement to develop flexible transparent and flexible devices [7].

2.4 Facile Fabrication of Three-Dimensional Graphene Foam/Poly(dimethylsiloxane) Composites and Their Potential Application as Strain Sensor.

A three-dimensional (3D) graphene foam (GF)/poly- (dimethylsiloxane) (PDMS) composite was fabricated by infiltrating PDMS into 3D GF, which was synthesized by chemical vapor deposition (CVD) with nickel foam as template [5]. The electrical properties of the GF/PDMS composite under bending stress were investigated, indicating the resistance of the GF/ PDMS composite was increased with the bending curvature. To improve the bending sensitivity of the GF/PDMS composite, a thin layer of poly(ethylene terephthalate) (PET) was introduced as substrate to form double-layer GF/ PDMS−PET composite, whose measurements showed that the resistance of the GF/PDMS−PET composite was still increased when bended to the side of PET, whereas its resistance would be decreased when bended to the side of GF [6]. For both cases, the absolute value of the relative variation of electrical resistance was increased with the bending curvature. More importantly, the relative variation of electrical resistance for double-layer GF/PDMS−PET composite can be up to six times higher than single-layer GF/ PDMS composite for the same bending curvature [6]. These observations were further supported by the principle of mechanics of material. The 3D GF/PDMS−PET composite also has higher flexibility and environment stability and can be utilized as a strain sensor with high sensitivity, which can find important applications in real-time monitoring of buildings, such as a bridge, dam, and high-speed railway [10].

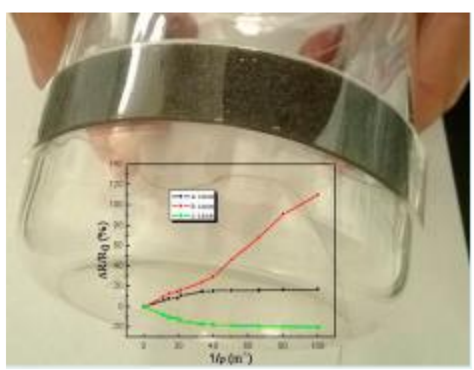

Figure 6: Graphene sample

2.5 Strain gauge

A strain gauge takes advantage of the physical property of electrical conductance and its dependence on the conductor's geometry. When an electrical conductor is stretched within the limits of its elasticity such that it does not break or permanently deform, it will become narrower and longer, changes that increase its electrical resistance end-to-end. Conversely, when a conductor is compressed such that it does not buckle, it will broaden and shorten, changes that decrease its electrical resistance end-to-end. From the measured electrical resistance of the strain gauge, the amount of induced stress may be inferred. A typical strain gauge arranges a long, thin conductive strip in a zig-zag pattern of parallel lines such that a small amount of stress in the direction of the orientation of the parallel lines results in a multiplicatively larger strain measurement over the effective length of the conductor surfaces in the array of conductive lines and hence a multiplicatively larger change in resistance than would be observed with a single straight-line conductive wire.

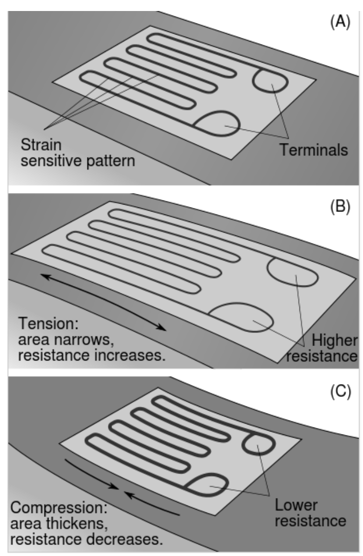

Figure 7: Strain gauge

CHAPTER 3 – METHODOLOGY

3.1 Research Methodology

This chapter will focus on the preparation and synthesis of 3D graphene. The growth of 3D graphene is performed using chemical vapor deposition technique with nickel foam acting as the sacrificial template and scaffold for the growth of graphene. The etching of nickel foam and subsequent analysis will be discussed. The integration of graphene with PDMS and the evaluation of electromechanical properties of the composite will be explained at end of chapter. Figure 6 shows the overall experimental work that has been undertaken in fabricating 3D graphene/PDMS composite film for strain sensing.

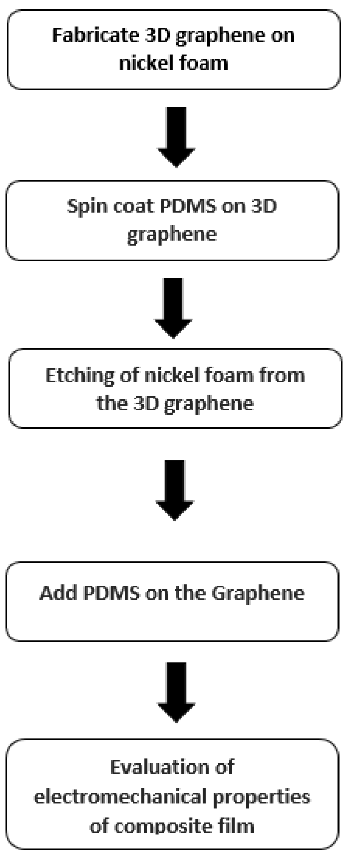

Figure 8: Flow chart of 3D graphene/PDMS composite film.

3.2 Synthesis of 3D graphene

The 3D graphene is synthesized using chemical vapor deposition technique with nickel foam as the scaffold and site for carbon nucleation that leads to formation of graphene. The nickel foam is cleaned by using the isopropanol (IPA). The cleaned nickel foam is then placed in the CVD quartz chamber for the graphene growth. The synthesis temperature is set to 1000^{o}C with the ramping rate of 25^{o}C/min. During the ramping time, hydrogen (H_2) and Argon (Ar) were flowed in to create an inert environment in the quartz chamber. Once the temperature reached 1000^{o}C, methane (CH_4) is introduced as the hydrocarbon source for the growth of graphene. The growth duration is set to 30 minutes. The tube furnace is then moved away from the sample to ensure fast cooling to room temperature. Figure 7 shows the as-synthesized graphene grown on nickel foam.

Figure 9: Graphene with nickel foam

3.3 Integration of PDMS with 3D Graphene-Nickel Foam

Polydimethylsiloxane (PDMS) is a silicon-based polymer and it will be used to retain the structural integrity of 3D graphene during the etching of nickel foam and also to provide flexibility and stretchability for the fabrication of composite. Figure 8 shows the Dow Corning's Sylgard 184 elastromer kit consisting base and curing agent for the preparation of PDMS. The solution is prepared for base and curing at the ratio of 10:1 and whisked vigorously with spatula for 20 minutes. Next, the bubbles present in the solution is removed by leaving the solution in ambient atmosphere for 60 minutes. The solution is then drop-coated on graphene with nickel foam and subsequently baked at 70^{o}C for three hours. The composite will be stiff due to the presence of nickel foam and will be removed to obtain a flexible and stretchable graphene-based composite film.

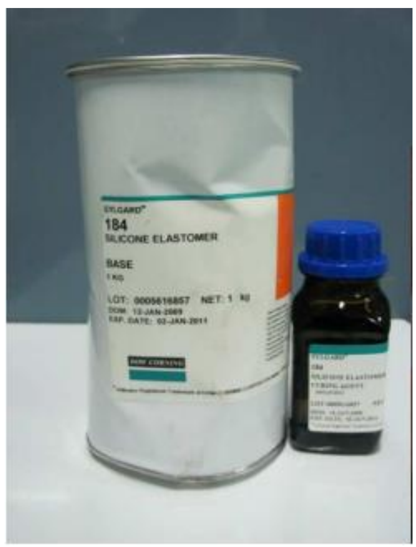

Figure 10: Dow Corning’s Sylgard 184 elastromer kit, base and curing agent for the preparation of PDMS.

3.4 Etching of Nickel Foam

The prepared graphene/Ni foam encapsulated with PDMS will be subjected to acid treatment to remove nickel foam. Initially, the all four sides of the composite film will be removed to remove the PDMS layer. Then the film is immersed in iron (III) chloride acid solution for five to eight hours and followed by immersion in hydrochloric acid for 15 minutes for complete removal of nickel foam and the Fe^{3+} ions from the composite film. The 3D graphene/PDMS composite film is then rinsed with deionized water and dried in air.

