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Flexible and High-Power Density Supercapacitor from Activated Carbon and DES Solvent Solution Coated Graphite Felt for Low-Cost and Fast Fabrication

Brayden Noh

Auburn High School Independent Research accepted as Intel ISEF Project
Intel ISEF Project Title: Flexible and High-Powered Supercapacitor from Low-Cost and Simple Building Method
Email: 3rayd8n@gmail.com

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ABSTRACT

Supercapacitor cost and production variables should be looked upon equal as the performance of the supercapacitor. In this report, the fabrication of symmetric supercapacitor using activated carbon and deep eutectic solvent solution infused graphite felt as positive and negative electrode is built, which allows for a single-step fabrication that requires less than 5 minutes. Fiber-made electrode allows for flexibility without material damage or performance loss, which makes greater range of application in supercapacitor. A single supercapacitor with 6 cm2 area shows a voltage range between 1.8~2.1 V and delivers capacity of 100 Farads or 17 mAh and energy density of 13 mWh. The supercapacitor also shows excellent voltage stability when the device is bent, which shows that 80% of the voltage remained at 40 degrees bent without any protecting case. The cost of the supercapacitor lower than an average commercial supercapacitor, which is 50 cents per square centimeter.

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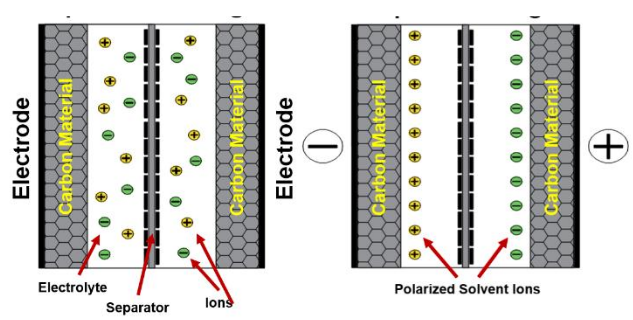
Introduction

As devices increase in needs for alternative energy source other than batteries, supercapacitors have been in development since its beginning of discovery. Thanks to wonder-materials such as carbon nanotube and graphene, the researches have further advanced the technologies behind making supercapacitors with high energy density. Some of the research of supercapacitors with the most advanced materials and production methods had been built to surpass the capacity of both lead-acid and lithium ion batteries, which means it could replace the slow charging process that batteries suffer. [1] However, most of the researched supercapacitors cannot be produced for commericial use, because of the production methodology and the cost. This is because materials such as graphene cost exceedingly high for consumer product and the assembling method is tedious and difficult. [1,2] This means that the supercapacitor must not only be superior in its capacitance, but also the production method and its cost must be low.

Logical approach to the research was simple. First, the phyiscal and chemical characterstics of each components of the supercapacitors were found. A basic supercapacitor consists of two electrodes, two carbon-materials, electrolytes, and a separator. [3,4] Each component is required to achieve a certain charateristics in order for the supercapacitor to achieve high capacitance. An example would be carbon-material requiring large surface area, which allows more ion storage and electrode requiring to be conductive. After the characteristics were found, the materials were than researched. Cost was a large factor during material research, because the objective was to build a cheap supercapacitor.

Supercapacitor Diagram



Methods

Electrode: Exploring the suitable electrode came early due to the low-capacitance the previous electrodes such as graphite foil and copper foil. Biggest challenge came from this phase, since active material, which determines the ion charge storage, was not included in the research. This meant, the only method of increasing the ion charge area is to increase the phyiscal surface area of the electrode. Porous 3-D electrodes have been increasingly used for making batteries and fuel cells, due to the charactericteriscs of porosity and conductivity. [5] Porosity was an important factor into choosing the electrode, because it increases the surface area of the electrode. A material called graphite felt was found. This material is manufactured by the carbonization and grapihtization of carbon felt. [6] It is not a novel material related to electrochemistry, since it has been used for

