IMR Quarterly

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IMR Institute For Materials Research

Inside this issue:

Mobile Magnetic Tweezers: Harnessing Nano-Magnetism for Medicine and Engineering

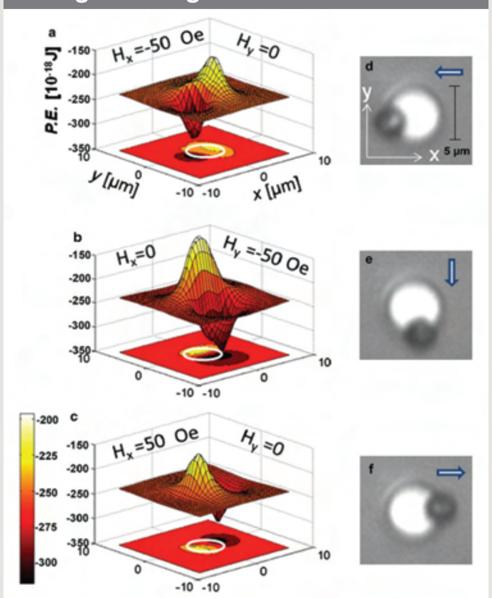
– Featuring Research by Dr. R. Sooryakumar

One of the major challenges in nanoscience and the advancement of nanotechnology in general is the development of precision tools for the manipulation and transport of nano-particles and biological entities with directed forces. While methods such as those based on atomic force microscopy, optical- and conventional magnetic tweezers can manipulate small objects with high accuracy, these methods have generally not demonstrated sufficient flexibility and throughput required for widespread adoption. The difficulty of manipulation becomes even more pronounced in a native fluid environment when stochastic Brownian motion disrupts targeted activities of the tiny entities and severely restrict the ability to trap them for extended periods of time.

Professor R. Sooryakumar (Department of Physics), along with graduate students Greg Vieira, Aaron Chen and undergraduate Thomas Henighan have been exploring a new method to combine highly localized magnetic fields that originate from designed magnetic wires and disks to manipulate micro- and nano-magnetic entities.

For more information on Dr. Sooryakumar's research and images of magnetic wire manipulation see page 10.

Designed Magnetic Disks:



Calculated energy and force profiles from a permalloy disk 5 mm in diameter and 40 mm thick magnetized with an in-plane field |Hx + Hy|l = 50 Oe and perpendicular field Hz = + 50 Oe. (a–c) Potential energy (P.E.) profiles of a 2.8-mm magnetic particle and contour plot of the energy profile in the x-y plane. The trap strengths are tunable with Hz. The trap strengths are tunable with Hz. (d–f) Real images of a microsphere moved along the periphery of the disk. Arrows indicate orientation of in-plane field Hx + Hy.

Faculty Spotlight: Wolfgang Windl

Prof. Wolfgang Windl joined the department of Materials Science and Engineering at The Ohio State University as an Associate Professor in October 2001. Prof. Windl's work focuses on the area of nanoscale computational materials science.

For more information on Dr. Windl's research go to page 8.

The Ohio State University

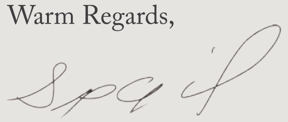
Director's Note

Dear Colleagues,

In this issue of the IMR Quarterly newsletter, we close the 2009-2010 academic year by showcasing the breadth of excellence in materials research at The Ohio State University, from the physics of nano-magnetism to create "nano-tweezers" for biomedical applications led by R. Sooryakumar, to Wolfgang Windl's research on nanoscale computational materials science to better understand the fascinating properties of a recently discovered material known as graphene – single atom thick sheets of carbon. Several of OSU's materials research centers provided updates in this issue, including a report from the Wright Center for Multifunctional Polymer Nanomaterials and Devices (CMPND) about one of their industry members, Zyvex Performance Materials, and their new nano-composite material technology for seaborne vehicular applications. We also feature a broad overview of another Ohio Wright Center for Innovation, the Ohio Bioproducts Innovation Center (OBIC), describing its special focus on enabling commercialization in bioproducts based on sustainable materials sources. In May, IMR closed its annual IMR Colloquia Series with a special lecture by Subra Suresh of MIT, who is awaiting congressional approval of his appointment as NSF's next director at the time of this writing. Regarding facilities, I am happy to welcome Dr. Camelia Marginean, who joined the ENCOMM NanoSystems Laboratory as a technical staff member this quarter. Inside you will read about all of these happenings and more.

I wish you all a productive and vibrant summer quarter, and I hope to see each of you at the third annual OSU Materials Week, which will run from September 13 – 15, 2010 at the new Ohio Union. This year's Materials Week is co-sponsored by the Center for Emergent Materials, the NSF MRSEC at Ohio State, and promises to be three full days of stimulating cross-cutting and technical sessions.

Warm Regards,



Steven A. Ringel, Ph.D.
Neal A. Smith Chair Professor
Director, The Ohio State University Institute for Materials Research

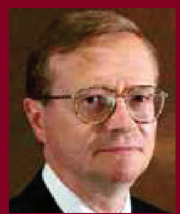
IMR Member News

Betty Lise Anderson and Paul Berger, two professors in the Department of Electrical and Computer Engineering, have been named senior members of the Optical Society of America. The senior membership designation formally recognizes the professional accomplishments and significant experience of individuals who have contributed to the field of optics and photonics at a senior level for ten or more years.

