LightScribe Graphene Supercapacitor

Making Scalable Inexpensive High Power and Energy Density Graphene Supercapacitors with the LightScribe Method

Introduction

Improvements in charging and discharging rates, number of charging cycles, energy density, safety, efficiency, and cost in energy storage devices can help stimulate the implementation of renewable energy resources. This research project aims to create an inexpensive scalable method to fabricate high energy and power density graphene supercapacitors using laser scribing methods. Some variables in the experiment include: the concentration of the graphite oxide solution, the volume of the graphite oxide, the capacitor pattern, the substrate, and the laser intensity. Factors such as the working voltage window, discharge rate, mass, and conductivity determine the performance of the graphene supercapacitors. The LightScribe method has the potential to make high energy density graphene supercapacitors.

Process

Materials

- Graphene Oxide Water Dispersion 4 mg/mL (Graphenea, n.d.).
- Wintale USB 3.0 External Slim DVD Drive with LightScribe (Wintale, n.d.).
- Verbatim LightScribe DVD for this experiment (Verbatim, n.d.).
- SureThing Labeler 6 Gold (SureThing, 2014).
- Clear Craft Plastic .007 Thickness 12-Inch by 12-Inch (Rafix, n.d.).
- Repositionable Mounting Spray Adhesive, 10 Oz, Clear (Elmer, n.d.)

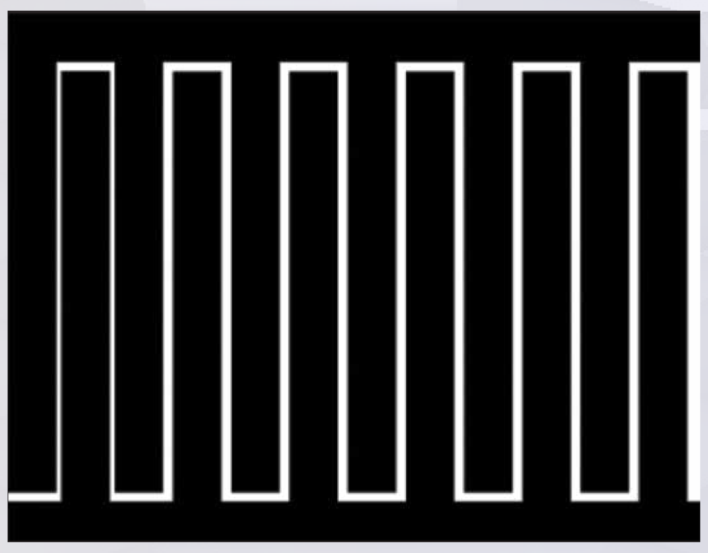

Figure 1. The interdigitated planer structure of the capacitor

Procedures

1. Cut the plastic film into the shape of the DVD disks. Trim the plastic so it does not cover the center rim of the disk, which is important for the LightScribe process.
2. Glue the plastic film temporarily onto the disk.
3. Dilute the graphite oxide solution to 2 mg/mL. Mix 8 mg/mL of the solution with 8 mg/mL of distilled water.
4. Drop cast 16 mL of the solution onto the plastic film substrate with a pipet and let it dry in a fume hood. Be careful not to spill or touch the surface of the disc.
5. Design a capacitor pattern. There needs to be two electrodes that do not touch one another. The pattern should be black. Save the pattern as an image file **(Figure 1**).
6. Place the coated DVD disk into the LightScribe DVD burner. Use the capacitor pattern image with a LightScribe software to reduce the GO. This process converts the brown dried GO to graphene capacitor circuit and takes about 30 minutes **(Figure 2)**.
7. Remove the plastic film substrate from the disk and cut out the capacitor.
8. Glue copper wires at the end of the positive and negative electrodes for testing.
9. Cover the capacitor surface with tape to prevent scraping and damage **(Figure 3)**.

