NOVEL CARBON-BASED MATERIALS FOR ADVANCED SUPERCAPACITORS AND LI-ION BATTERIES

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Introduction

High power, lightweight, long-lasting energy storage devices, such as supercapacitors and Li-ion batteries, are critical for the development of zero-emission electrical vehicles, large scale smart grid, and energy efficient cargo ships and locomotives[1]. The energy storage characteristics of supercapacitors and Li-ion batteries are mostly determined by the specific capacities of their electrodes, while their power characteristics are influenced by the maximum rate of the ion transport. The ability of carbon to afford very high electrical conductivity and very high surface area with controlled pore size complement attractive properties of polymers, semiconductors, metals and metal oxides, including their ability to efficiently adsorb ions. Such properties make carbon-containing nanocomposites attractive for supercapacitor and battery applications, where superior power and energy characteristics have been achieved.

Supercapacitors

Supercapacitors are energy storage devices where the charges are stored at the interface between the electrode and the electrolyte [1-5]. The electrolyte ions may be electrostatically adsorbed on the surface of porous electrodes, typically made of carbon, without involving faradaic reactions. Those systems are able to deliver more power than a battery and have nearly an infinite cyclability[2]. Conductive polymers and transition metal oxides may exhibit faradaic reactions at the surface and offer capacitance higher than porous carbon do. Their power characteristics, however, are commonly poor due to the low electrical conductivity. In addition, conductive polymers exhibit large volume changes during the faradaic reactions and commonly suffer from relatively short cycle life. Deposition of polymers or metal oxide nanoparticles on high surface area conductive carbon matrix allows significant increase in the material capacitance (Fig. 1) without sacrificing their power characteristics and cyclability.

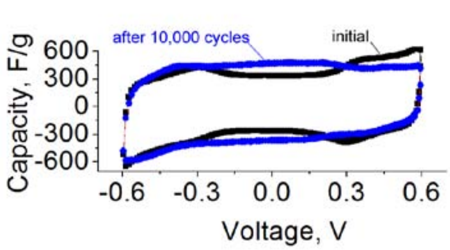

Fig. 1. Cyclic voltammetry of a carbon-polymer composite electrode tested in a symmetric two-electrode configuration before and after 10,000 charge-discharge cycles.

Li-ion Batteries

Improvements in all the components of Li-ion batteries are needed for the major enhancement in the batteries' specific energy and power. This talk, though, will primarily focus on increasing the specific capacity of Li-ion battery anodes [6-7]. The high theoretical capacity of Si, its low cost and abundance in nature have triggered significant research efforts on Si-based anodes. Unfortunately, high capacity Si anodes exhibit large volume changes during Li insertion and extraction, leading to electrode failure. Porous Si-C composite particles may offer a viable solution to overcome the limitations of pure Si anodes [6-7]. Pre-existing pores will provide the volume needed for Si expansion and allow for fast transport of Li ions, while C will allow the improved solid/electrolyte interface formation, structural integrity and high electrical conductivity.

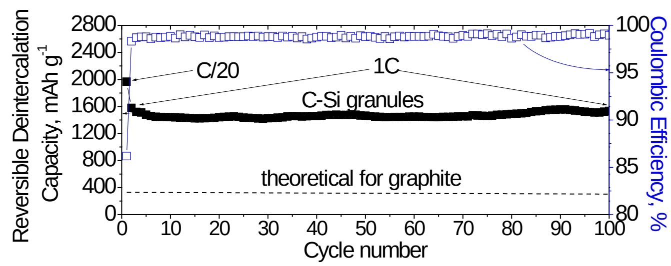

Fig. 2. Reversible Li deintercalation capacity and coulombic efficiency of the C-Si granule electrode vs. cycle number in comparison to the theoretical capacity of graphite [6].

The bottom-up assembly offers an attractive route for low-cost synthesis of Si-C composites [6]. The specific reversible deintercalation capacity of the produced composite samples with an estimated ~ 50 wt. % of Si, reach ~ 2000 mAh/g at C/20 and ~ 1600 mAh/g at C/1 (Fig. 2). The synthesized materials demonstrate excellent stability during cycling (Fig. 2) and other positive attributes. Our experiments suggest that a hierarchical bottom-up assembly method offers an exceptional potential in energy storage applications [6].

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