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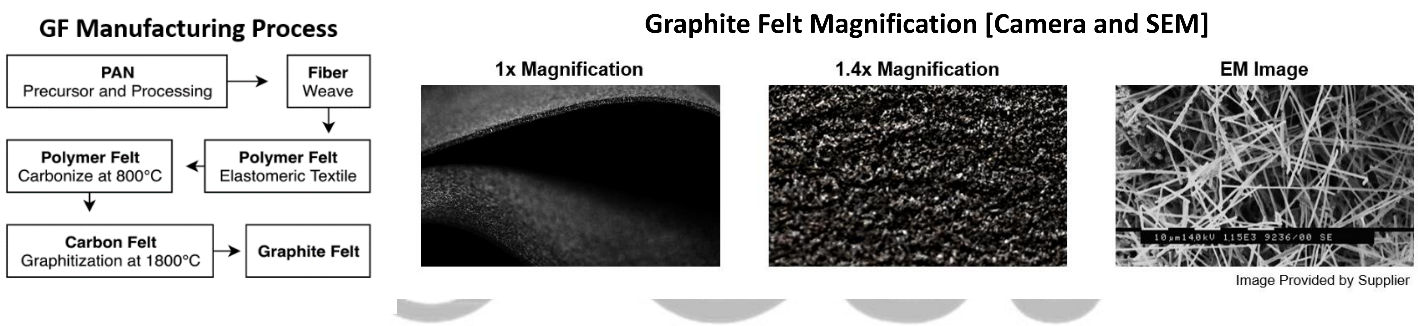
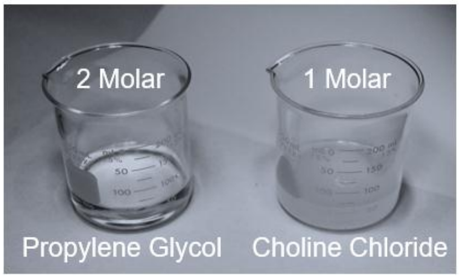
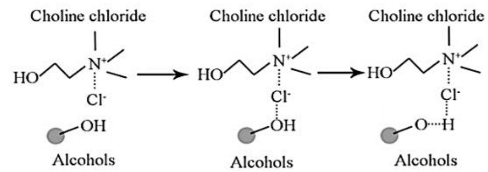
electrode in energy storage devices like battery and fuel cell. However, the conductivity is relatively low compare to metal 3-D electrode and research continues to increase the conductivity. The reason why graphite felt was used instead of other 3-D electrode materials was due to its porosity and its cost. It has been evaluated that graphite felt electrodes has a typcial surface area that is 800 times greater than pyrolytic carbon. [6] The cost was relatively low compare to other materials costing $9.45 per 600 mm2. The principal precursor used to manufacture the GF is PAN, which is a form of acrylic fibre and this type of precursor is stronger than other type of precursor-based carbon fibre. The carbonisation occurs at 700-1300 °C followed by graphitisation at 1600-1800 °C. Overall, the use of graphite felt as the positive and negative electrode showed good conductivity, flexibility, and porosity. A simple demonstration was done with the material comparison between graphite foil, a metal electrode and graphite felt by building a simple capacitor. It showed that the graphite felt showed about 2.5 times the capacity rate compares to the metal electrodes



Electrolyte: Electrolyte development is the most important factor in the research because the voltage window is directly related to the theoretical energy density, which is $E = \frac{1}{2}CV^2$. [7] Oragnic electrolytes and ionic liquids were found and researched due to its high voltage window, however due to its toxicity and its high-cost, alternative electroltes were focused. [7] Deep eutectic solvent was found to be the alternative electrolyte. Eutectic mixure is a unique composition of two phase-immiscible solid components that undergoes a complete change of phase to liqiud at a precise temperature. [8] Deep eutectic solvent can be considered as organic salt in the liquid state. During the research, cheap biocompatiable deep eutectic solvents were developed using choline chloride and propylene glycol, which could be produced under 2 dollars per 100 millilitters. As the DES electrolyte was applied to the supercapacitor, it showed a starting voltage of 2 volts. Comparing to the previous electrolyte, sodium sulfate, which showed a starting voltage of 0.5 to 1 volt, the DES electrolyte gave an excellent starting voltage and increased the energy density 4 times.