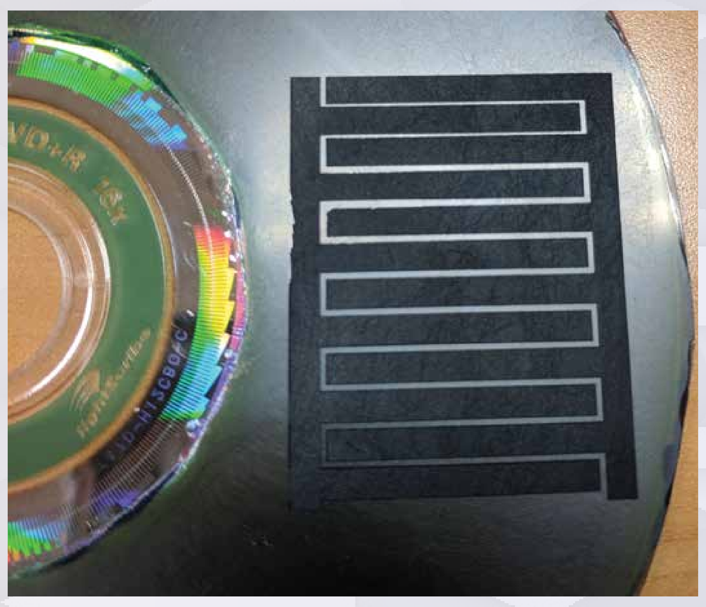

Figure 2. The laser scribed graphene capacitor on the DVD disk

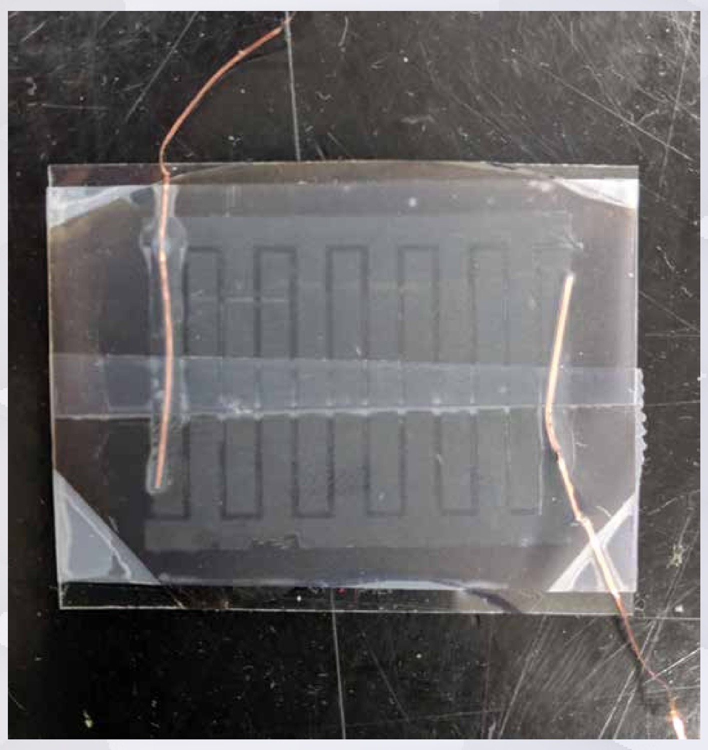

Figure 3. Image of the finished graphene supercapacitor

Results

After the LightScribe process, the conductive reduced graphite oxide becomes black while the insulative graphite oxide remains dark brown. The reduced graphite oxide exhibits electrical conductivity similar to that of graphene.