Gerald Frankel, Professor of Materials Science and Engineering and Director of the Fontana Corrosion Center, received a Distinguished Scholar Award for being "one of the world's most innovative scholars in corrosion science - a globally impacting, cross-cutting field that ensures the safety and reliability of materials." The Distinguished Scholar Award is supported by OSU's Office of Research and recognizes exceptional scholarly accomplishments by senior professors who have compiled a substantial body of research, as well as the work of younger faculty who have demonstrated great scholarly potential.

Somnath Ghosh, John B. Nordholt Professor of Mechanical Engineering, has been elected by the International Association for Computational Mechanics (IACM) to receive the IACM Fellow Award for his pioneering contributions to the field of multi-scale computational modeling of mechanical behavior and failure of heterogeneous materials like composites and polycrystalline materials. Professor Ghosh also was recently elected as a General Council member of IACM. The IACM Fellow Award will be presented to Professor Ghosh at the World Congress of Computational Mechanics in Sydney, Australia in July 2010.

Professor Ghosh was also recently elected by The American Academy of Mechanics (AAM) as a Fellow of the Academy for his pioneering contributions to the field of multi-scale computational modeling of mechanical behavior and failure of heterogeneous materials like composites and polycrystalline materials.



Joseph Heremans, Ohio Eminent Scholar and Professor of Mechanical Engineering, was named Inventor of the Year by TechColumbus for his research and invention of high-efficiency thermoelectric materials for energy solutions. The TechColumbus Awards recognize Central Ohio companies and leaders for their outstanding achievements in technology leadership and innovation.

Winston Ho, University Scholar Professor in the Department of Chemical and Bimolecular Engineering, has been awarded The Lumley Research Award which recognizes the research contributions of faculty and research scientists. Lumley Research Awards are selected on the basis of recipients' research accomplishments made at The Ohio State University during the five-year period prior to the award.

L. James Lee, Helen C. Kurtz Chair of Chemical and Biomolecular Engineering, has been awarded the Society for Plastics Engineers (SPE) 2010 International Award. This is the highest award from the largest polymer engineering society for an individual who has demonstrated outstanding achievement and recognized as an international leader in the field of polymeric materials and technology.

Professor Lee has also been awarded the Lumley Interdisciplinary Research Award. This award recognizes the interdisciplinary research contributions of faculty demonstrating significant research collaborations that cut across departmental or discipline boundaries.

Jeffery McNeal, professor of Mathematics, was named a Fellow of the American Association for the Advancement of Science. McNeal received this award for widely-recognized contributions to research in real and complex analysis, partial differential equations and differential geometry, and for administrative service to Princeton and to The Ohio State University.

Srinivasan Parthasarathy, Associate Professor in the Department of Computer Science and Engineering and the Department of Biomedical Informatics, has been awarded a Google Research Award to investigate hashing algorithms for semi-structured and structured data. Prof. Parthasarathy's research team will investigate the theoretical significance of this work together with the practical application, enhancing the ability to process and store masses of structured information ranging from XML documents to social network data efficiently and succinctly.

Ronald Reano, Assistant Professor in the Department of Electrical and Computer Engineering, was recognized by the National Science Foundation through a Faculty Early Career Development (CAREER) award. CAREER awards are the NSF's most prestigious awards in support of junior faculty who exemplify the role of teacher-scholars through outstanding research, excellent education and the integration of education and research within the context of the mission of their organizations. Reano was awarded $400,000 to support his project, "Creating a New Class of Organic-Inorganic Dispersion Engineered RF-Optical Modulators."

Steven Ringel, Neal A. Smith Chair Professor of Electrical and Computer Engineering and IMR Director, has been awarded The Lumley Research Award which recognizes the research contributions of faculty and research scientists. Lumley Research Awards are selected on the basis of recipients' research accomplishments made at The Ohio State University during the five-year period prior to the award.

John Wilkins, Ohio Eminent Scholar and Professor of Physics, was elected a Fellow of the American Academy of Arts and Sciences. The Academy membership encompasses over 4,000 Fellows and 600 Foreign Honorary Members and reflects the full range of disciplines: mathematics, the physical and biological sciences, medicine, the social sciences and humanities, business, government, public affairs, and the arts.

Jessica Winter, Assistant Professor in the Department of Chemical and Biomolecular Engineering has been awarded the David C. McCarthy Engineering Teaching Award, which recognizes the contributions of College of Engineering junior faculty and staff to create more innovative and effective teaching and learning.