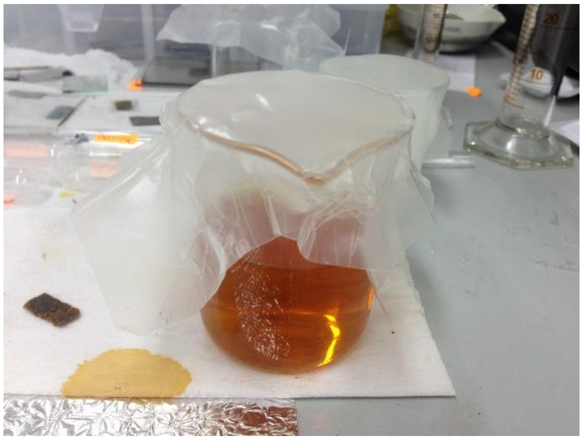

Figure 11: Iron (III) chloride acid for the removal of nickel foam.

3.5 Evaluation of electromechanical properties of composite film

There are several electromechanical measurements conducted using the fabricated 3D graphene/PDMS composite film namely, bending, compression, tensile, and torsion. Electrical contacts are connected to the samples and attached to a digital multimeter 34465A for the data acquisition. The electrical resistance change will be obtained during the testing and the corresponding resistance change to strain is plotted in Excel to understand the characteristics of electromechanical properties of the composite film.