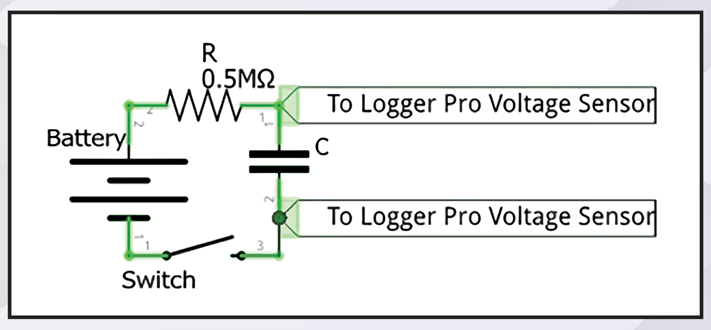

Figure 4. Circuit diagram of the RC circuit for testing the capacitance

In this experiment, the capacitance of the capacitor is measured in an RC circuit **(Figure 4)**. The circuit uses a 1.5 V AA battery as the power source and a 0.5-megaOhm resistor. With the capacitor and the resistor in series, electrons can only flow through the resistor. Ignoring the internal resistance of the capacitor, the voltage (V) at time (t) of the circuit can be derived from the equation $V(t) = V * e^{-\frac{t}{R*C}}$ whereas R is the resistance of the external resistor, V is the voltage of the power source, and C is the capacitance of the graphene capacitor ("RC circuit," 2017). The Logger Pro voltage sensor produces a graph of the voltage drop over time **(Figure 5)**. With the voltage over time data, I then plotted a natural log plot of voltage and time, with the slope of the plot being $-\frac{1}{RC}$. Hence, the capacitance is the negative reciprocal of the time constant divided by the resistance of the external resistor **(Figure 6)**.

Since the RC time constant is the slope of the natural log plot, we can measure it. The time constant is $\mathbf{0.01 \pm 2.4 * 10^{-3}}$. Since the time constant is equal to $-\frac{1}{RC}$, the capacitance is therefore $\mathbf{209 \mu F \pm 25\%}$.

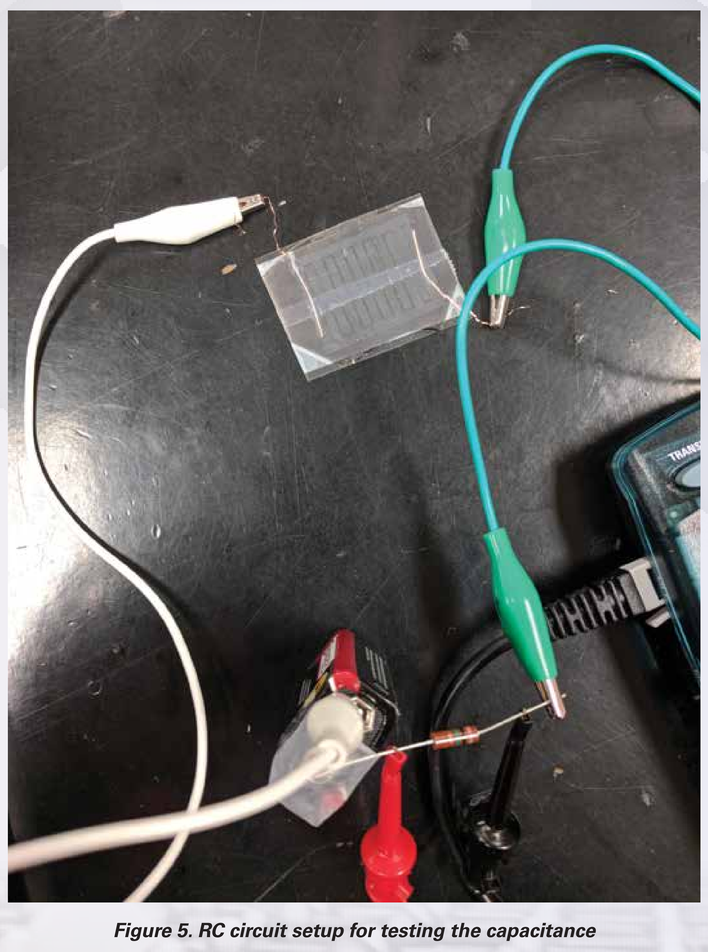

Figure 5. RC circuit setup for testing the capacitance

As shown in the graph below, the capacitor is instantaneously charged to 1.5 volts. Then once disconnected from the power source (the 1.5 V battery), the voltage drop is also almost spontaneous **(Figure 7)**.

