The Department of Chemical Engineering and Materials Science  
Michigan State University  

Ph.D. Dissertation Defense  

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High Surface Area Aerogels for Energy Efficiency and Storage  

Abstract  

It is becoming increasingly self-evident that energy efficiency, generation and storage will be one of the defining technological challenges for our society in the coming decades. Aerogels, with their high surface area, tailorable microstructure and ease of sol-gel processing, are uniquely suited to assist by both increasing the efficiency of thermal systems and improving power- and energy-densities of electrochemical energy storage systems. In this spirit, this dissertation describes the fabrication and characterization of a variety of aerogels for such applications. It is shown that aerogels perform well in both situations, and that further work is warranted to take full advantage of their unique properties.  

The dissertation is divided into two main chapters, each focused on a different application for aerogel. The first chapter concerns the development of silica aerogel for thermal insulation. It begins with initial characterization of a silica aerogel insulation for a next-generation Advanced Radioisotope Stirling Generator for space vehicles. While the aerogel as made performs well, it is apparent that further improvements in mechanical strength and durability are necessary.  

The chapter then continues with the exploration of chlorotrimethylsilane surface modification, which somewhat surprisingly provides a drastic increase in mechanical properties, allowing the inherently brittle silica network to deform plastically to $\geq 80\%$ strain. It is hypothesized that the hydrophobic surface groups reduce capillary forces during drying, lowering the number of microcracks that may form and weaken the gel.  

This surface modification scheme is then implemented in a fiber-reinforced, opacified aerogel insulation for a prototypical thermoelectric generator for automotive waste heat recovery. This is the first known report of aerogel insulation for thermoelectrics. The aerogel insulation is able to increase the efficiency of the thermoelectric generator by 40\% compared with commercial high-temperature insulating wool. Unfortunately, the
supercritical drying process adds significant cost to the aerogel insulation, limiting its commercial viability.

The chapter then culminates in the development and characterization of an Ambiently Dried Aerogel Insulation (ADAI) that eliminates the need for expensive supercritical drying. It is believed that this report represents the first aerogel insulation that can be dried without undergoing a large volume change before "springing back" to near its original volume, which allows it to be cast into place into complex geometries and around rigid inclusions. This reduces a large barrier to the commercial viability of aerogel insulation. The advantages of ADAI are demonstrated in a third-generation prototypical thermoelectric generator for automotive waste heat recovery.

The second chapter then details two different aerogel-based materials for electrochemical energy storage. It begins with lithium titanate aerogel, which takes advantage of the high surface area of the aerogel morphology to display a batt-cap behavior. This should allow the lithium titanate aerogel to perform at higher rates than would normally be expected for the bulk oxide material. Additionally, the flexibility of the sol-gel process is demonstrated through the incorporation of electrically conductive high-surface area exfoliated graphite nanoplatelets in the oxide.

The last section describes the characterization of a LiMn2O4 spinel coated carbon nanofoam in a non-aqueous electrolyte. The short diffusion path, high surface area and intimately wired architecture of the nanofoam allows the oxide to retain its capacity at significantly higher rates when compared with literature values for the bulk oxide. Additionally, the nanometric length scale improves cycle life, and the high surface area dramatically increases the insertion capacity by providing a higher concentration of surface defects.

Taken together, it is clear that aerogels are an extremely attractive class of material for applications pertaining to energy and efficiency, and further research in this area will provide valuable solutions for pressing societal needs.

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