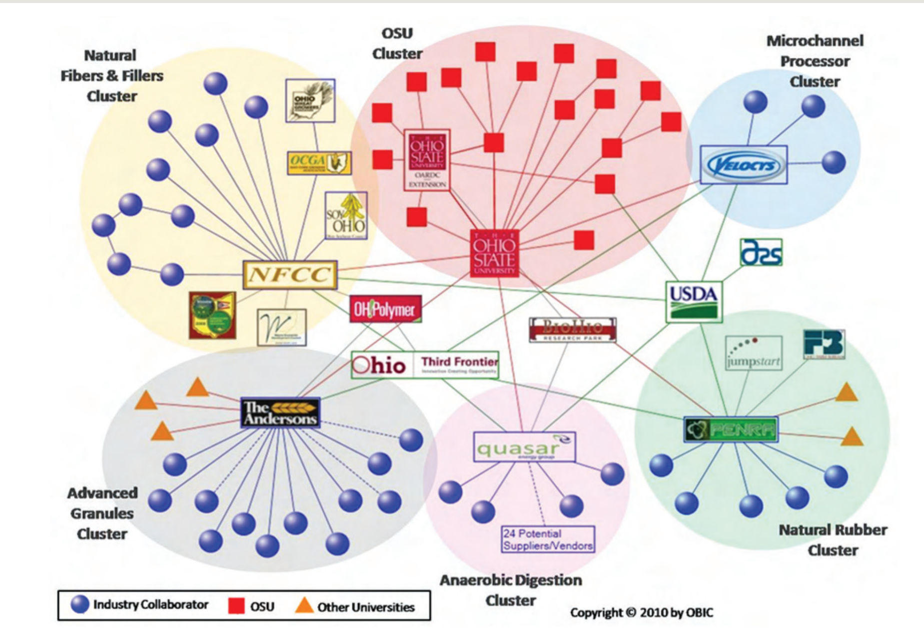
Dr. Winter has also been awarded the Lumley Research Award which recognizes the research contributions of faculty and research scientists. Lumley Research Awards are selected on the basis of recipients' research accomplishments made at The Ohio State University during the five-year period prior to the award.

Materials Centers Updates:

Wright Center Review: OBIC Commercializing New Bio-Products in Ohio

Since its inception in 2005, the Ohio BioProducts Innovation Center (OBIC) has been accelerating the commercialization of new biobased products, strengthening a burgeoning bioeconomy by linking Ohio's top industries: agriculture, specialty chemicals, and polymers. OBIC follows a market-pull model that connects core research capabilities in genetics, biotechnology, bioprocessing, chemical conversion, and materials applications to bioproduct development and commercialization opportunities driven by industry entrepreneurs. OBIC, a Wright Center of Innovation, was established in 2005 with an $11.6 million grant from the State of Ohio's Third Frontier Program. Capital investments have been made in several colleges at The Ohio State University, including the Colleges of Engineering; Food, Agricultural, and Environmental Sciences; and Mathematical and Physical Sciences; as well as several interdisciplinary programs and Battelle. To date, OBIC has leveraged in excess of $70 million in R&D activities.

OBIC serves as a 'cluster agent,' meaning it brings together people, technology, and funding to develop clusters of interrelated organizations that provide the right ingredients at



the right time to meet challenges that might otherwise derail a commercialization effort. Cluster members are typically located near each other, finding productive advantage in their common interests and close proximity, making it possible for products to be manufactured in the most efficient and cost effective manner. OBIC plays a pivotal role in bringing bioproducts to market faster, by identifying cluster members and initiatives and helping acquire funding from federal, state, and private grants, such as Ohio's Third Frontier. In the process, OBIC is helping create new businesses and jobs for Ohio. All of Ohio benefits as clusters promote innovation and entrepreneurship – critical components of continued economic growth.

OBIC assists entrepreneurs using the **Cell to Sell®** process to advance commercialization of new Ohio biobased products. There are seven basic steps:

1. Establish market needs and business case
2. Identify enabling technologies
3. Facilitate linkages within and between clusters
4. Provide impartial advocacy
5. Build relationships and collaborative value propositions
6. Leverage policy, industry, and academic assets
7. Accelerate development of a functional supply chain

Since 2005, OBIC has brought together many companies, government agencies, universities, and research organizations using the **Cell to Sell®** process and cluster development. To the left is a diagram showing several clusters established within Ohio and how they are interconnected.

As part of Ohio's Third Frontier initiatives OBIC facilitates the use of agriculture products, or bioproducts, in new ways to meet market demands, solve environmental issues, and create jobs across Ohio, including in rural areas. Several companies at the core of new clusters received funding from the Ohio Third Frontier. These include:

Andersons: $5 million to support the commercialization of granular technology

- Granular technology more effectively contains, transports, and delivers fertilizer and pesticides, or other biologically active ingredients, to specific areas. It eliminates spray drift common in liquid chemical applications, reduces spills, and is more environmentally safe.

Natural Fiber Composites Corporation (NFCC) in partnership with OBIC: OBIC helped NFCC win a $3 million grant to create a new generation of composite materials from plant-derived fibers for use in transportation, construction, consumer, and industrial products.

- In collaboration with the City of Wooster and Wayne Economic Development Council, a pilot plant in Wooster, producing six million pounds of fiber materials a year and employing eight people. Expected to generate $12 million in revenue and 37 jobs in Ohio by 2012

Quasar Energy Group (formerly Schmack BioEnergy): OBIC assisted Quasar in winning a Third Frontier grant of $2 million to help Quasar commercialize an OARDC-patented process for converting solid wastes, such as yard trimmings and crop residue, to methane.

- The Cleveland-based company has set up a laboratory and engineering office on OARDC's Wooster campus, and is working with researchers to optimize methane-production technologies.
- This innovation can produce double the biogas as conventional liquid bio-digesters and recycle the effluent coming out of those systems, reducing the cost of disposal and benefiting the environment.
- To showcase its technology, quasar is building a biomass-to-energy facility on the OARDC campus incorporating a 500,000-gallon digester capable of processing 40–50 wet tons of waste/day, the capacity to produce 400 kW of electricity, and the ability to supply one-third of the campus's energy needs.

