MRL
FREDERICK SEITZ MATERIALS RESEARCH LABORATORY
Advances
Summer 2011
Advancing the science of materials (e-brief)

From the Director

I am pleased to present the current issue of *Advances*, a quarterly e-brief update of the Frederick Seitz Materials Research Laboratory (MRL) at the University of Illinois. In this issue, we feature important advances in understanding of novel electronic and ionic materials as well as recent awards received by my colleagues.

The primary mission of the MRL is to foster interdisciplinary research at the forefront of materials science. Our laboratory brings together world-class faculty, graduate students, and post-doctoral researchers with expertise in condensed matter physics, chemistry, and materials science. We house several multi-investigator programs in the broadly defined areas of quantum, nanoscale, computational, and soft materials. These programs derive great benefit from our central facilities for materials fabrication and characterization, which are widely recognized

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The FSMRL gratefully acknowledges financial support from the DOE/BES Division of Materials Sciences and Engineering.

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Illinois Research Shines at DOE EFRC Summit

Several researchers from the University of Illinois participated in the DOE Energy Frontier Research Center (EFRC) Summit held in Washington, D.C. on May 25-27, 2011. Of special note, work by MRL researchers **John Rogers** (materials science and engineering) and **Ralph Nuzzo** (chemistry) on flexible photovoltaics was highlighted by Steven Chu (Secretary of Energy) in his Keynote Address. In addition, Eric Issacs' (Director, Argonne National Laboratory) talk featured research by **Jeff Moore** (chemistry), Nancy Sottos (materials science and engineering), and Scott White (aerospace engineering) on self-healing materials for lithium ion batteries.

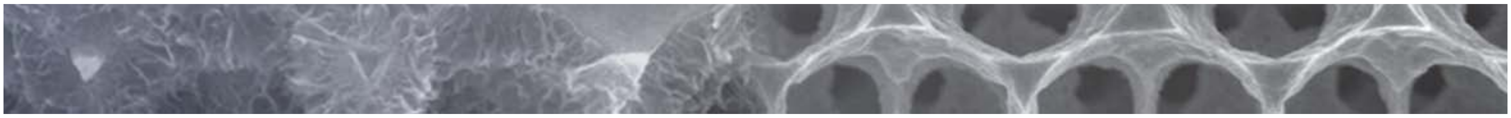
First observation of individual Andreev bound states in graphene

In a paper published earlier this year in *Nature Physics*, a team led by MRL researchers **Nadya Mason** (physics) and theorist **Paul Goldbart** (now at Georgia Institute of Technology), reported the first observation in graphene of individual, gate-tunable superconducting states known as Andreev bound states (ABS). While ABS have been theoretically predicted since the 1960s and have been invoked to explain supercurrents in superconductor–normal metal junctions, ABS have proven to be very difficult to isolate and measure individually.

For the first time, Mason's group has succeeded in identifying and manipulating discrete ABS in graphene. Their approach relies on attaching superconducting probes to an exfoliated graphene sheet, which is a two-dimensional semi-metal. Although graphene is not normally a superconductor, it can carry a superconducting current when connected to superconducting electrodes. Because of a work-function mismatch between the graphene film and the superconducting lead, a confined particle-in-a-box region, or 'quantum dot,' forms in the graphene. The individual ABS are formed on the discrete energy levels of this quantum dot. Now that these states have been isolated, she and her colleagues are studying the exact mechanisms of superconductivity and coherence in normal metals with the aim of improving electronic devices based on these junctions, which may find potential application as superconducting transistors and solid-state bits for quantum computers.

This work was supported in part by the DOE/BES Materials Sciences and Engineering Division through the *Quantum Materials at the Nanoscale Cluster* in the Frederick Seitz Materials Research Laboratory.

Celia Elliott (UI Physics) contributed to this article.



From the Director (continued from page 1)

as amongst the finest mid-scale facilities in the nation.