DES Fabrication Material

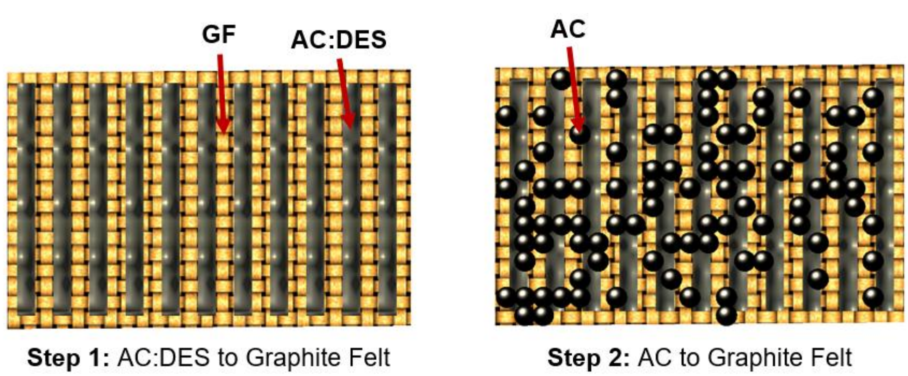


DES Chemistry

Herein, a flexible symmetric supercapacitor with excellent electrochemical performance were assembled using low cost pan-based graphite and deep eutectic solvent. Due to the combination of the two materials, the production time decreased from 60 minutes to 5 minutes. However, due to its foam-like electrode, the supercapacitor has larger height than average devices. [1] Moreover, it is a significant challenge to perfect the supercapacitor to have the same capacitance when it is being mass produced, since most of the materials used during the research are not for scientific use. Despite the drawbacks, the supercapacitor can easily compete in the current market, thanks to its advantage of low-cost, flexibility, fast charging, and safe production method.

Painting Method: There are two steps in the electrode and carbon material assembly. First, the AC and DES solution is poured evenly through the graphite felt surface. (5 grams/6 cm^2) Second step is embedding activated carbon on top of the wet surface for maximum surface area.

With the new fabrication method, which was possible from DES and GF, the building time reduced from 50 minutes (painting) to 5 minutes. Also, the novel method did not require a binder substance, which is used for adhesive purpose, which reduces the conductivity for traditional supercapacitor. With the novel process, the electrode became more conductive and the surface area increased.



Electrode Fabrication Method

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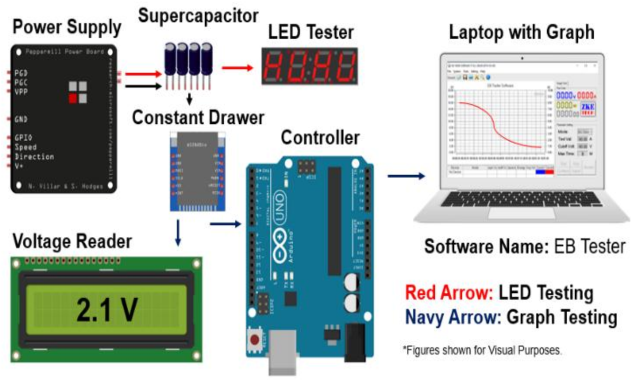
Experimental Setup

By using constant current drawer device and its software, supercapacitor capacity was calculated fast with the setup shown below. LED testing was done prior to the capacity testing to confirm that the supercapacitor functioned. The visual shows the setup that was used to test the supercapacitor. There are two output to the test trial. Red arrow runs the LED lights and the navy arrow goes to the computer to test the actual capacitance.



Experimental Setup

Electronic load Capacity tester was used to best the supercapacitor energy-density and power-density. The device connected to the computer, which would connect to program called EB Tester Software where constant amperage pull would show visually with graph.

Supply Power: Online USB power supply (5V)

Voltage Range: 0-21V

Voltage Accuracy: 0.1%+1mV

Current Range: 0-4A

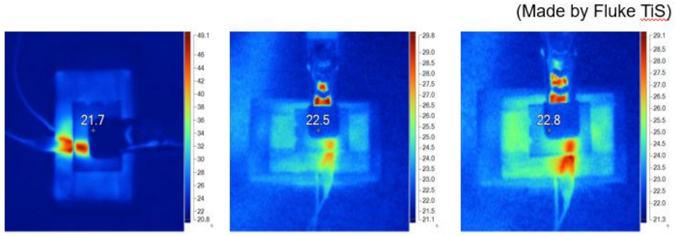
Current Accuracy: 0.2%+0.2mA

Resolution: 0.1mA

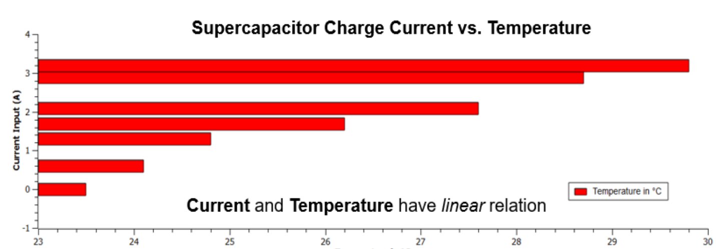
Results and Discussion

Temperature Testing: Three types of experiments were tested with the phase 3 supercapacitor. The first experiment tested the safety of the supercapacitor. Optimal way to do this was to look at the temperature of the supercapacitor during charging. Three voltage rates were input to the device and during its maximum charge, which was 12 V and 2.9 A, the temperature did not go over 30 degrees.