OBIC is also helping to commercialize technology to reduce dependency on imported natural rubber by Ohio industry, the Third Frontier-funded project is leading the effort to develop a domestic source of rubber for the state of Ohio and for our nation.

The Ohio State University, the University of Akron, Oregon State University, and Cooper Tire and Bridgestone Americas: Collaborators received a $3 million Third Frontier Wright Projects Program grant through the Ohio Department of Development.

- This industry will create more than $130 million in total revenues and create 165 jobs in Ohio in the near term in the state's agricultural and rubber-products sectors.
- In the longer term, a new industry centered in Ohio can expand to address this very important national need.
- Most of the funding is targeted to build a pilot-scale processing facility on OARDC's Wooster campus that will generate 20 metric tons of rubber per year for industrial testing.

To learn more about OBIC go to: bioproducts.osu.edu.

Wright Center: PVIC Update

On April 22, 2010, Ohio State hosted the semi-annual meeting of the Wright Center for Photovoltaics Innovation and Commercialization (PVIC). The meeting, which attracted approximately 65 attendees, featured a plenary talk by Dr. Ryne Raffaelle, Director of the National Center for Photovoltaics at the National Renewable Energy Laboratory (NREL). The meeting also featured updates from representatives of the three PVIC nodes around the state -The Ohio State University (Robert Davis), the University of Toledo (Robert Collins), and Bowling Green State University (Phil Castellano). Several companies also gave updates on photovoltaics-related product research and development activities, including Ferro Inc. (Cleveland, OH), Replex Plastics (Mt. Vernon, OH), GreenField Solar (North Ridgeville, OH), and DuPont (Circleville, OH). Brian Auman of DuPont reported on the company's recent announcement of the expansion of the Circleville division with a new manufacturing line for Tedlar®, a material with widespread use as a PV panel backing, while Replex and Ferro reported on new Third Frontier PV program awards. The full program for the event can be found on PVIC's website: www.pvic.org.

◄ Left: Sylvain Marsillac, University of Toledo; Center Left: Steve Ringel, the Institute for Materials Research; Center Right: Ryne Raffaelle, National Renewable Energy Laboratory; Right: Bob Davis, Nanotech West Laboratory

Materials Centers Updates Continued

Wright Center Update: Piranha Technology Soars Ahead For CMPND Member Zyvex

Microscopic carbon nanotubes (CNTs) have been a huge R&D focus because they can impart strength and weight reduction – and other needed materials characteristics – to polymers. But it's still big news when a nanocomposite product makes a big splash entering the realm of commercialized products. Columbus-based Zyvex Performance Materials has literally made such a big splash recently by introducing its Piranha unmanned surface vessel (USV).

By incorporating Arovex™, Zyvex's proprietary CNT-reinforced carbon fiber prepreg in the design of the Piranha, Zyvex has created the largest boat ever built from CNT-enhanced materials. "This 54-foot USV weighs only about 8,000 pounds," says Lance Criscuolo, Zyvex president. "Yet it has the ability to cruise at 45 knots for 2800 nautical miles on 1400 gallons of fuel, which is ten-fold increase over traditional USVs. And it weighs half as much and is approximately twice as large as the existing generation of USVs." This is no small feat.

"In designing Piranha, we took advantage of the unique properties of Arovex, including the 40 to 50 percent stiffer modulus and its 20 to 30 percent increase in strength compared to traditional materials," said Criscuolo. "Piranha was designed entirely by Zyvex and prototyped using our materials processing supply chain partners within Ohio," he said. "The electronics and systems were outfitted through a partnering agreement with a defense contractor."

Initially, Zyvex had begun work on this project before setting up the defense partnership because Zyvex leaders felt that the availability of a prototype would be an outstanding way to market the properties and potential that Arovex provides. "We also had solid support from Ohio Third Frontier funding, and we used this to leverage the prototype development," said Criscuolo. "We had worked with Arovex enough to have great confidence in what it could do, and we also had a lot of help from the Center for Multifunctional Polymer Nanomaterials and Devices (CMPND) and PolymerOhio in networking us to Ohio vendors and tapping into the strength and convenience of working with the local supply chain," he said. "All the intermediates/prepregs we used – resins and epoxies – were made in Ohio."

Prepregs are uncured carbon fiber/epoxy materials that are semi-rigid, somewhat sticky, and can be molded, moved to another location, then assembled and oven-cured. These inherent qualities make possible a huge structure like the Piranha. "We made Piranha in two pieces, hull and deck, that would 'pop' together," said Criscuolo. "That aspect of the design makes transportation of the parts much more feasible and reduces the labor required for assembly." Both of these advantages were attractive for commercialization.

"What's interesting is that we did all this during the economic slowdown. It turned out to be an excellent time to develop the Piranha concept and it also helped keep our suppliers busy when their business was slow," said Criscuolo. "It also brought a lot of positive attention to Ohio's advanced technology businesses and gave them a share of the limelight."

