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CPCPC Success Story

Carbon nanofiber paper for lithium ion applications

Collaborators: Inorganic Specialists, Inc.

Description: CPCPC sponsored two research projects focused on developing a coal-derived nanofiber paper with the goal of developing a nanofiber product and a continuous papermaking technology. Applied Sciences, Inc. (ASI) provided nanofibers to Inorganic Specialists, Inc. for studies aimed at improving paper conductivity, strength and flexibility, and increasing paper size. In addition to paper improvements, researchers investigated the materials and processes associated with a continuous sheet production process and the feasibility of creating a papermaking machine.

At the time of these projects there was a high interest in carbon nanofibers. In addition, oil hydrocarbon costs were increasing, making ASI's coal-derived nanofibers more appealing. Processing these nanofibers into a paper, which has various applications, including membranes, electrodes, composite pre-forms, EMI shielding, electrochemical capacitors, and fuel cell components, could have added value and expanded the commercial prospects for coal-derived nanofibers.

Papermaking techniques continued to be developed after the projects ended; however, Inorganic Specialists switched nanofiber suppliers when ASI discontinued their coal-derived nanofibers. Although the current nanofibers are not coal-derived, the initial CPCPC-supported research was a significant step in the paper's development. The company's work ultimately resulted in the construction of pilot-scale nanofiber papermaking equipment (Figure 1). The initial unit, the first unit of its kind, was built with the support of EMTEC (Edison Materials and Technology Center), and was designed to make a 14-inch wide continuous sheet of nanofiber paper (Figure 2).

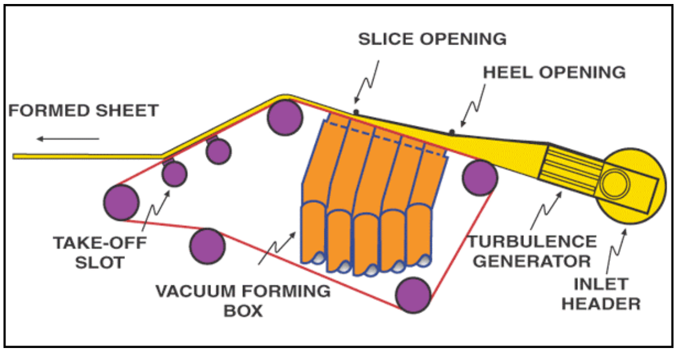

Figure 1. Schematic of nanofiber papermaking equipment.

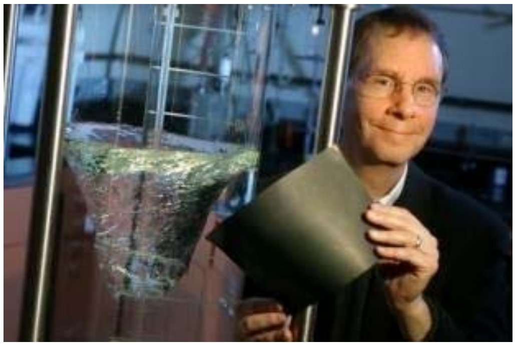

Figure 2. Nanofiber paper sample.

The highest impact application for nanofiber paper is silicon-coated carbon nanofiber paper as a lithium ion anode, which is a transformative advance for battery technology. This unique anode material shows stable cycling, low irreversible capacity, and energy storage >1000 mAh/g (milliamp hour per gram) based on its full weight. In addition, it can have far higher effective energy storage through dual use as an active material and a current collector, reducing weight, cost, and volume. The combination of using bulk available nanofibers and an advanced inexpensive Si deposition method keeps the materials cost for the silicon-coated paper low, under $185/lb. Because of silicon's potential energy storage of up to 4200mAh/g, its use as a lithium ion battery anode has been studied a great deal in recent years. It has been determined that the thinner the silicon form, the better the cycling performance because of lower expansion/contraction forces as the silicon inserts/de-inserts lithium. Inorganic Specialists has developed a patent-pending process, which allows them to host a large quantity of Si in submicron form. The approach is to silicon coat a carbon nanofiber paper; it only takes a 10nm Si coat on an 80 nm carbon nanofiber to create a material that is 30% Si (Figure 3-5).

This technology is still under development; however, energy storage values between 600 and 1050 mAh/g, depending on Si content and rate, have been observed in sealed cells based on the entire electrode weight (nanofibers plus silicon). At cycle rates of C/5, stable reversible capacities of over 800 mAh/g have been seen. It is expected that reversible storage can be increased to 1400 mAh/g by adding Si to the paper and distributing it more uniformly. The ability to tailor the nanofiber paper for thickness, density, porosity, surface area, and conductivity is critical for this breakthrough technology.

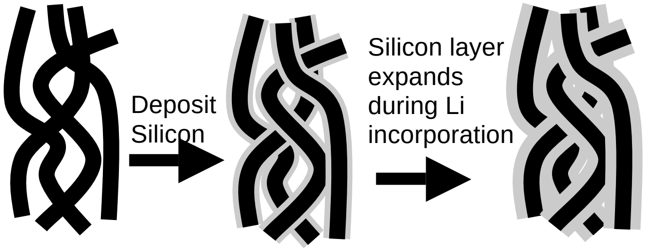

Figure 3. Silicon coating on nanofibers.

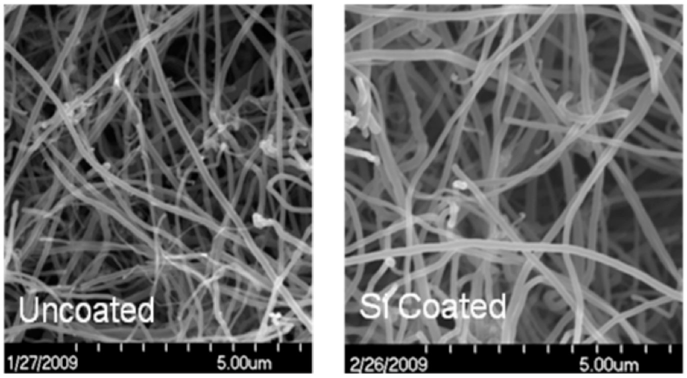

Figure 4. SEM images of the nanofibers in a nanofiber paper before and after Si-coating.

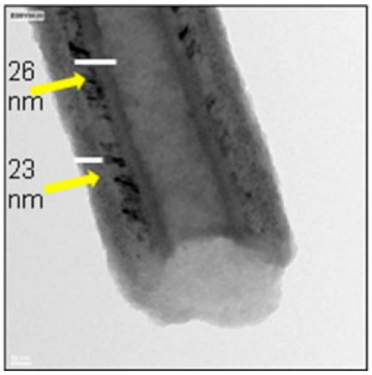

Figure 5. TEM image of a 23 nm silicon layer on a carbon nanofiber with a hollow core.

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