Synthesis and Characterization of Electrochemical Capacitors Using Nanoporous SiO_2

Kevin C. Leonard* and Marc A. Anderson
SolRayo LLC
617 Orion Trail Madison, WI 53718
*kevin.leonard@solrayo.com – (262) 909-2479

INTRODUCTION

Many metal oxides have historically been used in the making of electrochemical capacitors, including but not limited to RuO_2 (1), MnO_2 (2), and NiO (3). Also, many of these metal oxide electrochemical capacitors undergo faradaic reactions as part of their capacitive behavior, i.e. psuedocapacitors (4). However, this study investigated electrochemical capacitors using nanoporous SiO_2 deposited on a porous conductive backing electrode. This material is different than most traditional ultracapacitor or psuedocapacitor materials because SiO_2 is considered an electronic insulator. However, the capacitive behavior of this material may arise from its ionic conductivity along with its surface chemistry instead of its electronic conductivity. These SiO_2 electrochemical capacitors are providing a new low-cost material for electrochemical double-layer capacitors.

SYNTHESIS

The nanoporous SiO_2 material was synthesized using sol-gel chemistry techniques and then deposited on a porous conductive backing electrode. This study focused on how the performance of the SiO_2 electrochemical capacitor is affected by different coating properties and synthesis variables.

CHARACTERIZATION

To characterize the SiO_2 electrochemical capacitors, we determined the capacitance, energy, and power as functions of the discharge frequency for each synthesis variable. The capacitance was determined using two different methods. The first method was cyclic voltammetry. Figure 1 shows an example of a voltammagram of an SiO_2 coated material along with an uncoated material. The capacitance from the cyclic voltammetry experiments was determined using the following equation

$$C = \frac{|q_c| + |q_a|}{2v} \qquad [1]$$

where q_c and q_a are the average cathodic and average anodic current over the voltage range and v is the voltage scan rate. The volumetric capacitance of the SiO_2 coated material was calculated to be 146 F/L whereas the capacitance of the uncoated material is 14 F/L at a scan rate of 100 mV/s. Cycle lifetime of these materials was also investigated by running 10,000 cyclic voltammetry cycles. It was found that the capacitance of these materials decreased less than 25% over 10,000 cycles at a scan rate of 100 mV/s.

Electrochemical impedance spectroscopy (EIS) was the second technique used to determine the capacitance of these materials as a function of discharge frequency. The capacitance was found from the real and imaginary parts of the impedance using the following equation (5)

$$C(\omega) = \frac{-Z_{im}(\omega)}{\omega |Z(\omega)|^2} \qquad [2]$$

where $-Z_{im}$ is the imaginary part of the impedance, ω is the angular discharge frequency, and $|Z(\omega)|^2$ is the sum of the squares of the real and imaginary parts of the impedance. Figure 2 shows an example of the volumetric capacitance as a function of discharge frequency for an uncoated and an SiO_2 coated electrode. The specific energy and specific power as functions of the discharge frequency were also calculated using EIS and the following equations

$$E(f) = \frac{C(f)V^2}{2} \qquad [3]$$

$$P(f) = E(f) \times 2f \qquad [4]$$

where E is the energy, C is the capacitance, V is the cell voltage, P is the power, and f is the discharge frequency. We determined that the SiO_2 coating results in an order of magnitude increase in both the specific energy and the specific power at the same discharge frequency.

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FIGURES

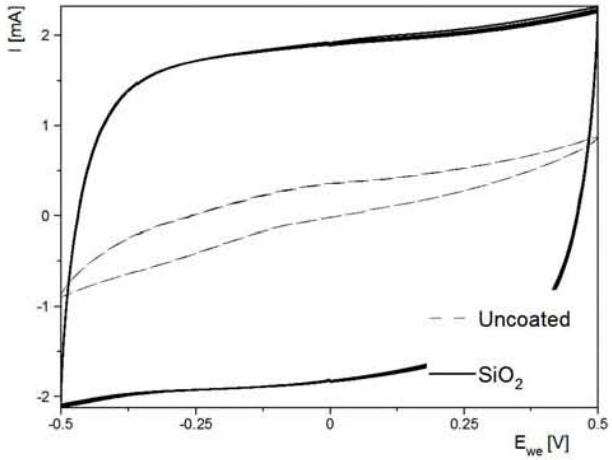

Figure 1: Cyclic voltammagram of an SiO_2 and uncoated conductive backing electrode at a scan rate of 100 mV/s

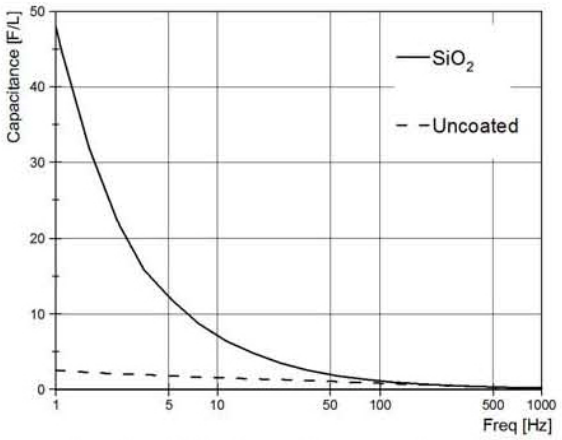

Figure 2: Capacitance as a function of discharge frequency for an SiO_2 and uncoated electrode obtained from EIS experiment.

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