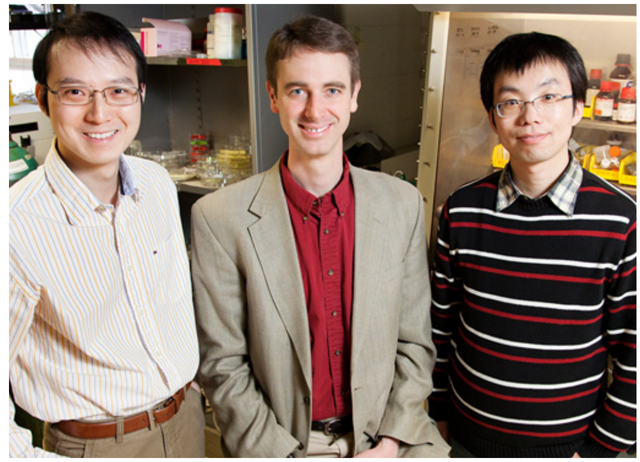
Each quarter, *Advances* introduces the researchers involved in the MRL and highlights their recent accomplishments. Together, we are transforming fundamental scientific discoveries into technological advances in the areas of photonics, flexible electronics, superconductor devices, and energy materials (e.g., photovoltaics, catalysts, and fuel cells).

I hope that you enjoy learning more about the Frederick Seitz Materials Research Laboratory and our impact on the scientific community and society as a whole.

Jennifer A. Lewis

MRL Director

Templated assembly of 3-D nanostructured battery cathodes



MRL researcher **Paul Braun** (materials science and engineering) and his team have created battery cathodes composed of three-dimensional nanostructures that allow for dramatically faster charging and discharging without sacrificing energy storage capacity. The researchers' findings were published in *Nature Nanotechnology* in May 2011. Typically, the performance of lithium-ion (Li-ion) or nickel metal hydride (NiMH) rechargeable batteries degrades significantly when they are rapidly charged or discharged. While making the active material in the battery a thin film enables very fast charging and discharging, it reduces the capacity to nearly zero because the active material lacks volume to store energy. To overcome this limitation, Braun's group wraps a thin film into three-dimensional structure, achieving both high active volume (high capacity) and large current. They have demonstrated battery electrodes that can charge or discharge in a few seconds, 10 to 100 times faster than equivalent bulk electrodes, yet can perform normally in existing devices.

The key to the group's novel 3-D structure is templated self-assembly via colloidal crystals followed by electrodeposition of nickel and electropolishing to uniformly etch away the surface of the nickel scaffold to make an open framework. The researchers then coat this 3-D structure with a thin film of the active material. The result is a bicontinuous electrode structure with small interconnects, so the lithium ions can move rapidly; a thin-film active material, so the diffusion kinetics are rapid; and a metal framework with good electrical conductivity. The group demonstrated both NiMH and Li-ion batteries, but the structure is general, so any battery material that can be deposited on the metal frame could be used.

This work was supported in part by the DOE/BES Materials Sciences and Engineering Division through the *Programming Function via Soft Materials Cluster* in the Frederick Seitz Materials Research Laboratory.

UI News Bureau Physical Sciences Editor Liz Ahlberg contributed to this article.

Rogers receives Lemelson-MIT Prize

MRL researcher **John Rogers** (materials science and engineering), the Lee J. Flory-Founder Chair in Engineering at the University of Illinois, has won the 2011 Lemelson-MIT Prize. The annual award recognizes outstanding innovation and creativity. Rogers accepted the $500,000 prize – one of the world's largest single cash prizes for invention – and presented his accomplishments to the public at a ceremony during the Lemelson-MIT program's annual EurekaFest at the Massachusetts Institute of Technology in June 2011. Renowned for his recent pioneering work with semiconductor materials and flexible, stretchable electronics, Rogers applies his expertise to devise technology solutions across such broad fields as solar power, biointegrated electronics, sensing, thin film metrology and fiber optics. Rogers combines soft, stretchable materials with micro-and nanoscale electronic components to create classes of devices with a wide range of practical applications. In addition, he is co-founder and director of the device companies MC10 Inc. and Semprius Inc., both of which work to apply and commercialize technology he has invented.

The Lemelson-MIT Program was founded by Jerome H. Lemelson, one of America's most prolific inventors, and his wife, Dorothy, in 1994. It is funded by The Lemelson Foundation, a private philanthropy that sparks, sustains and celebrates innovation and the inventive spirit.

Dillon receives DOE Early Career Award

MRL researcher **Shen Dillon** (materials science and engineering) is among 65 scientists from across the nation selected for five-year awards under the Department of Energy Office of Science's Early Career Research Program. This funding will support his research on "In-Situ TEM Observations of Degradation Mechanisms in Next-Generation High-Energy Density Lithium-Ion Battery Systems".