INDUSTRIAL & SYSTEMS ENGINEERING
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MECHANICAL ENGINEERING
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ME/ISE SEMINAR: James Pikul, Ph.D.

Design and fabrication of high power microbatteries and high specific strength cellular solids from mesostructured hierarchical materials

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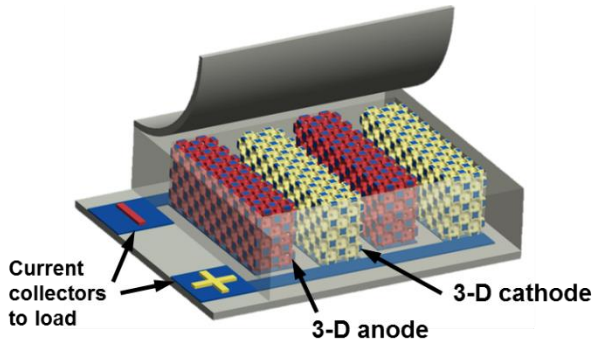
An emerging paradigm in engineering design is the development of materials by constructing hierarchical assemblies of simple building blocks into complex architectures that address physics at multiple length scales. These hierarchical materials are increasingly important for the next generation of mechanical, electrical, chemical, and biological technologies. However, fabricating hierarchical materials with nm control over multiple chemistries in a scalable fashion is a challenge yet to be overcome. This talk reports the design and fabrication of hierarchical microbattery electrodes that demonstrate unprecedented power density as well as large area cellular solids with controllable moduli and high specific strengths.

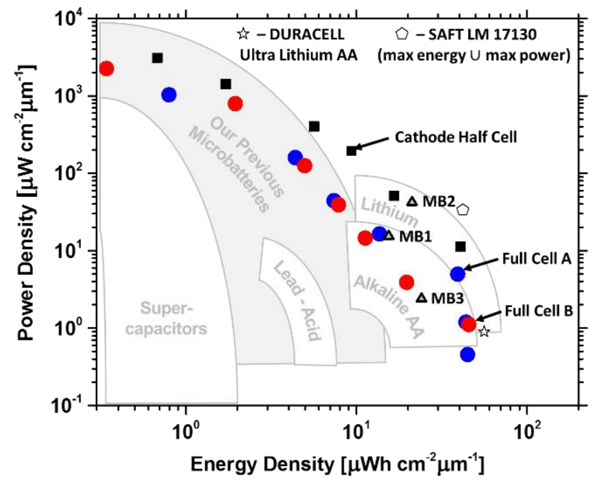
The microbatteries have up to 7.4 mW cm^{-2} μm^{-1} power density, which equals or exceeds that of the best supercapacitors and is 2000 times greater than other microbatteries. The three-dimensional bicontinuous interdigitated microelectrode architecture improves power performance by simultaneously controlling ion and electron transport distances through the anode, cathode, and electrolyte. The low internal transport resistances reduce the microbattery internal heat generation by more than 50% at normal (0.1 – 10 C) discharge rates. Self-assembly and electrochemical deposition techniques integrate large volume fractions of high capacity materials into the microbattery architecture to enable up to 45.5 μWh cm^{-2} μm^{-1} energy densities, which is greater than previously reported three-dimensional microbatteries and comparable to commercially available lithium-based batteries, while maintaining high power density. A one dimensional electrochemical model of the microbatteries enables the development of battery design rules that suggest a 10X improvement in battery power performance is possible.

In addition, the electrode architecture has high specific compressive strengths up to 0.23 MPa / (kg m^{-3}) and Young's moduli that can be varied from 2.0 to 44.3 GPa. The specific strength is greater than most high strength steels and titanium alloys and is due to the size based strengthening of the nanometer scale struts in the porous architecture. The excellent mechanical properties, combined with the ability to precisely control chemistry, can be utilized to develop next generation multifunctional materials for energy, robotics, and medical applications.

James Pikul earned his B.S. (2009) M.S. (2011) and Ph.D. (2015) in Mechanical Engineering from University of Illinois at Urbana-Champaign under the advisement of Professors William P. King (Mechanical Engineering) and Paul V. Braun (Materials Science). He was a Department of Energy Office of Science Graduate Research Fellow and University of Illinois Carver Fellow. His Ph.D. research focused on the self-assembly and electrochemical fabrication of ultra-high power microbatteries and large area, high strength cellular solids. For this work, he won the Materials Research Society Gold Award. James has authored nine journal papers, four conference papers, and a patent application. His articles in *Nature Communications* and *PNAS* have generated significant interest in the popular media, having been featured in BBC, Discovery News, Yahoo News, arstechnica, Engadget, and many other outlets.

James Pikul is currently a postdoctoral associate in the Organic Robotics Laboratory at Cornell University under Professors Robert Shepherd (Mechanical Engineering) and Itai Cohen (Physics). In this position, he continues to develop advances in multi-scale manufacturing to enable critically important technologies. He is currently developing soft robotic rovers for extraterrestrial oceans for NASA and manufacturing technologies for adaptive camouflage for the ARL.


Current collectors to load
3-D anode
3-D cathode


☆ – DURACELL Ultra Lithium AA
⬠ – SAFT LM 17130 (max energy ∪ max power)
Cathode Half Cell
Our Previous Microbatteries
Lithium
MB1
MB2
MB3
Full Cell A
Full Cell B
Alkaline AA
Lead - Acid
Super-capacitors
Power Density [μW cm⁻²μm⁻¹]
Energy Density [μWh cm⁻²μm⁻¹]