USVs are used by military and governmental agencies to patrol open waters for piracy, participate in search and rescue missions, and provide on-sea surveillance, such as within harbors. They have the potential to be armed, but that depends on the intended use. While this Zyvex product is intended for a military-type application, several features of the Piranha would have uses in the commercial space as well. Lightweight, ultra-fuel efficient, high performance commercial boats will need to be a reality as well.

Zyvex Performance Materials is a leader in using the carbon nanotube, the strongest material in the world, to make composite products the strongest, lightest, toughest, and stiffest on the market. Zyvex offers the world's highest performing prepregs, epoxy resins, and adhesives that are drop-in replacements to existing manufacturing processes. An active industry partner of CMPND, Zyvex's customer base includes partnerships with world leaders in materials and production from defense technology to specialty chemicals.

The Center for Multifunctional Polymer Nanomaterials and Devices (CMPND), an Ohio Wright Center for Innovation centered at The Ohio State University, leads a research and commercialization partnership in polymer nanotechnology. CMPND puts Ohio at the forefront of nanotechnology research and commercialization opportunities, helps target markets that build on the research strengths of the participating universities and national labs, and develops manufacturing protocols and nanostructures for near-term industrial polymeric nanocomposites, emerging polymer photonic components and devices, and more futuristic biomedical devices and systems with nanoscale functions.

For more information on Zyvex Performance Materials, visit their website: http://www.zyvexpro.com/. The website for the Wright Center for Multifunctional Polymer Nanomaterials and Devices (CMPND) is: http://cmpnd.org.

Spring 2010 IMR Facility Grant Awards

For more information go to our website: imr.osu.edu and click on the program link

Eight new research projects were awarded by the IMR in June 2010, for a total investment of $16,000. The eight projects support faculty researchers from seven departments within the College of Engineering, the College of Biological, Mathematical and Physical Sciences, and the College of Dentistry.

June 2010 IMR Facility Grant Awards

FIB Characterization of MFM Probes
Lead Investigator: P. Chris Hammel, Physics; Co-Investigators: Gunjan Agarwal, Biomedical Engineering; Michael Page, Physics Undergraduate Student

Development of Low Work Function Metal "End-On" Contacts to Si Nanowires with High-Quality Si/SiO2 Interfaces
Lead Investigator: Jonathan Pelz, Physics

Lithium-ion Batteries, LiFePO4, Aging, High Resolution Characterization
Lead Investigator: Sudarsanam Suresh Babu, Materials Science and Engineering

XPS and Liquid AFM Facility Support for MIG Chemical Bonding and Conjugation on AlGaN Biosensors
Lead Investigator: Stephen Lee, Biomedical Engineering; Co-Investigator: Leonard Brillson, Electrical and Computer Engineering

Raman Microscopy of Poly-Diamond Films and Nanostructures
Lead Investigator: Ezekiel Johnston-Halperin, Physics

Mobile Magnetic Traps for Cell Manipulation and Sorting
Lead Investigator: R. Sooryakumar, Physics; Co-Investigator: Jeff Chalmers, Chemical and Biomolecular Engineering

Steep Sub-Threshold Quantum Tunneling Transistors
Lead Investigator: Paul R. Berger, Electrical and Computer Engineering

Characterization of Protein-Block Copolymer Interactions for Biomaterials Development
Lead Investigator: Bharat Bhushan, Mechanical Engineering; Co-Investigators: Scott Schricker, Restorative and Prosthetic Dentistry; Manuel Palacio, Mechanical Engineering Staff

MIT's Subra Suresh Closes 2009-2010 IMR Colloquia Series

Dr. Subra Suresh, Dean of Engineering and Vannevar Bush Professor of Massachusetts Institute of Technology, was the guest speaker for the final presentation of the 2009-2010 IMR Colloquia Series. This exciting event was co-sponsored by the Center for Emergent Materials, the NSF MRSEC program at The Ohio State University, and was well attended by approximately 250 OSU faculty, staff, and students.

Dr. Suresh's talk, *Engineering the Future of Human Health,* focused on technological advances at the intersections of engineering, nanotechnology, genetics, life sciences, medicine and public health. The colloquium devoted attention to the role research at the intersections of these different fields plays in advancing the boundaries of human disease diagnostics, in particular research targeted at diagnosing and treating different types of malaria.

Science magazine recently reported that Dr. Suresh has been nominated as the next Director of the National Science Foundation, pending a Senate confirmation.

◀ From the left:
Center for Emergent Materials Director, Dr. Nitin Padture,
OSU President, Dr. Gordon E. Gee, and
IMR Colloquium speaker, Dr. Subra Suresh.

Faculty Spotlight: Wolfgang Windl

Prof. Wolfgang Windl joined the department of Materials Science and Engineering at The Ohio State University as an Associate Professor in October 2001. Prof. Windl's work focuses on the area of nanoscale computational materials science. He previously held postdoctoral positions at Los Alamos National Laboratory and Arizona State University, and was a Principal Staff Scientist at Motorola's Digital DNA Laboratories. He received the 2004 Nanotechnology Industrial Impact Award from the Nano Science and Technology Institute for the discovery of atomically sharp "perfect" interfaces in Si:Ge devices (with Prof. Gerd Duscher) and in 2006 he was the first recipient of the Fraunhofer-Bessel Research Award, jointly awarded from the Fraunhofer Society and Humboldt Foundation in Germany. His teaching at OSU was recognized by a 2006 Mars Fontana Best Teacher Award from the Department of Materials Science and Engineering.