3.6 Gant Chart

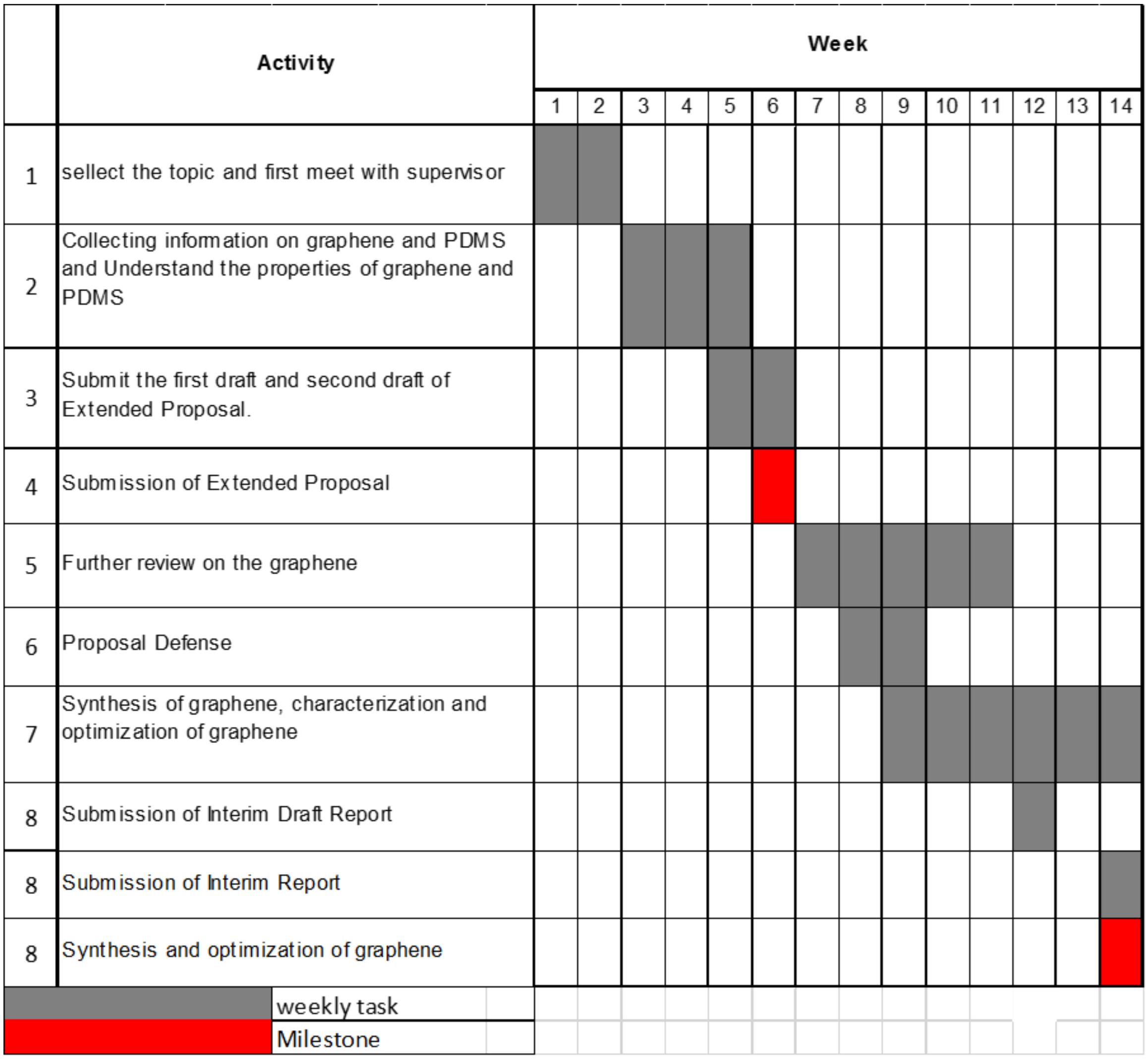

Figure 12: FYP 1 Gant chart

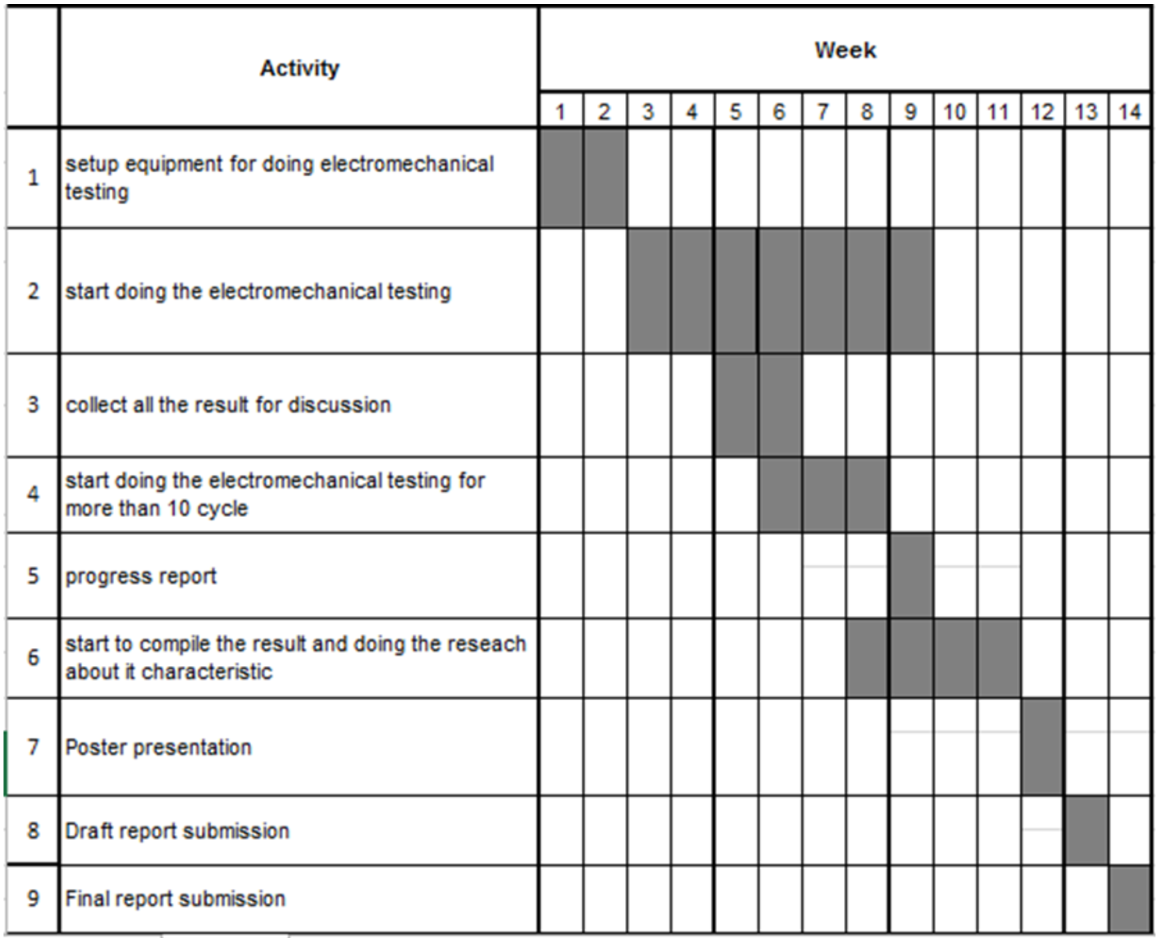

Figure 13: FYP 2 Gant chart

CHAPTER 4 – RESULTS & DISCUSSION

4.1 TEM Analysis

The transmission electron microscopy (TEM) analysis is performed to understand and study the number of layers, the spaces interlayer, atomic structure and also the diameter of the encapsulating wall. TEM is a sophiscated technique that used microscope where ultra-thin specimen will be receiving electrons beam and react with the specimen. Once reaction have been identified, the specimen will project an image and will be magnified with imaging device such CCD camera.

This technique able to give high resolutions up to smaller electrons in de Broglie wavelength chart. By this technique also, use able to examine specimen more detail and small as possible. This type of analysis widely used in physics, nanotechnology and so on.

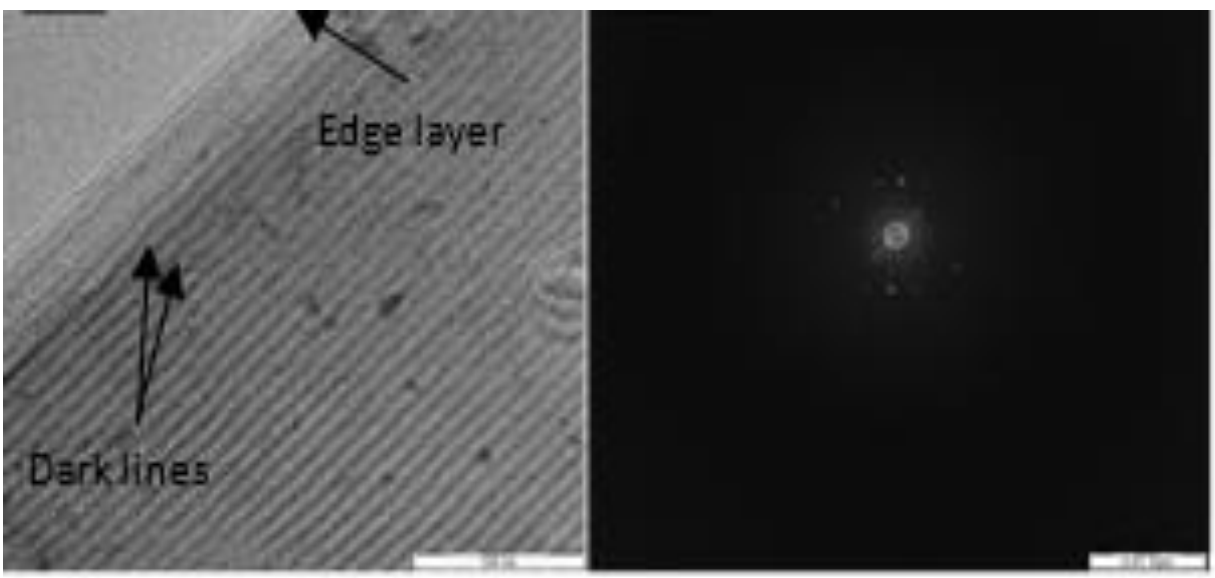

Figure 14: The image of TEM Test

From the result above, we can see the edge layer and the dark lines clearly. It was prove that the edge layer and the folded seen as a dark layer, so that electron diffraction will indicate the presence of multilayer which has been corresponded into it. A typical TEM image of graphene sheets freely suspended on a lacey carbon TEM grid.

4.2 SEM Analysis

Scanning Electron Microscopy (SEM) test is a test that scanning the surface of the morphology and the substrates composition. We can see the image below that is for the 3D graphene sample. From this image result, we can conclude that the sample of ligaments is in connected networks. The size of ligaments at increased magnification which around 48 μm. During cooling down process, the graphene surface had appeared with ripples and wrinkles due to differences in thermal of nickel and graphene. Thus, this occurrence confirmed with multilayer graphene. Carbon deposition at the curves of ligaments can be observed in detail where the ripples are formed and nickel template produced abrasive surfaces. Detection of secondary electrons emitted by atoms excited by the electron beam is the most widely used in SEM technique. An image displayed topography of the surface was created one the sample scanned and collected secondary electrons which later using special tool. Below is a SEM images of the 3D graphene foam at different magnification.

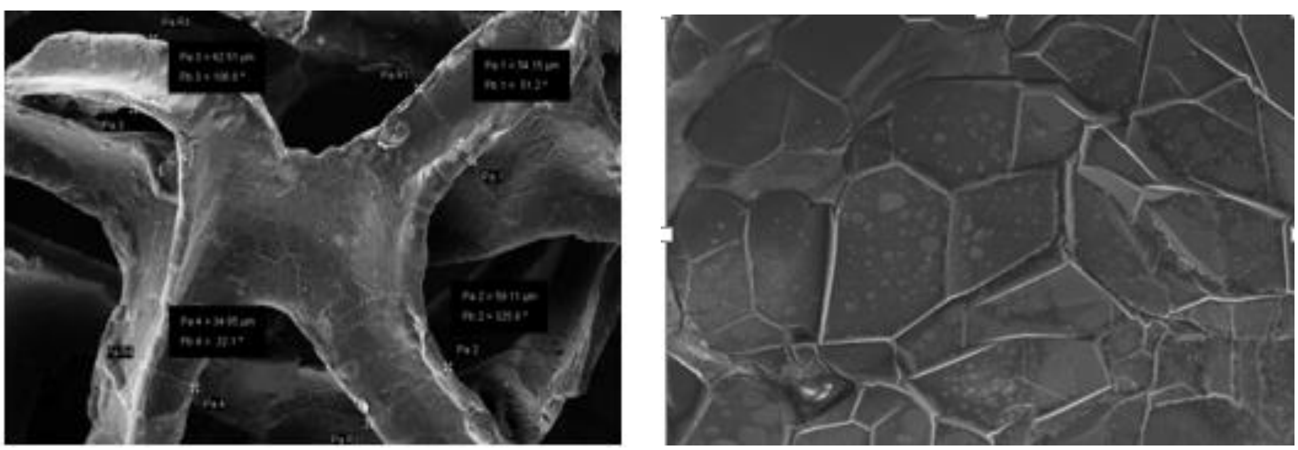

Figure 15: The image of SEM Test

4.3 RAMAN Analysis

Raman spectroscopy is used to study the graphene bonding and graphene structural defects. The intensity of scattered as the function of frequency (Raman shift) is called Raman spectra. Raman is a non-destructive tool to inspect samples at room temperature and ambient pressure. Typical Raman spectrum will have D-band, G-band and 2D band as the three major peaks. Figure. 1 illustrates the Raman spectrum of grown graphene with 15 minute duration. As observed in Raman spectrum, the defect related D band were suppressed, indicating high quality of graphene networks produced [1-3]. The ratio of the intensity of $I_{2D}/I_G < 1$, implying that the grown graphene consist of multilayer structure more than 5 layers which agrees with study done by Xiao et al [19]. The graphene grown for all deposition period gives sharp rise of G band which were higher than the second order 2D band. Furthermore, the 2D FWHM much boarder which can be splitted with at least 2 different Lorentzian fittings [20]. This Lorentzian peak fitting show the multilayer of grown graphene with more than 5 layers stacked.

