FMRI RET 2015-Conductive Porous Carbon Electrodes for Energy Storage

Pedro Villavicencio M.Ed.[1], Mentors[2]: Fatemeh Rahimi M.S., Arash Takshi Ph.D.

1. Steinbrenner High School; 2. Department of Electrical Engineering, University of South Florida

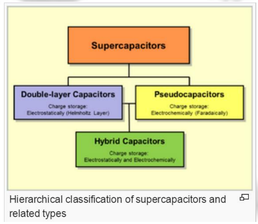
Abstract

The Bio-Organic Electronics group is active in studying soft materials, including polymers and proteins, for electronic and electrochemical devices, particularly devices related to energy harvesting and storage.

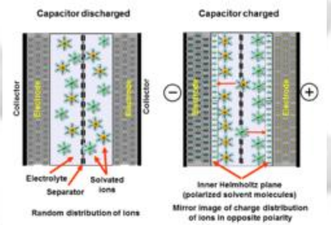
The studies cover a large area from material synthesis and characterization to device fabrication and test. The research emphasize in Takshi's group is on using the electrical and mechanical advantages of some soft materials to fabricate new devices with features different than those in existing technologies. Considering the soft structure of the materials, flexibility and stretchability are the two major features addressed in most of our research.

Background

Electrochemical double-layer capacitors are special devices which can store large amount of electric charges in very small volume/mass. The mechanism of charge storage is based on diffusion of the ions in an electrolyte into the pores of a conductive electrode. The capacitance of such a device depends on the porosity of the material. To achieve high energy/charge storage capacity, conductive electrodes with nano size pore should be used.



Hierarchical classification of supercapacitors and related types



The aim of this work is to use carbon nano structures such as Carbon Nanotubes, Graphene, Carbon Nanofibers, and Activated Carbon to make porous electrodes using paper as substrate. Paper substrates promise to be an alternative to traditional batteries, because they provide better life cycle, charging time and weight. Among the carbon based electrodes, this work suggests that Carbon Nanotubes is the best option.

Objectives

Comparing different porous carbon electrodes for supercapacitor applications

Approach

The approach is to make a homogeneous solution of the carbon structure and deposit the solution on a substrate to make a thin porous carbon film. The fabricated electrodes will be tested for characterization using advanced techniques such as electrochemical impedance spectroscopy and scanning electron microscopy in an electrochemical cells to measure the porosity and the capacitance.

Electrode Fabrication

After mixing the material together, the solution was probe sonicated for 30 minutes.
The ink was drop casted (2 ml per side) on a piece of paper with $4 \times 7\ cm^2$.
The substrate was cured in a vacuum oven 100°C for 30 minutes per side.

Substrate	Material Concentration
Paper-based Activated Carbon Substrate (AC)	250mg AC+125mg SDBS+ 25ml DI Water
Paper-based Carbon Nanofiber Substrate (CNF)	250mg CNF+125mg SDBS+ 25ml DI Water
Paper-based Carbon Nanotube Substrate (CNT)	250mg CNT+125mg SDBS+ 25ml DI Water
Paper-based Carbon Graphene Substrate (G)	250mg G+125mg SDBS+ 25ml DI Water

Four Probe Conductivity Measurement

Using Keithley 2602A System Source Meter with I = 10 µA; V = 40 volts

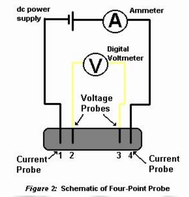
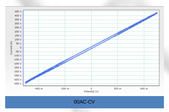


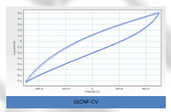
Figure 2: Schematic of Four-Point Probe

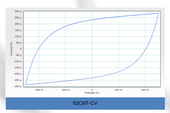
Substrate	Resistance
AC Substrate	35 kΩ
CNF Substrate	1.2 kΩ
CNT Substrate	4 Ω
G Substrate	3 kΩ

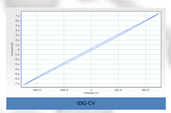
Electrochemical Testing

Two identical electrodes in 1 M TBAP-PC electrolyte or H_2SO_4



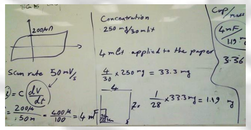


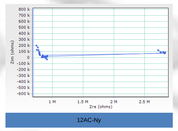


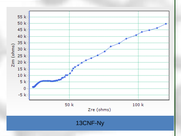


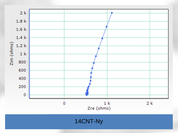
Cyclic Voltammetry (CV): To compare capacitance density. Performed for scan rates of 50 mV/s and 5 mV/s between -0.5 V to +0.5 V

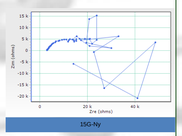
Paper Substrate	Specific Capacitance (F/g)
AC	0.00028
CNF	0.028
CNT	3.38
G	0.003





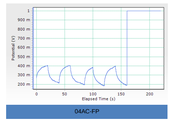


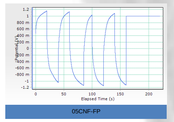


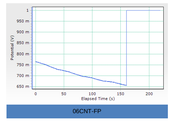


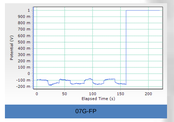
Electrochemical Impedance Spectroscopy (EIS): To determine if behavior is pseudo (linear) or double layer (hill.) Performed with a 20 mV sin-wave with frequency ranging from amplitude 10 kHz to 0.01 Hz (or 0.1 Hz)

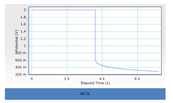
Galvanostatic Charge-discharge (GCD): To compare resistance and capacity. Performed +/- 1 uA (or 10 uA) 20 sec charging 20 sec discharging

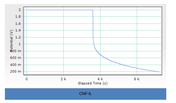


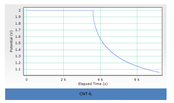


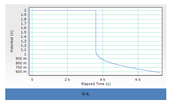








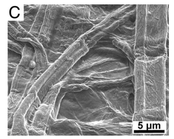




Leakage: To determine charge loss. Charge up to 2 V for 2 hrs, monitor the open circuit potential (OCP) after charging

Scanning Electron Microscopy

C



Surface Morphology of Xerox Paper

CNT Coating Along Fibers in Xerox Paper

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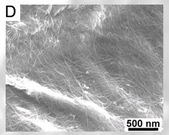

Carbon Nanotubes(CNT, 10mg/ml)+Sodiumdodecylbenzenosulfonate(SDBS, 1–5mg/ml)

Conclusions

- Carbon Nanotube (CNT) gave us better results during the electrochemical testing with: high conductivity, high porosity, better adhesion to the paper substrate, minimum reaction with the electrolyte, and minimum leakage when compared with the other carbon options.
- Natural absorption to coat paper with carbon is not that uniform. Spin coating or Meyer rod coating are alternatives to improve results.
- Although stability testing and SEM for other samples were still under work, it is expected that they will reaffirm our choice of CNT.
- Further work is needed to investigate the mechanical stability and electrical behavior of the films and devices for different applications.

Referenced Resources

1. Supercapacitors Wikipedia https://en.wikipedia.org/wiki/Supercapacitor
2. Liangbing Hu, Jang Wook Choi, Yuan Yang, Sangmoo Jeong, Fabio La Mantia, Li-Feng Cui "HighlyConductive Paper for Energy-storage Devices" PNAS December22, 2009, vol. 106, no. 51

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