Graphene: The Next Generation of Printed Circuits

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Background: Graphene is a novel electronic material with extraordinary properties and potential to revolutionize the electronics industry. Graphene is a 2 dimensional sheet of carbon atoms that conducts electricity 35% better than copper at the atomic level. It is also 100x stronger than steel, flexible, an excellent conductor of heat and is optically transparent. It has a high energy density which can be used to make supercapacitors. (Novoselov 2012, Sun 2015) A method to make graphene easily using graphite and scotch tape was discovered in 2004 by Geim and Novosolev, leading to the Nobel Prize in 2010. (Novoselov & Geim 2004) Recently, teams at UBC and in Japan have announced superconducting properties in graphene doped with lithium or calcium. (Lubrook 2015, Ichinokura 2016)

Graphene Oxide is a made by treating graphite with a strong acid (Hummer's Method), and reacting with oxygen.(Sun J, 2015) Oxygen binds the edges of the graphite layers, exfoliating as graphene oxide, which is soluble in water. (As a non-polar molecule graphite and/or graphene needs to be dissolved in a hydrophobic solvent such as heptane.) Heat (laser) or chemicals can then be used to reduce the graphene oxide, producing reduced Graphene oxide (rGO). rGO has similar properties to pure Graphene but is less conductive. This is because rGO is not a pure crystal, there may be some non conductive carbon formed by the laser, and some oxygen molecules may still be attached. Typical lab results have resistance measurements of about 1000Ω

Purpose: To synthesize reduced graphene oxide (rGO) using various techniques in order to characterize the substance's conductive properties and suitability for printed circuit boards.

Hypothesis: It is hypothesized that reduced Graphene Oxide (rGO) would make a suitable material for printed circuit boards (PCBs). The resistance of an rGO film is expected to be a linear function of the ratio of length/width.

Procedure:

Materials: aqueous graphene oxide (4mg/mL), syringe, ultrasonic bath, lightscribe DVD burner and discs, graphite powder, CO_2 laser cutter, glass microscope slides, n-Heptane, multimeter, high intensity UV lamp, Ag epoxy paste, capacitance meter, EnVIA   Raman Microscope

Liquid Phase Sonication (adapted from Woltornist 2013)

1. Crush graphite pencil lead or obtain graphite powder.
2. Put 5mL of n-Heptane in a glass scintillation vial. Add 2mg of graphite powder.
3. Put the suspension in a sonication bath at 100% power for 15min.
4. Add 5mL of water and sonicate for 15min. (Figure 1)
5. Insert glass microscope slide. Close lid and shake.
6. Remove the glass slide with the graphene coated on it.
7. Apply silver paste to facilitate resistance measurement.

Laser Etching (adapted from Strong 2012)

1. Treat Lightscribe DVD disc using a high intensity UV light source for 15 min. (Strong's paper used oxygen plasma)
2. Dropcast about 5mL rGO liquid evenly over the Lightscribe DVD.
3. Let the Reduced Graphene Oxide dry for 24h.
4. Design shape for printing on disc using a computer program (SureThing DVD Labeler).

5. Use the laser and print object 20 times.
6. Using a multimeter, capacitance meter or MTCH112 Touchscreen controller, measure the resistance or capacitance of the samples.

Industrial CO2 Laser (some overlap with method from Sinara 2014)

1. Dropcast Graphene Oxide on glass slides (cannot use DVD plastic substrate in laser cutter).
2. Let the Graphene Oxide dry for 24h.
3. Etch pattern in a CO_2 Laser cutter at 2% power and 10% speed.

Data and Observations: Graphene made using the liquid phase sonication method did not stick to the glass slide very well and would flake off when the probe touched the surface. When it could be measured, the resistance was 10MΩ. The Lightscribe method grew rGO crystals on the surface of the disc along the circular path of the laser. 1x2cm films of Lightscribe reduced Graphene oxide had a resistance of approximately 1-4 kΩ. One capacitor was printed with the Lightscribe. It had a capacitance of 1.4µF and a total area of about 1 cm^2. Using the industrial laser, resistance values of 20 – 40 MΩ were measured initially. This process took only about 5 mins as compared to almost 24h of Lightscribing. On further attempts, a resistor with a sheet resistance of 2.8 kΩ/□ was produced. Two capacitors of 25nF were made.

Discussion: The sheet resistances (R_s) of four rGO samples were measured experimentally by determining the slope of the Resistance versus length/width ratio (L/W) of the sample. The first set was made with the Lightscribe, the other three with the CO_2 laser cutter. Most samples did not have statistically significant results as the data was scattered and the Linear Correlation

Coefficient was poor. Only the CO_2 rectangular samples had a good linear fit. Their sheet resistance was 2.8kΩ/□.

The sheet resistance for rGO in this experiment agrees with the published literature. Bonaccorso et al. (2010) reported a sheet resistance for rGO on the order of 1kΩ/□. The exact value of the sheet resistance varies with the thickness of the reduced graphene oxide layer. Reasons for the inconsistent results with the first three samples are discussed in sources of error below. The laser scribing technique took many more runs than expected. Five burning runs were commonly reported in the literature but more runs were needed for this sample. The thinner the rGO layer was, the faster the graphene formed. This is likely due to the laser energy being focused on fewer molecules. Capacitance values in the nF to μF range are high for a small area planar capacitor. This suggests that a large surface area to store charge is available.

The resistance measurements may not have followed a linear relation for several reasons. One cause is variation in the thickness and shape of the rGO film. Another is inaccuracy in the length measurement, especially if the width of the resistor was very small compared to the size of the multimeter probe. The fourth CO_2 laser sample was 19m wide, which greatly reduced this error, resulting in a much more linear sheet resistance measurement. Using the dropcasting method did not give an even application of the Graphene Oxide liquid, but spincoating the disc may improve thickness and consistency of the application. It is difficult to get reliable resistance or capacitance measurements using regular multimeter probes, and attempts to solder wires to the graphene just melted the DVD plastic. Silver epoxy seemed to work better, but may have an adverse effect on capacitance. Copper tape was used and this has been more reliable. A Raman spectrum was measured on the sample. Preliminary data shows similar peaks to graphene but more detailed analysis must still be done.

Conclusions:

Reduced Graphene Oxide can be made using the Lightscribe method but this procedure is fairly slow and has too great a resistance for PCB traces. However, this material shows potential for making discrete resistors and especially capacitors.

More experimentation to improve the yield and shorten the time of the fabrication procedure for reduced Graphene Oxide throughout the burning process will be pursued. The CO_2 laser seems more promising in this regard. I would also like to compare Copper and Reduced Graphene Oxide at extreme temperatures and see how they perform. It is possible that in extreme environments such as outer space, a rGO chip could outperform a copper based chip. I would like to try to see if there is an effect of a transverse electric field on the resistance of a graphene strip, and whether adding dopants such as lithium or calcium to the graphene oxide would have any effect. To more fully understand the sheet resistance I would like to use a precise measuring tool to determine the thickness of the sample.

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