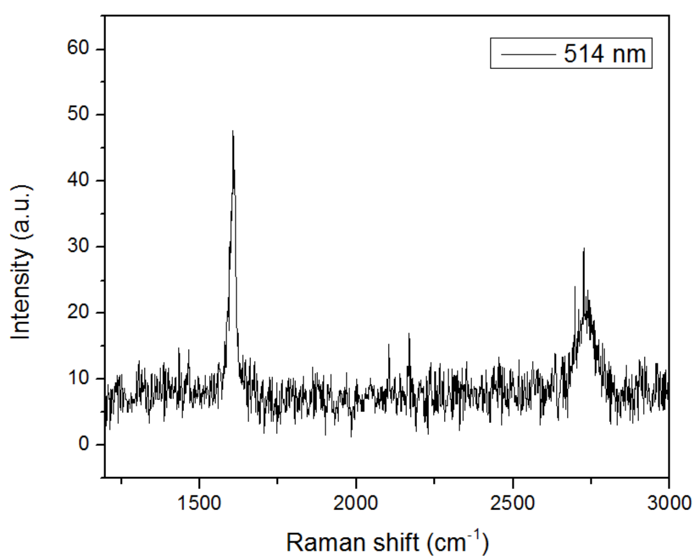

Figure 16: Raman test [18].

4.4 Electrical Characteristics of Graphene

4.4.1 Hall Effect Test

Hall Effect Test is a test to measure the different of the voltage across the conductor. From this test we will get the value of the mobility and the conductivity of 3D graphene. Below is the result of this test for 10 times. The best range for the mobility of 3D graphene is from 500 to 2000 cm^2/Vs.

TEST	MOBILITY (cm2 /Vs)	CONDUCTIVITY 1/Ohm*cm
1	1.99E+03	2.26E-04
2	2.52E+02	1.52E-04
3	4.63E+02	3.14E-04
4	4.00E+02	1.34E-04
5	3.17E+02	1.29E-04
6	4.96E+02	1.43E-04
7	2.65E+02	1.21E-04
8	2.96E+02	1.43E-04
9	3.11E+02	1.31E-04
10	1.01E+02	2.03E-04

Figure 17: Result table for Hall Effect Test

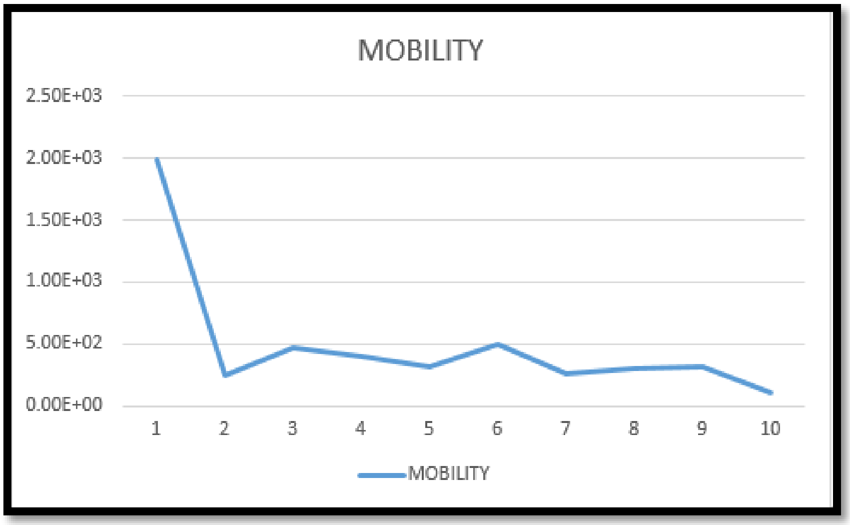

Figure 18: Mobility result

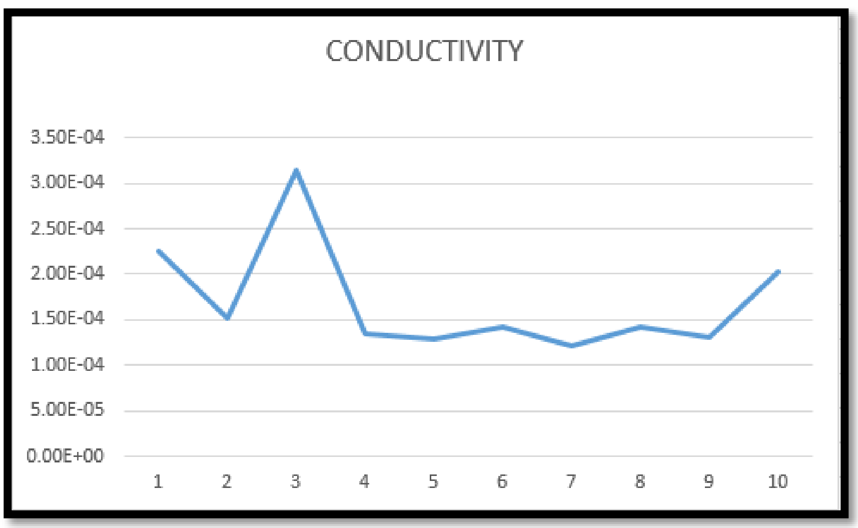

Figure 19: Conductivity result

4.4.2 Four Point Probe Test

The four point probe test is a test to measure the resistivity of the sample. This test is one of the important because we will get the exact value of resistivity of our sample. The four point probes test is a technique of measuring by using the separate pairs of current and voltage electrodes. This test is more accurate and we will get the true value of our sample resistivity. From this test we can measure the low resistance value. For this test, the value of current that is usually used is from 1mA to 5mA and 5V for voltage.

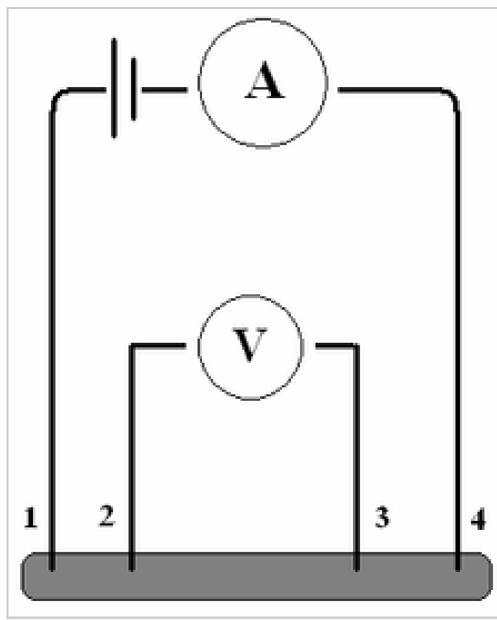

Figure 20: Schematic diagram of four-point measurement.

Test	Resistace (ohm)	Sheet Resistance (ohm)
1	1.28	5.79
2	0.77	3.48
3	1.27	5.76
4	1.08	4.9
5	0.74	3.33
6	0.9	4.08
7	0.72	3.27
8	1.97	8.92
9	0.89	4.03
10	1.06	4.79

Figure 21: The resistance and sheet resistance result of 4-point probe test for ten times test.

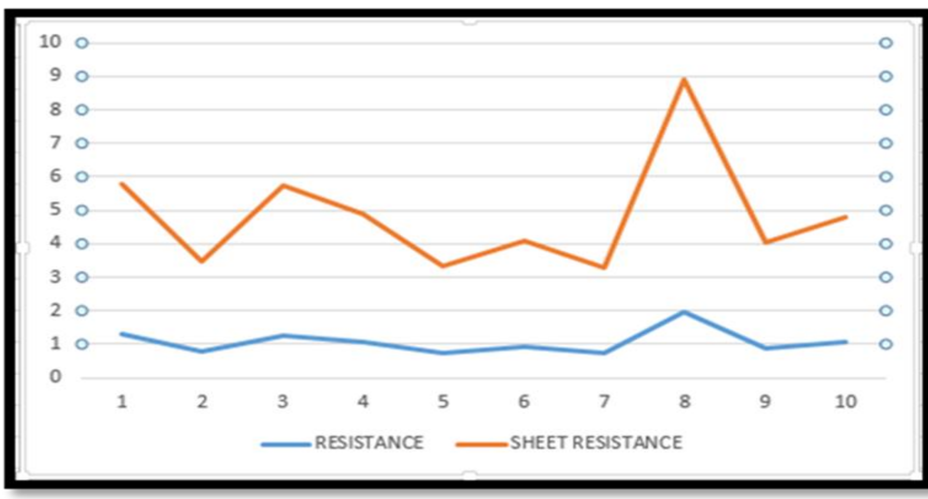

Figure 22: Resistance and Sheet Resistance result graph

Here is the result of the Four Point Probe test, we have made ten section of test with the start voltage value at 1V and stop at 5V. We have made the test at the middle and the side of our Graphene/PMMA sample. From this test, we get the average resistance is 1.068 ohm and the average for sheet resistance is 4.835 ohm.

