Zeolite Templated Sucrose Derived Carbons for Supercapacitors

Brandon Piercy, Case Western Reserve University
Georgia Institute of Technology SURF 2010 Fellow
Advisor: Dr. Gleb Yushin; Mentor: Lu Wei

Introduction

Improved energy storage technologies are crucial for an alternative energy economy. Electric double-layer capacitors, or "supercapacitors", offer high energy storage, exceptional operational life of up to 500,000 charge-discharge cycles, and the ability to charge or discharge within seconds - feats that cannot be matched by conventional Li-ion batteries.

Current technology uses aligned carbon nanotubes or activated carbon electrodes to maximize ion transport or surface area, but sacrifices either specific capacitance or charge-discharge rate. By depositing carbon on an ordered porous template, it is possible to overcome the slow ion transport of activated carbon while retaining extremely high surface area.

Existing techniques using chemical vapor deposition (CVD) are prohibitively expensive and do not scale well to commercial production. By investigating cheaper carbon precursors and synthesis methods, advanced supercapacitors can become a viable and vital component within a new energy economy.

Procedure

The procedure followed a general process of carbonization, etching of the zeolite template, and electrode preparation and characterization. Carbonization began with a 4:1 suspension of sucrose and zeolite Y, which was dehydrated with concentrated sulfuric acid. This was heated in a tube furnace for 2 hours at a variety of temperatures under argon gas.

The etching procedure used 50% hydrofluoric acid for two days to eliminate the zeolite template, and was followed by treatment with concentrated sulfuric acid in order to remove cryolites (Na_3AlF_6) formed from the HF reaction. After each step the sample was dried overnight in a vacuum oven at 80° C.

Selected samples underwent an activation process at 900° C in the presence of CO_2 gas in order to introduce micropores into the carbon to improve surface area. The heating and cooling stages of this process were conducted under argon gas. The different tests are presented below.

$T_{carbonization}$ (°C)	$t_{activation}$ (min)
700	60
800	15
800	0 (none)
900	60

Table 1

After activation, the sample was ground using a commercial ball mill. The resulting powder was mixed with a PTFE solution at a ratio of 92 wt% carbon to 8 wt% PTFE. This was rolled to a thickness of 300 µm using a commercial rolling mill, and then dried in a vacuum oven. The film produced from this was cut into two 1 cm squares and arranged in the following order: Teflon® block, gold current collector, carbon film, separator, and then repeated in the opposite order. This device was then submerged in 1 M sulfuric acid and allowed to equilibrate for one day.

Results and Discussion

The electrodes produced from carbonized sucrose exhibited exceptional stability, but did not demonstrate the same level of capacitance observed from using CVD.

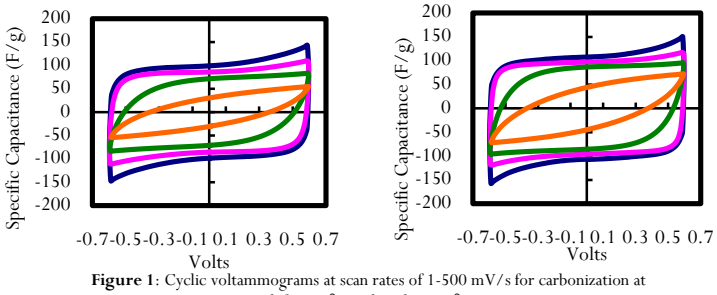

Figure 1: Cyclic voltammograms at scan rates of 1-500 mV/s for carbonization at (left) 700°C and (right) 900°C

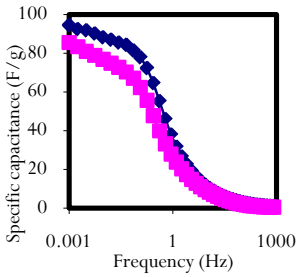

Figure 2: EIS frequency response for (top) 900°C and (bottom) 700°C

Electrochemical impedance spectroscopy (EIS) indicates a specific capacitance of both materials at between 80 and 100 F/g. Both samples remain stable at high frequencies, only dropping significantly at 0.1 Hz. Cyclic voltammetry shows the long-term stability of the capacitance due to the nearly horizontal sections for scan rates of 1 – 100 mV/s.

Low overall capacitance is likely dictated by overly large pores, implying excess volume that does not contribute to the capacitance. Good frequency response shows that ions can move freely without being hindered by micropores. The high stability indicates that the electrode is very robust, and will not lose significant capacitance over its life cycle.

Characterization using surface area measurements and electron microscopy are still needed to determine pore size and the success of the sucrose coating method.

Conclusions

Sucrose-derived carbon offers a cheap and efficient way of producing high-rate, high-capacity supercapacitors based on a zeolite template. These experimental results demonstrate the long lifespan that this type of material offers, with many avenues to improve capacitance. Future work may involve using a different zeolite template, exploring the effects of activation, and investigating other carbon precursors.

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References

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