Prof. Windl's research focuses on the field of computational materials, chiefly on simulations of atomic-level structures and their properties. Since modeling methods on the atomic level are rather universal, independent of what kind of material the atoms form, the materials systems that his group studies span a wide range. Current projects examine the deformation behavior of amorphous metals (so-called "bulk metallic glasses"); the effect of irradiation on silicon carbide materials and fiberoptic cables in a nuclear environment; half-metallic double perovskites; and spin-lifetimes and carrier mobilities in spintronics materials. Since atomic-level simulations can only predict realistic behavior of materials if they are performed for a sensible, realistic arrangement of atoms, Prof. Windl works primarily on team projects in collaboration with experimental groups that help with the definition of the modeling tasks and their validation.

Professor Windl notes that his research group benefits immensely from the vast array of atomic-level characterization methods available at OSU, from the Campus Electron Optics Facility, where top-of-the-line atomic-resolution electron microscopy is available, to surface techniques available in the Physics department, to detailed electronic-structure measurement methods available in the Electrical and Computer Engineering department. State-of-the-art processing methods in various OSU departments and at Nanotech West Laboratory, as well as testing and irradiation facilities such as the OSU Nuclear Reactor Laboratory allow the group to prepare materials samples and study their changes in various environments. The availability of large amounts of computer time at the Ohio Supercomputer Center allows tackling demanding computations – which is usually the case for simulations on "real" materials. In addition, the bundling of expertise within the IMR and most recently in large-scale projects such as the Center for Emergent Materials, an NSF MRSEC at Ohio State, facilitate collaborations across departmental and college boundaries and make OSU a great place for atomistic modeling.

Research Highlights

Computational materials modeling is often an economic way to investigate if a material is the right choice for an application before a time consuming and expensive series of experimental investigations is started. In the following, two examples are given with opposite outcomes – first, subsequent, successful experimental proof through simulations indicate that a new method for fabrication of graphene-based devices based on "stamping" should work, while the second one shows that the use of amorphous silicon, which would be a much cheaper substrate for semiconductor applications than the common (single-)crystalline silicon, seems to be limited to applications that only require low doping levels (equivalent to small carrier concentrations).

1. Graphene Stamping

While scientists have known of graphene for many years, electronics industry officials became particularly excited about the potential use of graphene about five years ago, when it was discovered that graphene has a number of special properties. Researchers found that thin layers of graphite – the dark gray carbon material that fills most pencils – is highly stable, visible under the right conditions even when only one atom thick, stronger than steel and conducts electricity quickly and in exceptional ways.

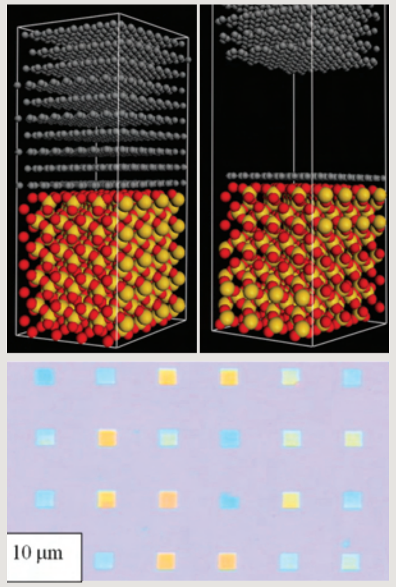


Figure 1.
Graphene stamping: Structures optimized by atomistic first-principles modeling for (A) a graphite crystal in contact with the (0001) plane of an oxygen-terminated quartz SiO_2 crystal; (B) graphite crystal removed, leaving one graphene sheet stamped on quartz SiO_2. The separation energy for (B) is calculated to be 60 mJ/m^2, only one third of the bulk separation energy (180 mJ/m^2) and much smaller than the 570 mJ/m^2 for interface separation, which will enable graphene stamping. (C) Optical micrograph of a large area of a stamped few-layer graphite pattern on SiO_2. Different colors indicate different heights of the stamped FLG. [D. Li, W. Windl, and N. P. Padture, *Towards Site-Specific Stamping of Graphene,* Adv. Mater. 21, 1243-46 (2009).]

While several researchers have been able to deposit small samples of graphene on a base material, Prof. Windl and his colleague Prof. Nitin Padture, Materials Science and Engineering department, wanted to develop a method to produce very accurate, very position-specific graphene patterns that industry partners could use to manufacture computer chips from this novel material. To do this, the OSU team etched their graphite samples to create numerous miniature "pillars" that then would be lightly pressed on a base material or "substrate." When the graphite was pulled away, they theorized, the silicon dioxide substrate would adhere to the graphite, forcing a very thin top layer to shear off from the pillars. Indeed, theoretical calculations in Prof. Windl's group showed that graphite should cleave under the right circumstances very close to the interface to the substrate, leaving one atomic layer of graphene behind. Experiments performed in Padture's group found that indeed the principle of the stamping process worked, but additional optimization work on the stamping process and substrate are necessary. This is currently being further examined in collaboration with Prof. Siddharth Rajan's group from OSU's Electrical and Computer Engineering department. The researchers have also filed a patent application for the stamping process together with Postdoctoral Researcher Dongshen Li.

