EE 128 Project

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Introduction

In todays era, humans have an invested interest in finding methods to charge their technology in the most efficient way possible. In order to do this, scientists put a priority on maximizing power and energy densities. Traditionally, batteries have a high energy storage but charge and discharge very slowly. Electrochemical capacitors on the other hand have a low energy storage but charge and discharge very fast.

Exciting research is being done right here at UCLA which would allow a graphene superconductor to have the best of both worlds. Our group's interest was sparked after watching the film "The Super Superconductor" directed by Brian Golden Davis. Davis presents the UCLA scientists who are changing the world of energy storage as we know it. Our group was excited by this cutting edge technology, especially considering that it is being pioneered at our own college.The popularity of this video on the internet shows the true potential of this discovery for humans day to day life.

Fabrication

In this paper, Maher F. El-Kady et.al. describe in the supporting material how they synthesized their laser scribed graphene (LSG) electrodes, and then the capacitors themselves. The process begins with a graphite powder that they made using "Hummer's method" (Supplemental 2). From this powder they make GO films on substrates such as "polyethylene terephthalate, nitrocellulose membrane, aluminum foil, and regular Xerox paper" (Supplemental 2). The films get placed onto DVDs and into $20 commercially available

LightScribe DVD drives. These DVD drives are made with a laser that uses 5 mW, and a standard wavelength of 788 nm. They make the graphics by shining the laser onto DVDs with a gel that changes color when a laser is shined on them. The research team repurposed these LightScribe drives so that the laser would go in concentric circles around the drive. The result of this is that the laser reduces the graphene oxide (GO) to laser scribed graphene (LSG). The resistance of the material before laser treatment is more than 20 megaohms/m but the conductivity of the treated sheets is quite high, 1738 S/m. A complete electrode is completed after doing the process about 6 times, and the process only takes about 20 minutes.

Next, the LSG electrodes were put together in order to make actual capacitors. Because of the features of these electrodes, two films do need additional binders, constructive additives, or metal current collectors, which are all parts that conventional capacitors need to function(Supplement 3). Polymer gelled electrolyte is poured slowly on the electrode and left for 5 hours to dry. The details of the electrolyte were left in reference 39 and not detailed in the paper itself. Then another electrode is left face to face with it and left until the electrolyte solidifies. The result is a completed capacitor.

The physical principle of operation

Laser-scribed graphene can be used as electrochemical capacitor electrodes without the use of binders or conductive additives. The graphene can be used as the active material as well as the current collector in the electrochemical capacitor, as the laser-scribed graphene films possess a high conductivity (at 1738 S/m) relative to the much lower conductivity of activated carbon (the gold standard, at 10-100 S/m), and the laser-scribed graphene is highly flexible and robust, suffering only a 1% change in resistance after 1000 bending cycles.

Laser-scribed graphene, when used in an electrochemical capacitor, also has an extremely large charge storage capacity, which can be attributed to its larger surface area (1520m^2/g relative to 1000-2000m^2/h of traditional activated carbon).

The LightScribe laser-scribing method of making laser-scribed graphene produces an open network of laser-scribed graphene, which prevents the graphene sheets from clumping together, which has traditionally been an extremely large obstacle when trying to harness the full extent of the power of graphene. The network of laser-scribed graphene has open pores which allow electrolytes to diffuse more easily to the electrode surfaces. This facilitates the ionic diffusion process in laser-scribed graphene, which is important in charging the capacitor and allows for a higher power rating. The graphene is also highly conductive, which is important in achieving a high power output.

Key result/contributions of the paper

Laser-scribed graphene is an easy and cheap to manufacture graphene which can be used to make biodegradable, flexible, and highly efficient capacitors. These capacitors are unique to graphene, having a porous electrode that facilitates ion transport and results in the capacitor having high capacitance. These capacitors also do not require binders, which decreases the amount of interfacial resistance, allowing for a more efficient capacitor.

Laser-scribed graphene based electrochemical capacitors have many advantages as a result of their many properties of being cheap, biodegradable, flexible, and highly efficient. These capacitors can be used in cars and aircraft and other vehicles when the weight of a capacitor is of concern; the lightweight yet highly efficient graphene capacitor would outperform traditional capacitors in this respect. Other smaller one-time-use commercial products can also benefit from the use of laser-scribed graphene based capacitors, as the graphene capacitor is made simply from carbon, and is biodegradable and will not harm the environment, regardless of how it is disposed.

These graphene capacitors can also be used in a variety of products which require that the capacitor be compact and flexible, such as in the case of products that have natural semi-permanent curves, such as the rumored-to-be-in-development Apple product, iWatch. The versatility of this graphene is most exemplified by the fact that it can be "readily made into different designs, including stacked and spirally wound structures to target different applications" (1327). This means that certain geometries of space no longer have to be specially dedicated to capacitors in certain commercial devices, and that the graphene capacitor can be designed to the need of the product, rather than the other way around.

Discussion

The applications of the LSG capacitor are very clear and widespread. We only need to look at how the features of the LSG device differ from a conventional battery to see how this device may be used as a replacement for batteries. Firstly, we realize that the power of this LSG device is comparable to other contemporary tech: “LSG-ECs can deliver a power density of ~20 W/cm^3, which is 20 times higher than that of the AC-EC and three orders of magnitude higher than that of the 500 micro-Ah thin-film lithium battery.” Now that we have established it is comparable in power output, which is the first and most important feature of a battery, we can make comparison to other aspects of a battery.

Conventional batteries are heavy and bulky, while LSG devices are small and thin and light. The group demonstrated a 2 x 1 inch film with comparable to paper thinness was able to power an LED for 24 minutes. This means that the LSG capacitor has the potential to further the portability of devices without affecting the power and charging capabilities. Everything from a phone to a television could replace the typical battery and be replaced with an LSG device. We imagine a future where charging a cell phone could be as short as one minute, compared to the hour or two it takes now. And thinking on a larger scale, electric cars could make a quick pit stop to recharge, which would convince more consumers to choose an electric car over traditional gas run car.

Conventional batteries are toxic to be disposed of, while LSG devices are carbon based and so are biodegradable. Disposing of batteries can be extremely detrimental to the environment, which is why there are so many efforts to recycle batteries appropriately. Moving to this LSG technology would eliminate this problem, as could place it anywhere as it is biodegradable. Considering the amount of technology that requires batteries in current day, this has the potential to make a large charge in the environment.

Also consider that conventional batteries are rugged in shape, while LSG devices are flexible. This allows it to be possible to change the design of products with batteries in it because the flexible LSG devices could accommodate the changes.

All in all, we find that the LSG based devices are very appealing. There is more work to be done before these devices can be used as a replacement for commercial batteries, with regards to making them work with devices we actually have right now, but they are promising. This research does not make any claims about how scalable the process is and if the quality of the LaserScribed graphene sheets is high enough for technologies that require very reliable power sources, so complementary research could be done in that area. These limitations aside, we would love to see more progress in this field.