4.5 Electromechanical measurement of 3D Graphene/PDMS composite film

Electromechanical measurement is a test that involved electrical and mechanical. This test was conducted to obtain resistivity from mechanical test. There are four type's mechanical test to get the resistivity that have been done which are torsion, tensile, compress and bending. All these tests used special mechanical tool. This test need to prove level of sample resistivity when it goes in certain condition. This are result for electromechanical testing:

4.5.1 Torsion Measurement

Torsion testing is a test that has been made to get the resistance value of the sample based on the degree of torsion that has been implement at the sample. For this testing, it combined the electrical and mechanical part. To do this test, special equipment of mechanical that is torsion tester has been used and it combined with the electrical part such as multi meter.

Figure 23: Torsion Testing

From this testing, we started to test our sample starting with 0 degree until 180 degree and then releasing it back to 0 degree. We can see the resistance change when the degree change. So as a conclusion for this testing, it prove that the resistance of the graphene with PDMS is changing when it was in different degree. This test also has been done for 10 times to make sure the result is accurate. Below is the result of torsion test.

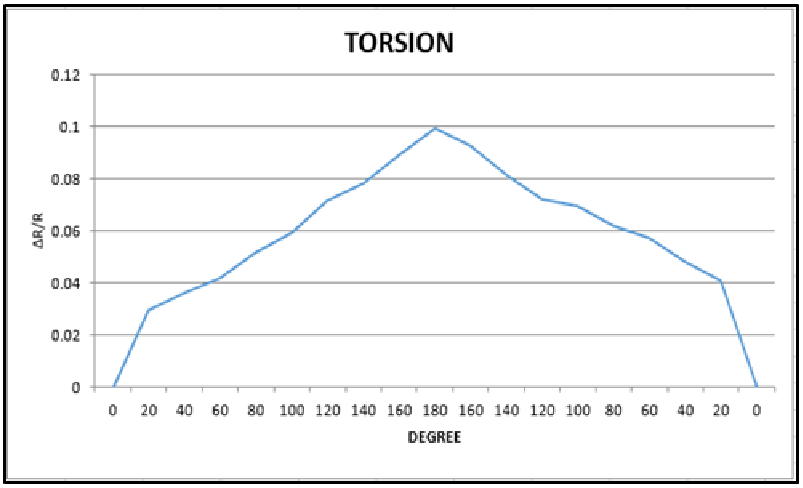

Figure 24: Electrical resistance variation of sample in a typical torsion cycle starting from 0 degree until 180 degree and back to 0 degree.

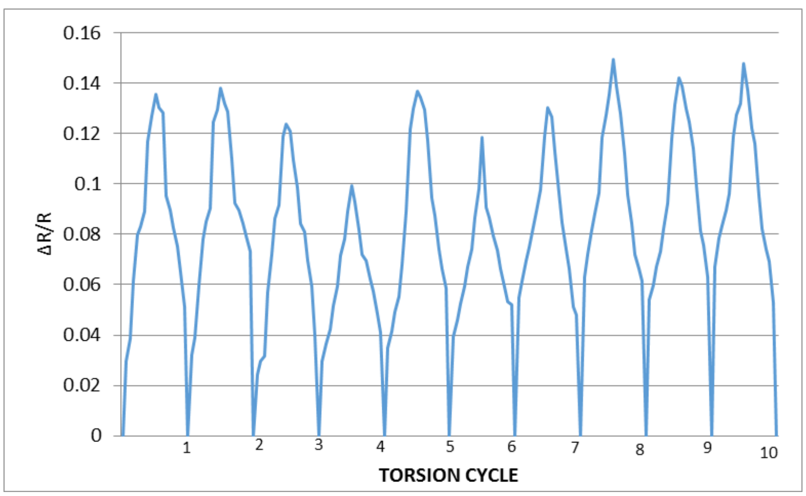

Figure 25: Torsion test cycle for 10 times

4.5.2 Bending Measurement

Bending test is a test that has been done to the sample to get the value of resistance based on the degree of bending that has been implement at the sample. In this test, special mechanical equipment has been used that is bending tester and for this test it also combine together with electrical equipment such as multi meter.

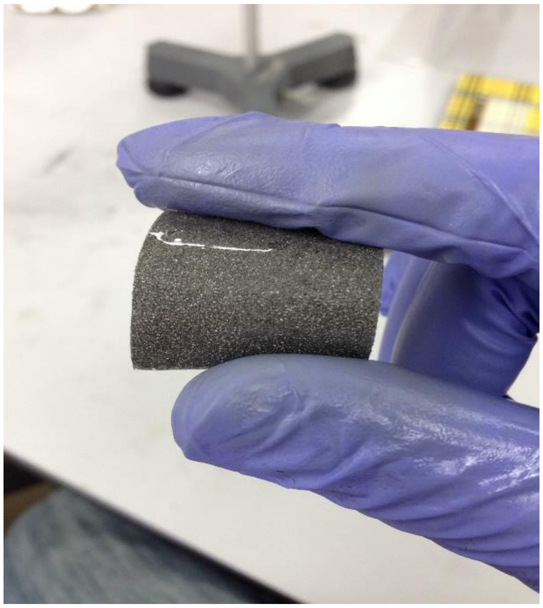

Figure 26: Bending test

In this testing, it started with 0 degree (means no bending) and 20 degree until 180 degree, we can see the resistance change when the degree of bending is change. It prove to us that the resistance of Graphene with PDMS will change when we bend it. This test also has been done for 10 times to make sure the result is accurate. Below is the result of bending test.

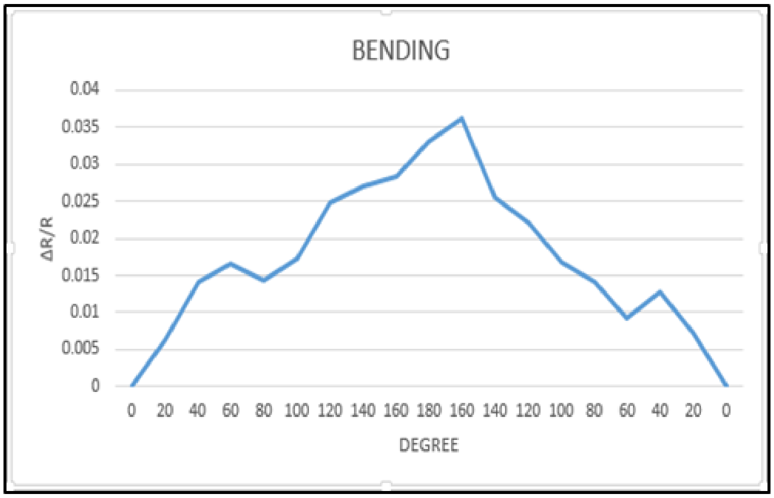

Figure 27: Electrical resistance variation of sample in a typical bending cycle starting from 0 degree until 180 degree and back to 0 degree.

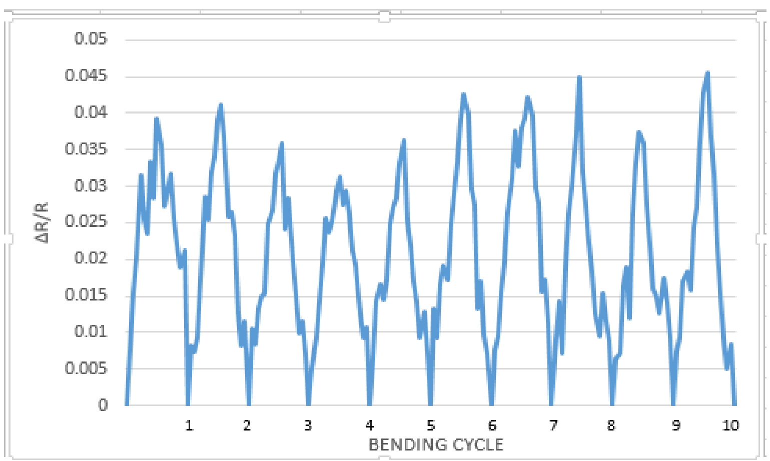

Figure 28: Bending test cycle for 10 times.