2. Limitations of "Cheap" Amorphous Silicon

The possibility of doping amorphous silicon and hydrogenated amorphous silicon in combination with their lower production cost, with respect to crystalline Si, have made them materials of choice for many different applications in optoelectronics and photovoltaics. Nevertheless, these materials have an unexpected low doping efficiency, which limits their use in device applications. In order to study whether this problem is of a fundamental nature or could be overcome, Prof. Windl and collaborators examined the origin of the low dopant efficiency by electronic structure modeling.

Doping in amorphous materials poses various interesting questions not encountered in crystals. In tetrahedral amorphous semiconductors, dopants have been proposed to become electrically active when they are in a fourfold configuration, known as substitutional doping, where they can provide the material with a carrier. However, structural relaxation effects in the amorphous matrix can be substantial after the incorporation of dopants. Thus, it is not obvious a priori whether they will end up in a doping-active configuration or not. In addition, experiments indicate that the majority of the excess carriers introduced by dopants do not occupy shallow tail states around the band edges in analogy to crystalline silicon but rather midgap states. Finally, it has also been found that the carrier mobility decreases while the activation energy for conduction grows when increasing the dopant concentration, findings that are characteristic of highly localized trapping states.

To answer these puzzling questions, Prof. Windl and collaborators used ab initio simulations to study the doping efficiency of amorphous semiconductors, in particular of B-doped amorphous silicon. Dr. Ivan Santos, a scientist from the Universidad de Valladolid in Spain visiting Prof. Windl's group, performed much of this work using highly optimized structural models for amorphous silicon provided by a group at Ohio University led by Prof. David Drabold, a specialist for amorphous semiconductors. After inserting boron at a large number of possible sites in those models it was found that even in the optimum case of substitutional doping in dangling-bond free amorphous Si the holes provided by B atoms do not behave as free carriers. Instead, they are trapped into regions with locally distorted bond angles.

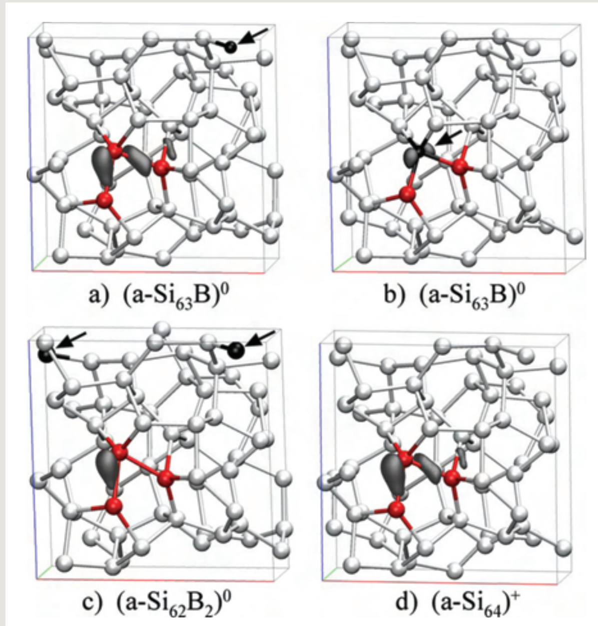


Figure 2.
Hole spatial localization in 64-atom cells with (a) a B atom far from the hole trap region, (b) a B atom at the hole trap, and (c) two B atoms far from the hole trap, (d) as well as in a positively charged undoped cell. The dark shadowed areas show the isosurface at 50% of the maximum hole density. B atoms are black and marked by arrows. Si atoms are white and red. The red Si atoms indicate the position of the hole trap. [I. Santos, P. Castrillo, W. Windl, D. A. Drabold, L. Pelaz, and L. A. Marqués, Self-trapping in B-doped amorphous Si: Intrinsic origin of low acceptor efficiency, Phys. Rev. B 81, 033203 (2010).

Thus, the effective activation energy for hole conduction turns out to be the hole binding energy to these traps. In the case of high B concentration, the trap states move deeper in the gap and the binding energy and spatial localization of holes increase. In addition, B atoms have lower energies for shorter bond lengths, configurations favored in the vicinity of these traps. Figure 2 shows the location of the trap states with respect to the boron dopant atom for different configuration. Thus, the collaboration concluded that the low doping efficiency in the case of boron is an intrinsic property of amorphous silicon with significant, fundamental hurdles to overcome before it could find application in devices that require higher carrier densities.

For more information on Dr. Windl's research visit his website at http://www.matsceng.ohio-state.edu/faculty/windl/index.htmlx, or email at windl.1@osu.edu.