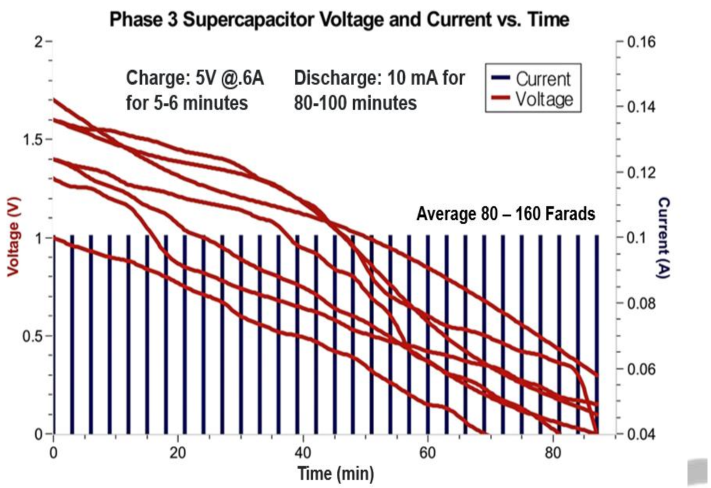
(Made by Fluke TiS)

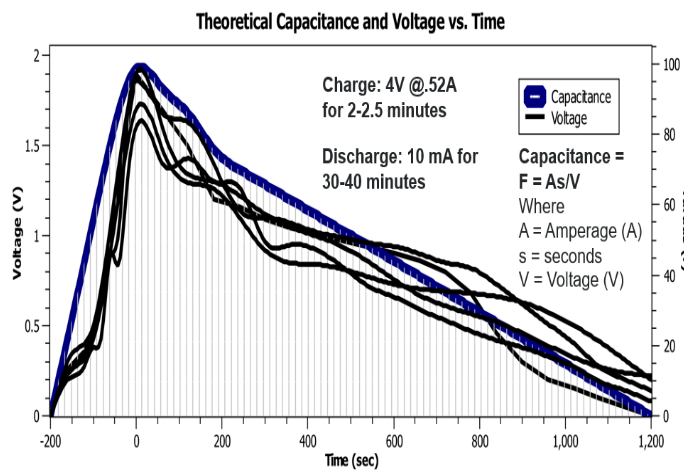


Charged at 3V 0.6 A   Charged at 6V 1.8 A   Charged at 12V 2.9 A

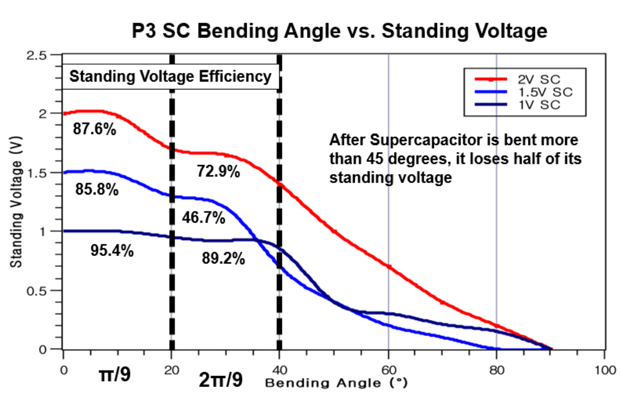


Capacitance Testing: All the experiments were acquired using the load drawer called QC2.0/3.0 MTK-PE EBD-USB DC. In the graph, red shows amperage and blue show voltage. Tests were held multiple times with the same capacitor to increase the reliability of the data. Average of 20 tests were held with each capacitor.