4.5.3 Compression Measurement

Compression testing is a test that has been made to get the resistance value of the sample based on the percentage of compress that has been implement at the sample. For this testing, it combined the electrical and mechanical part. To do this test, special equipment of mechanical that is compression tester has been used and it combined with the electrical part such as multi meter.

Figure 29: Compression test

In this testing, it started with 0 cm until 0.5 cm, in the percentage is starting from 0% and ended at 6.25% of compression. We can see the resistance change when the percentage of compression is change. It prove to us that the resistance of Graphene with PDMS will change when we compress it. This test also has been done for 10 times to make sure the result is accurate. Below is the result of compression test.

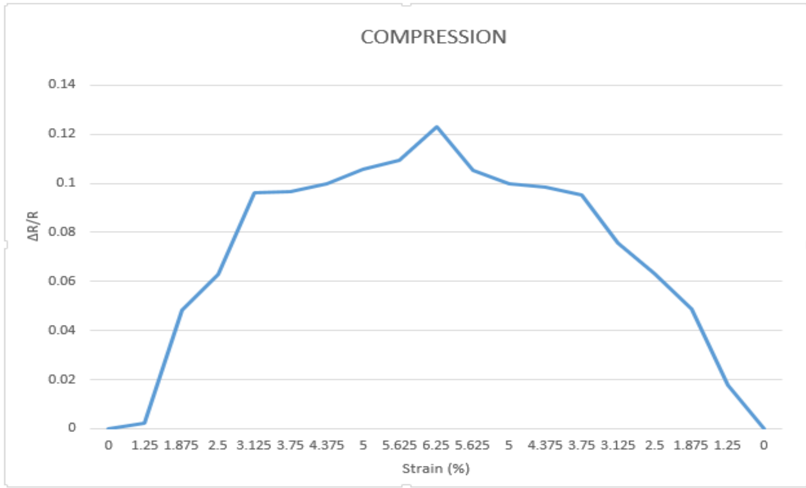

Figure 30: Electrical resistance variation of sample in a typical Compression cycle starting from 0 % until 6.25 % and back to 0 %.

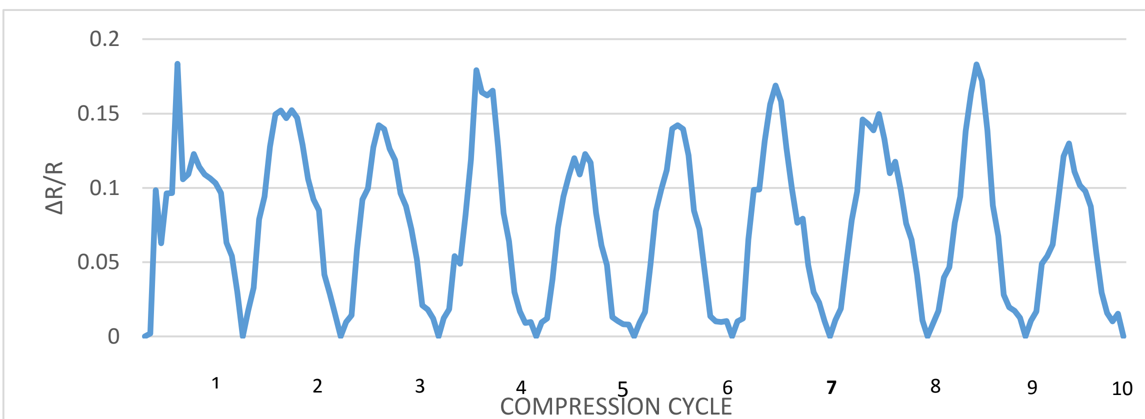

Figure 31: Compression test cycle for 10 times.

4.5.4 Tensile Measurement

Tensile testing is a test that has been made to get the resistance value of the sample based on the percentage of compress that has been implement at the sample. For this testing, it combined the electrical and mechanical part. To do this test, special equipment of mechanical that is tensile tester has been used and it combined with the electrical part such as multi meter.

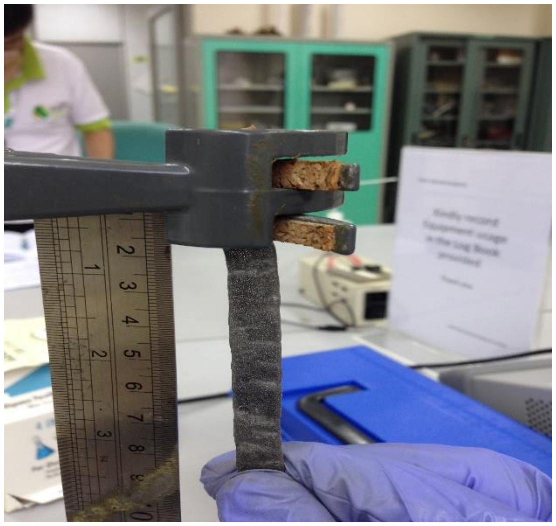

Figure 32: Tensile test

In this testing, it started with 0 cm until 1 cm, in the percentage is starting from 0% and ended at 12.5% of compression. We can see the resistance change when the percentage of tensile is change. It prove to us that the resistance of Graphene with PDMS will change when the stretch it. This test also has been done for 10 times to make sure the result is accurate. Below is the result of tensile test.

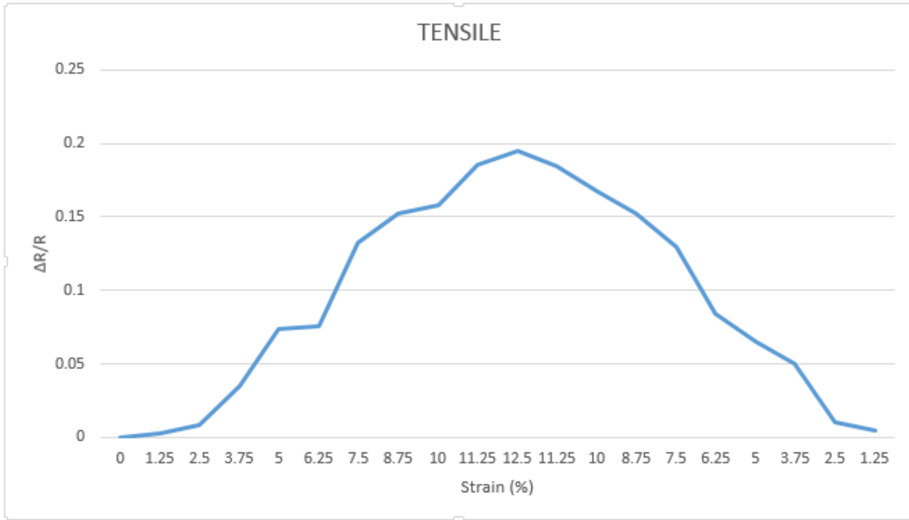

Figure 33: Electrical resistance variation of sample in a typical Compression cycle starting from 0 % until 12.5 % and back to 0 %.

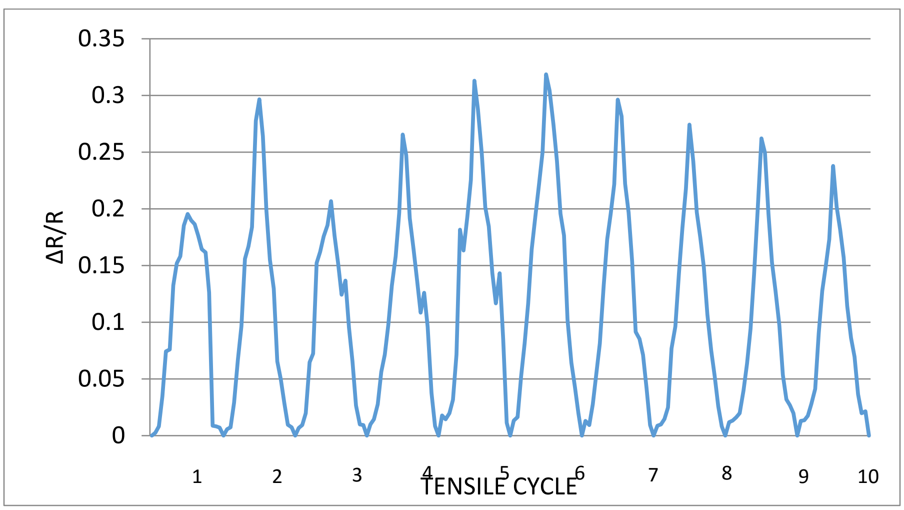

Figure 34: Tensile test cycle for 10 times.