After that, the voltage drops at a logarithmically slower rate over time. In comparison, another trial is performed without the external resistor. The difference between the trials with and without the resistor in the RC circuit is so insignificant that the electrons directly flowing through the circuit is negligible. Thus, this capacitor does not retain a charge very well.

To demo the performance of the graphene supercapacitor, the capacitor can light an LED in a circuit. However, the low voltage due to the instantaneous voltage drop makes it hard for the LED, which has a higher working voltage, to stay lit. I used a self-oscillating voltage booster to increase the working voltage of the capacitor, hoping to light the LED in the circuit **(Figure 8)**.

Unfortunately, the $\mathbf{200 \mu F}$ capacitor could not provide enough energy to keep the LED lit.

Furthermore, the mass of the $\mathbf{200 \mu F}$ graphene supercapacitor is 0.83 grams **(Figure 9)**. Hence, it will take approximately four kilograms of those capacitors in parallel to have one Farad of capacitance.

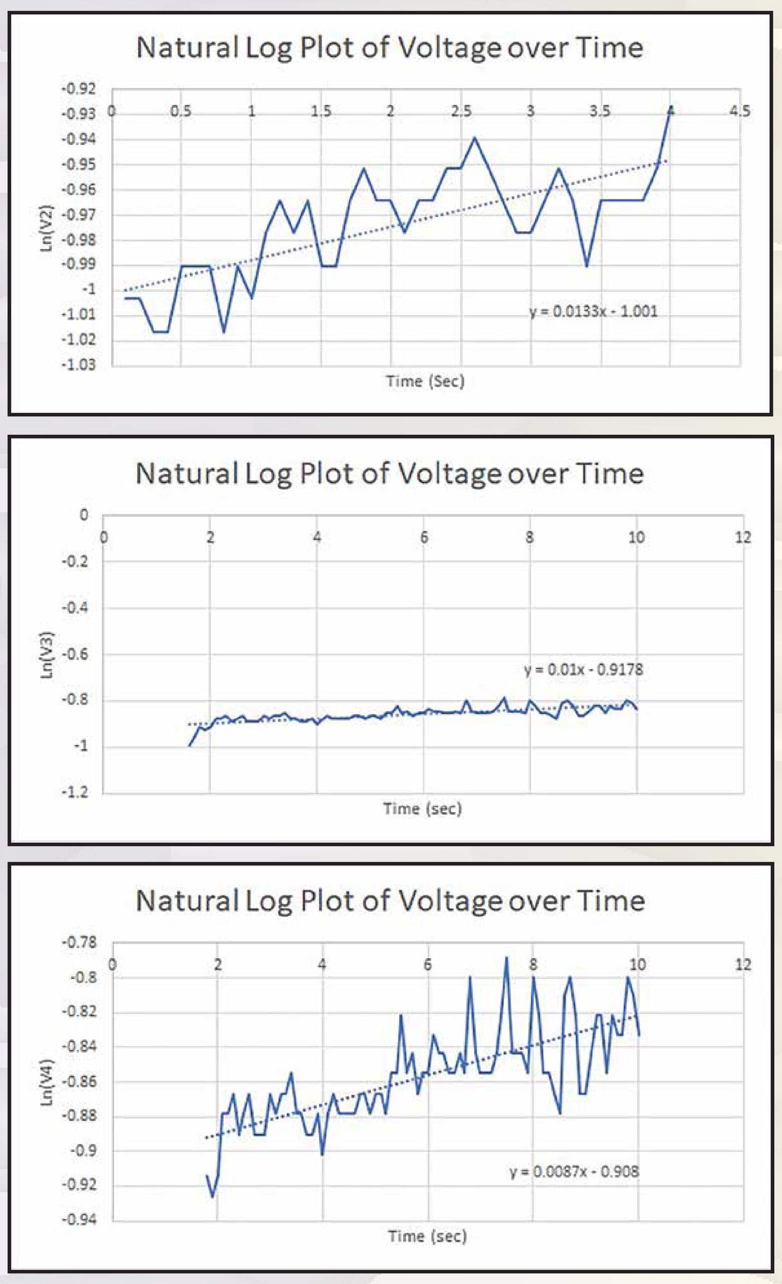

Figure 6. The natural log plots of voltage versus time of the capacitor

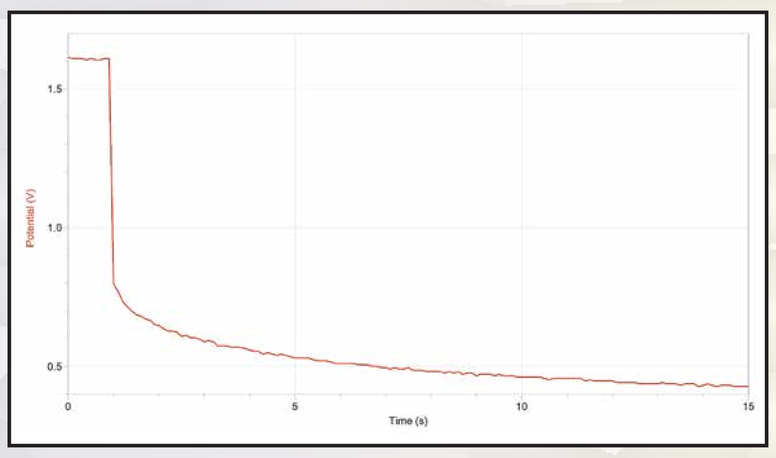

Figure 7. The graph of the voltage versus time

Discussion

As the experiment shows, graphene supercapacitors have good electrical conductivity and fast charging rates. Without a flammable electrolyte or lithium, they are safer and more environmentally friendly. They are lightweight and flexible, giving themselves many applications for energy storage in small-scale electronic devices.

Furthermore, the LightScribe method proves to be inexpensive and relatively easy to manufacture. On the other hand, the fast discharging rate and graphene supercapacitors' inability to retain a charge long enough hinder their implementation as a larger scale energy storage device in places like electric vehicles and solar farms. Nevertheless, graphene's high electrical conductivity, physical strength, flexibility, and transparency make it a great material for various electronics applications.