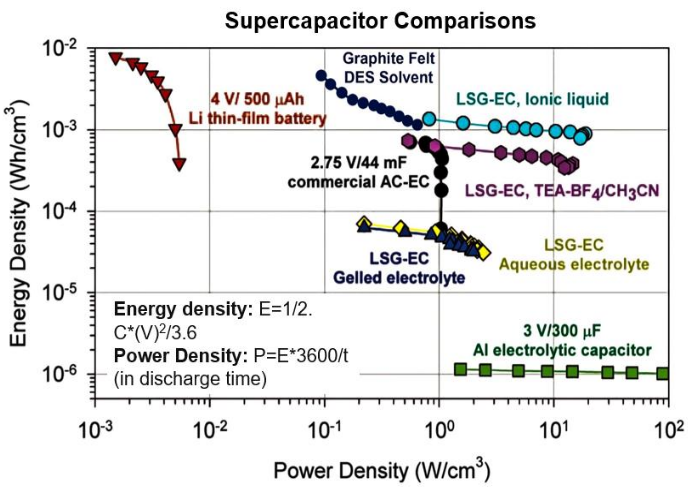


Fexibility Testing: One of the characteristics of the phase 3 supercapacitor is flexibility due to the flexible graphite felt used as electrode. However, this does not mean that the capacitance will stay the same during the bent, since the electrode's distance changes. During this experiment, the charged supercapacitor was bent without any casing or packing, which would improve the capacitance during the bend. When the supercapacitor is bend less than 40 degrees, the device still has about 80% of its original standing voltage. This can be improved by vacuum packing of the supercapacitor



Discussion

The supercapacitor's energy density was measured to be between 2.4x10-3 Wh/cm^3 and 1.01x10-2 Wh/cm^3. The power density showed an average value between 1x10-1 W/cm^3 and 1 W/cm^3. As shown in the graph: P3 SC Bending Angle vs. Standing Voltage, the supercapacitor's standing voltage decreased as the device was bent. This is due to the change of distance between the electrode, which can be fixed by vacuum packing. The P3 supercapacitor weighs 15g – 20g, which most of the weigh is from the electrolyte (6g). The supercapacitor shows a great charge to discharge ratio, which can be seen the graph: Theoretical Capacitance and Voltage vs. Time. The ratio is about 6, which is larger than commercial supercapacitors and batteries. By the end of the research, the supercapacitor could be discharged for 90 minutes @10mA when charged for 2 minutes at 6V and 5.2A.



Calcuation

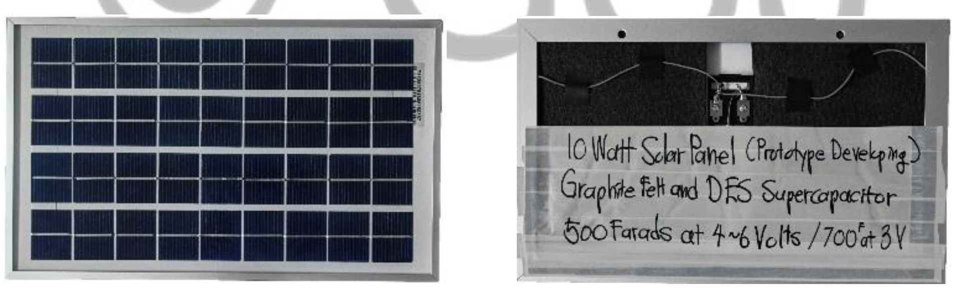
Measuring method of electric double layer capacitor (supercapacitor) differs from common capacitors due to its different discharge characteristics. All the measurements of the supercapacitors will be based on EIAJ RC-2377.

$$C = \frac{I * (T_2 - T_1)}{(V1 - V2)}$$

Phase and Materials	AVG Specific C	AVG Voltage	Trials	Current Output
1 (Graphite Foil, Na2SO4)	4.8F at .84V	0.42V	29	0.01 – 0.015A
2 (Graphite Felt, Na2SO4)	39.8F at 1.5V	0.71V	46	0.01 – 0.02A
3 (Graphite Felt, DES)	107.2F at 1.9V	0.93V	79	0.01 – 0.15A

Application

One of the best applications of a supercapacitor is a direct attachment with solar panels. Compare to lithium-ion batteries, supercapacitors are lighter, more rugged, and safer. From this project, it is possible to make a solar-panel supercapacitor hybrid, which can produce up to 500 Farads at 4-6 Volts or 700 Farads at 3 Volts.



Solar Panel Supercapacitor Hybird Prototype

Conclusion

A supercapacitor with deep eutectic solvent and graphite felt was developed. During the research assembly of a supercapacitors with novel materials for cheaper cost, innovate the production method for safer, and more affordable supercapacitor, and develop a supercapacitor that could complete in the current supercapacitor market. The supercapacitor's energy measured between 2.4x10-3 Wh/cm^3 to 1.01x10-2 Wh/cm^3. The power density showed an average value between 1x10-1 W/cm^3 and 1 W/cm^3. From these supercapacitors, basic power demands can rely on the supercapacitor, such as phone charging and microprocessor power-source.

Citation

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