4.6 IV-Curve

In this project, we also measured the current- voltage curve of graphene with PDMS nanocomposite for different level of applied degree for bending testing, which implied the fine linear current-voltage characteristic of the sample. Here is the result of IV-Curve for three different degree that is 0 degree, 45 degree and 90 degree.

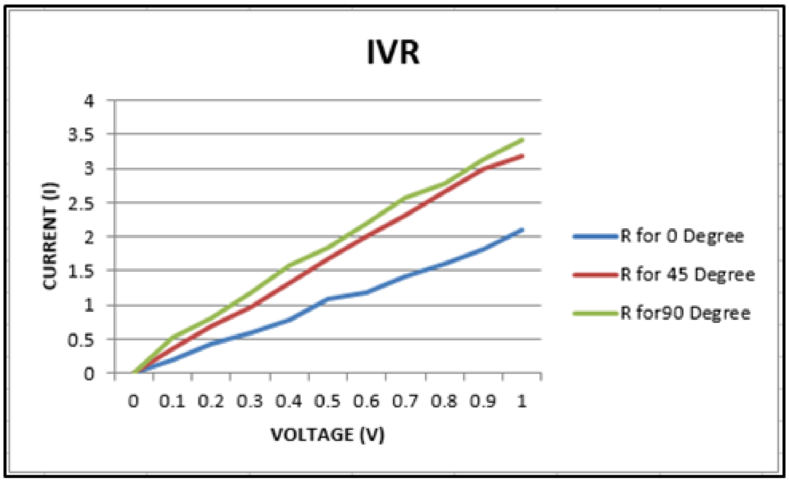

Figure 35: IV-Curve

Based from the graph, we can see that the resistance difference between degrees of bending testing. Starting from zero degree up to 45 degree, the resistance changed drastically. This shown value of resistance will change when sample surface was modified. At 45 degree to 90 degree, the change is small due to resistance achieved at maximum level.

CHAPTER 5 – CONCLUSION

5.0 Conclusion

In summary, three dimensional (3D) interconnected graphene has a very unique structure and the superior physical properties. From this project, it will bring out the new things in this new era by using this new technology. The 3D graphene has so many advantage in it characteristic. For the future, it will become the door to bring the technology to the next steps. This project will prove that the characteristic of graphene and PDMS will help to solve the problem that flexible film have. By using the graphene and PDMS as a flexible film, it will be more conductive compare to the others flexible film. It can be used as an alternative flexible film due to its excellent properties in term of electrical, optical and high thermal stability.

The graphene with PDMS also can become a Stretchable Sensor. It can happened because the characteristic of graphene with PDMS. The resistivity of graphene with PDMS is change when it was bend or stretch. So the graphene with PDMS can become a sensor because it can trigger the change of resistivity. Last but not least, we believe that such a simple and effective fabrication protocol will provide a new synthesis pathway for various multifunctional graphene hybrid foam based composites and this project will prove that the characteristic of graphene and PDMS will help to solve the problem that flexible film have. By using the graphene and PDMS as a flexible film, it will be more conductive compare to the others flexible film. It can be used as an alternative flexible film due to its excellent properties in term of electrical, optical and high thermal stability.

6.1 Recommendation

Based on the experimental that has been performed, several recommendations are purposed for future undertaking:

1. More testing need to be done to make sure the stability of the graphene sample in term of electrical and electromechanical.
2. For IV-Curve testing, it need to be done with torsion, tensile and compression test since it just be done with bending test in this project.
3. The sample size must be vary, to make sure that the result is still same and it will prove that the size will not affect the result.
4. Last but not least, all the data need to be compiled and it will help to create a strain sensor by using graphene/PDMS and achieve the ideas for this project.

6.0 REFERENCES

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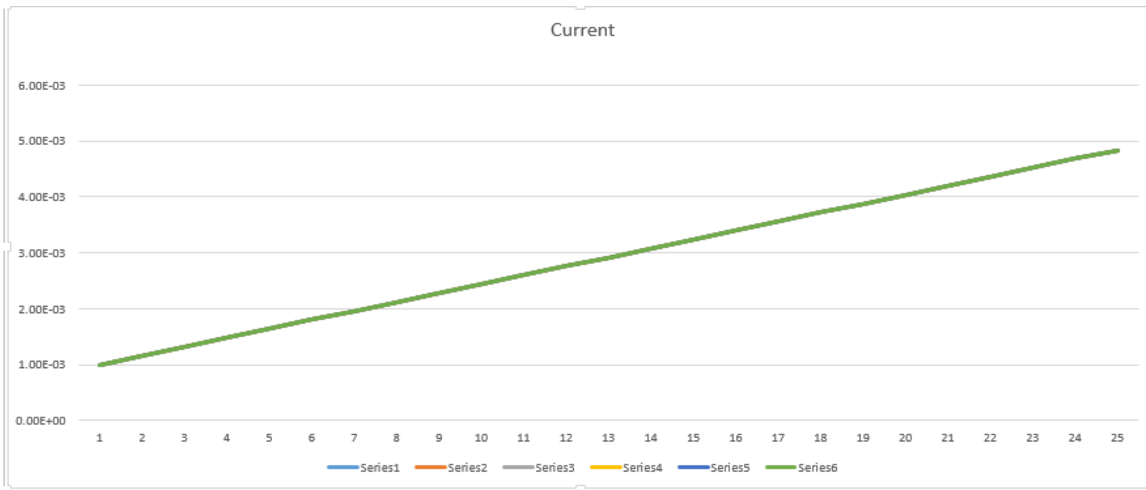
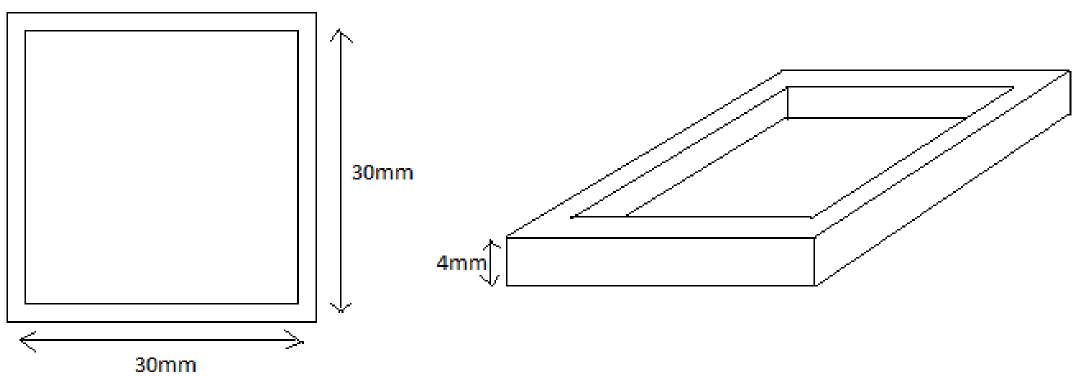
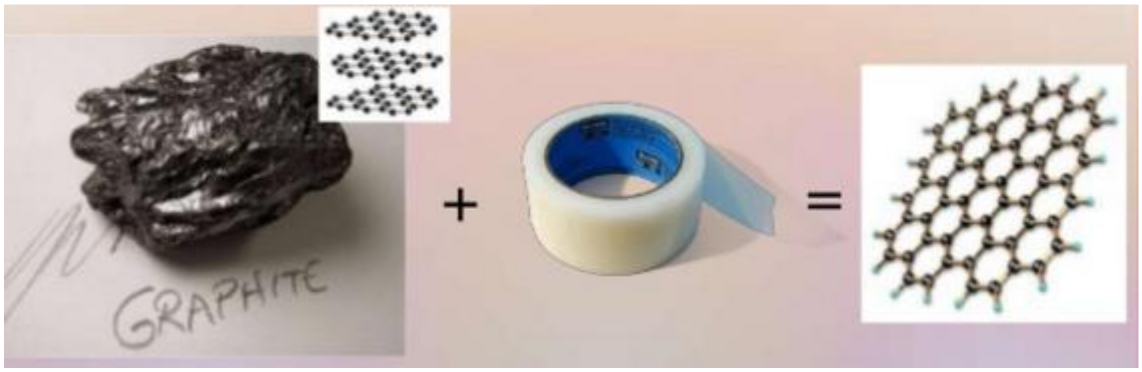
7.0 APPENDICES



