Overview of Supercapacitor/Advanced Battery Materials and Architecture Development Efforts

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Global climate change and anticipated decline in oil production demand improved utilization and management of energy, particularly electrical energy. Batteries are among the most common and efficient energy storage devices but have limited power and lifetimes. Supercapacitors, particularly electrical double layer supercapacitors (EDLCs), deliver much higher peak powers and have longer lifetimes. Such devices are capable of many more charge/discharge cycles than batteries, leading to much longer operational lifetimes. But, batteries have significantly higher energy density storage. Development of pseudocapacitor/battery hybrid devices with the energy storage capacity of batteries and the power delivery of supercapacitors would dramatically impact society.

Current generation supercapacitors are primarily EDLCs, where the charge is stored as ions at the surfaces of two high surface area electrodes. Capacity is determined by the accessible surface area and the voltage at which the device can be operated. Characteristics of these types of capacitors include very high power density, ultrafast response time, and close to unlimited cycle life but they are limited by their low energy density (only 0.1 Wh/kg). Higher energy densities can be realized through pseudocapacitors (also known as electrochemical capacitors), where charge is also stored by the oxidation and reduction of molecules at the electrode surfaces. This mechanism is similar to that in batteries, which also utilize oxidation/reduction, but pseuocapacitors do not require charge transport through the charge storage media. All these type of devices are limited by low energy density and low cell voltage. Dramatic improvement in capacitor storage performance can be achieved by the development of new materials and structures which is guided by fundamental relationships between electrode structures, interfacial relationships, electrolyte properties, charge storage/discharge processes and the atomic- and molecular-level interactions among the components of a charge storage device. Our group has expertise in i) fundamental electrochemistry; ii) organic and inorganic charge storage materials, iii) carbon and metal high surface area conductors; iv) ionic liquids for ionic conduction; v) multiscale modeling; and vi) device fabrication. We plan to develop pseudocapacitor/battery (PB) hybrids with long lifetimes, recyclability, fast charge/discharge rates, and high energy densities. We will develop new multiscale architectures integrating novel porous metal microfoams with graphene oxide (GO), carbon nanotubes (CNTs), nanostructured transition metal oxides (MO), redox-gradient dendrimers (RGD), and metal-organic framework (MOF) polymers as nanoscale current collectors and charge storage media. Integrated assembly of the charge storage media directly onto the current collectors will eliminate binders and improve response rate, energy density, and device lifetime. By optimizing ionic liquids we will increase the voltage range of the capacitive component, resulting in increased energy densities, and giving faster charge transport and improved device power. Fundamental electrochemical, spectroscopic and structural characterization of complete PBs and on components will be combined with atomic-level simulation of the elementary electrochemistry, charge flux, and the double-layer structure at electrode/electrolyte interfaces. The combination of such approaches will give insight into how the architectures and interfaces impact electron transport, ion diffusion and long-term stability.