Nanoporous Carbon Pillars Fabricated via Nanoimprint Lithography as Structural Metamaterials for Energy Storage Devices

Ayush Bharadwaj[1], Zhongyuan Li[2], Varun Pande[1], Seok-Woo Lee[2], James J Watkins[1*]

1. Department of Materials Science and Engineering & Institute of Materials Science, University of Connecticut, 25 King Hill Road, Storrs CT 06269-3136, United States

2. Department of Polymer Science and Engineering, University of Massachusetts Amherst, 120 Governors Drive, Amherst, MA 01003, United States

*watkins@polysci.umass.edu

The advent of miniaturized electronic devices has increased the demand of micro electrochemical energy storage devices. To increase the energy storage performance on limited footprint area, nano structuring (3D) of electrode materials is often employed. Unfortunately, conventional approaches to 3D fabrication require cost intensive processing and are slow to execute[1].

Herein, we demonstrate high- throughput nanoimprint lithography (NIL) for the preparation of high aspect ratio nanoporous carbon pillars. NIL enables the fabrication of 3D structures on flat substrates such as Si wafers and stainless steel. The nanoporous carbon was derived from the carbonization of self-assembled nanocomposites of polydimethylsiloxane – polyethylene oxide (PDMS-PEO) brush block copolymers (BBCPs) as the template and phenol formaldehyde resin as the carbon precursor. BBCP templates allowed us to introduce porosity in the carbon pillars and to tune the pore size of the carbon ranging from 10 nm -100 nm. The nanoporous carbon pillars exhibit very high strength to density ratios, approaching the theoretical limit. Moreover, we plan to utilize these porous pillars for the deposition of active materials to further increase the electrochemical performance. Our group has previously reported nanoporous amorphous carbons and their application for supercapacitors[2]. The nanoporous carbons show excellent areal capacitance of 6.7 mF/cm^2 (tested in 6 M KOH at 0.8 mA/cm^2) when prepared on stainless steel. This method provides a scalable pathway for the fabrication of high aspect ratio carbon

nanostructures with their promising applications in structural metamaterial and energy storage devices**.**

References:

1. Amato, Letizia, Arto Heiskanen, Rasmus Hansen, Lauge Gammelgaard, Tomas Rindzevicius, Maria Tenje, Jenny Emnéus, and Stephan S. Keller. "Dense high-aspect ratio 3D carbon pillars on interdigitated microelectrode arrays." *Carbon* 94 (2015): 792-803.
2. Bhardwaj, Ayush, James Nicolas Pagaduan, Yong-Guen Yu, Vincent J. Einck, Sravya Nuguri, Reika Katsumata, and James J. Watkins. "Large-pore ordered mesoporous turbostratic carbon films prepared using rapid thermal annealing for high-performance micro-pseudocapacitors." *ACS Applied Materials & Interfaces* 13, no. 51 (2021): 61027-61038.

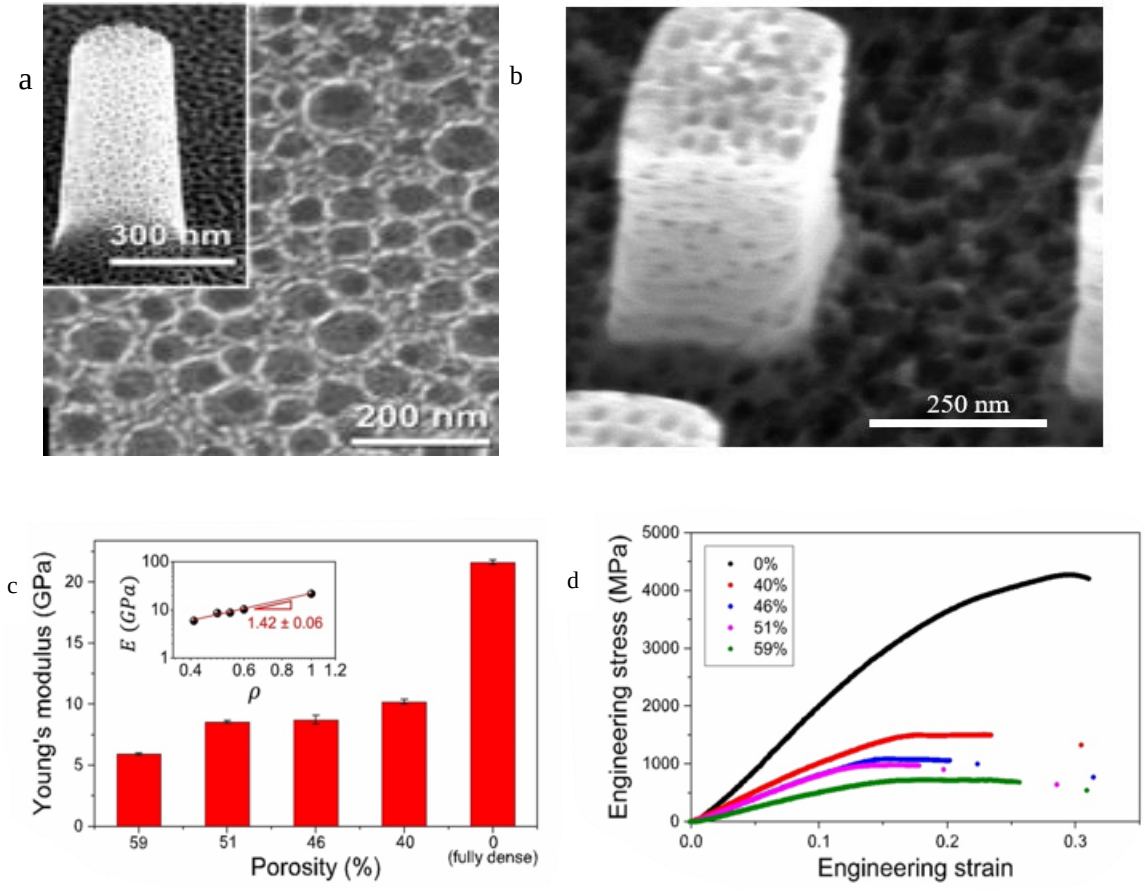

Figure 1: (a) Cylindrical nanoporous pillar, (b) Square nanoporous pillar, (c) Variation of the Young's modulus with porosity, (d) Stress strain curves of the cylindrical nanoporous pillar