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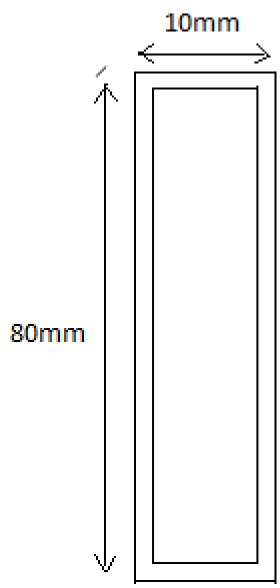
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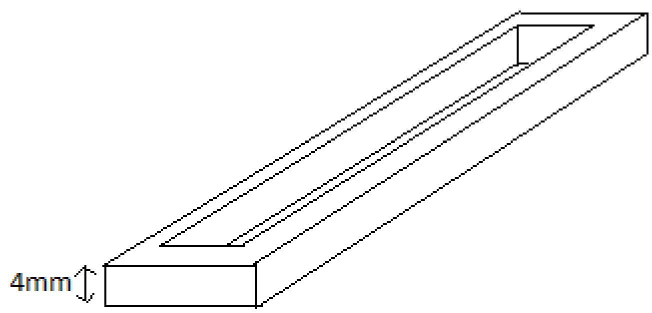
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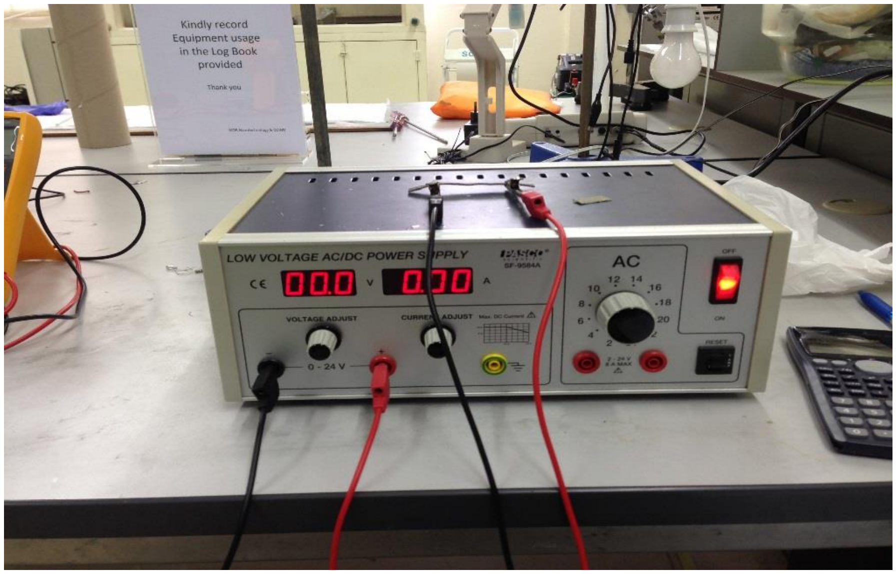
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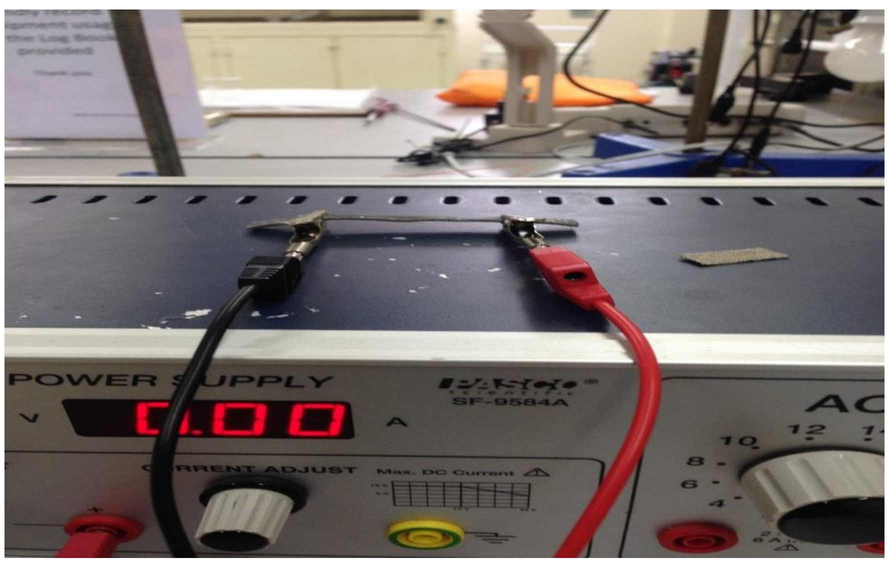
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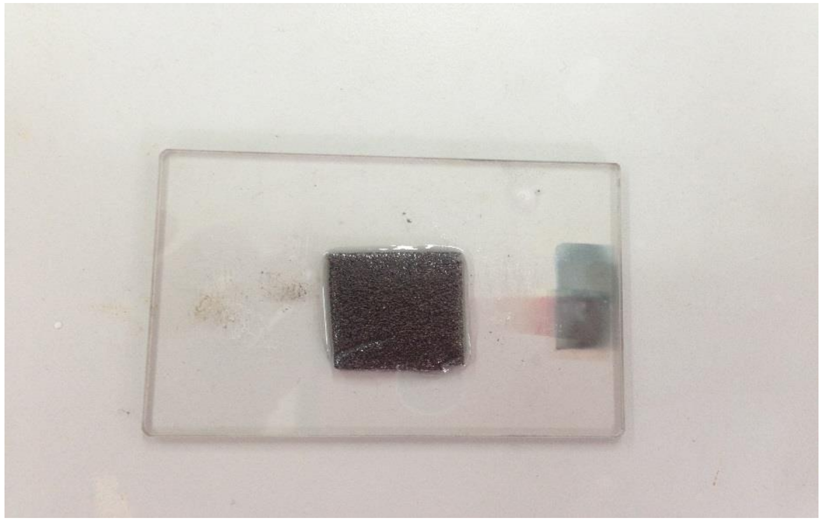

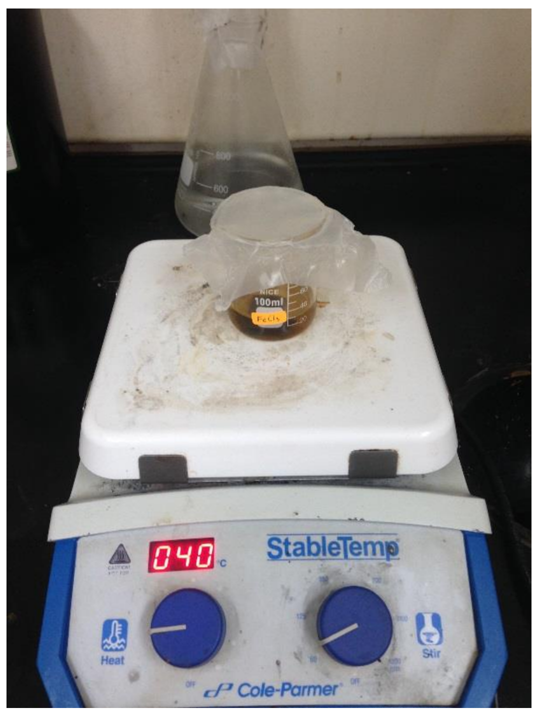
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