Figure 8. Image of the voltage booster

The simplicity of LightScribe laser scribing technology demonstrates the feasibility of a low-cost approach to making reduced graphite oxide, which exhibits similar physical properties to graphene. This research project has successfully demonstrated the feasibility of an inexpensive scalable approach to making graphene supercapacitors.

Some limitations of this experiment include the quality of the substrate, the LightScribe burner, and demonstrating the energy storage capabilities in a simple circuit. With the plastic substrate glued onto the disk, sometimes the LightScribe burner cannot recognize the disk. Most of the "printed" capacitor patterns have printing gaps that make them incomplete circuits. The disk space is very limited, resulting in small capacitor dimensions, although small capacitors can be arranged in parallel. The voltage drop of the capacitor is almost spontaneous, so the supercapacitors need a voltage booster to supply energy to an external circuit.

Figure 9. The mass of the graphene supercapacitor

For further improvement of this project, the graphene supercapacitor needs to be encapsulated inside a more insulative material. Using better substrate will help insulate the capacitor and prevent electrons from escaping, hence retain a charge longer. On the other hand, although it takes approximately four kilograms of those supercapacitors to make up only one Farad of capacitance, most of the mass come from the plastic substrate.

We can reduce a lot of the redundant weight by using a thinner and lighter substrate than the crafting plastic. I can also experiment with different fractal patterns such as the Hilbert curve to improve the capacitance by increasing the specific surface area. Moreover, since the LightScribe method has demonstrated the feasibility of graphene exfoliation with a laser, a CNC laser cutter with modified laser intensity can "print" larger graphene capacitors on an industrial scale.