Mobile Magnetic Tweezers: Harnessing Nano – Magnetism for Medicine and Engineering

Featuring Research by Dr. R. Sooryakumar

Continuation from page 1

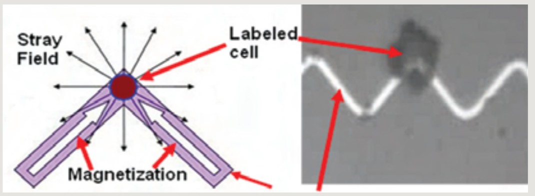
They have developed an unique multiplex approach based on storing magnetization profiles on continuous or discrete patterns imprinted on silicon or glass surfaces to provide programmable forces to individually manipulate multiple nano- and micro-particles as well as biological cells and molecules. In addition to remotely directing the forces, the platform enables real-time microscope viewing/recording, non-contact suppression of Brownian motion and ready integration into microfluidic structures for on-chip applications. The mobile magnetic tweezers require only four tiny electromagnets, a game controller to remotely direct the movement, and the power equivalent of a 60-watt light bulb. Together with undergraduate Alex Beltyukov (Computer Science and Engineering), the tweezers has also been advanced to respond to voice commands thereby opening up opportunities for hands-free nano-manipulation

Collaborations with other OSU researchers have illustrated numerous applications and advantages of the mobile tweezers. For instance, in partnership with Professors Jeff Chalmers (Chemical and Biomolecular Engineering), Fengyuan Yang (Physics) and their research groups, human T-cells -- the white blood cells that destroy infected cells in the body – were manipulated by either attaching tiny magnetic beads to the cells or by using magnetic beads as an "engine" to push the cells across surfaces. Together with Professor Jessica Winter's (Chemical and Biomolecular Engineering) group, individual, ~50 nm sized, micelles containing a quantum dot (for optical tracking) and a force transmitting magnetic nano-particle have been transported with the tweezers functioning as a nanocoveyor. In association with Professor Jayaprakash (Physics), the tweezers has been used to elegantly control and bias Brownian fluctuations of submicron sized polymeric beads with embedded nanomagnets - thereby opening avenues for targeted drug delivery and bottom-up nanoscale assembly.

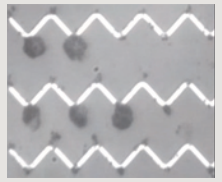
This research contributes to our fundamental understanding of nanomagnetism and its application to generate forces on the pico- and femto-Newton scale that are relevant to biology and nanoengineering. Given the limited technologies that are currently available for rapid, multiplex manipulation at the nanoscale, the mobile magnetic tweezers is notable and of broad interest transcending many disciplines It offers numerous applications with regard to selective manipulation on ultra-small length and force scales.

For more information, Professor Sooryakumar may be contacted at sooryakumar.1@osu.edu or at 614 292 3130.

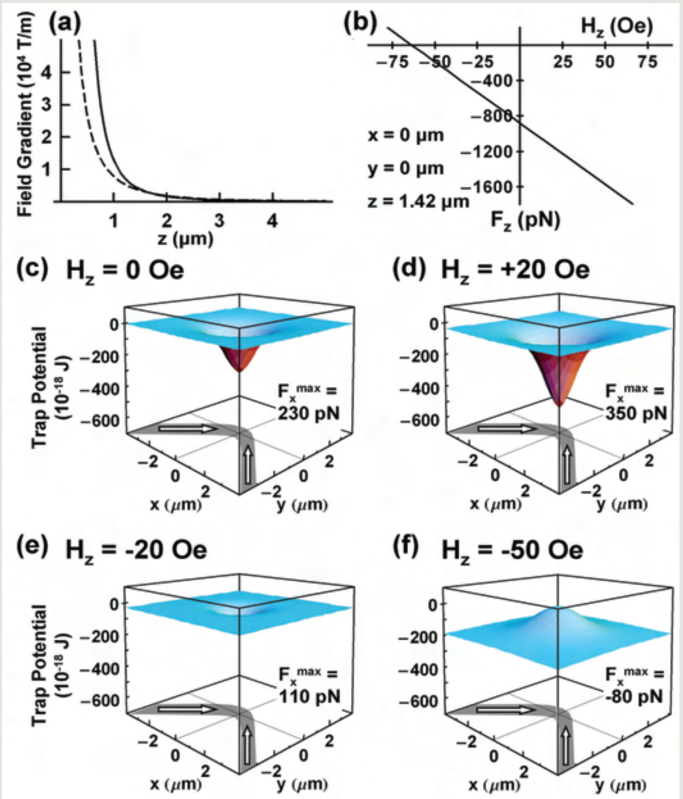
Designed Magnetic Wires:



(Left) Schematic of zigzag wire with magnetizations directed towards the vertex leading to localized fields. (Right) Human T-lymphocyte cell trapped at vertices of 2 µm wide zigzag wire on a silicon surface.

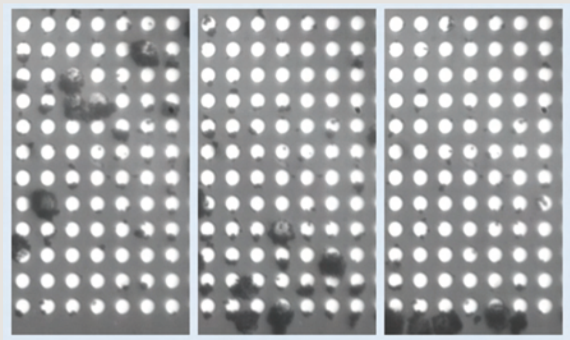


Human T-lymphocyte cells trapped at vertices of 2 µm wide zigzag wires on a silicon surface.



Calculated field gradient, force and energy profiles from a 1000 nm wide domain wall localized on a 40 nm thick, 1 µm wide FeCo wire. (a) Magnetic field gradients above the wire based on "point charge" (solid line) model and micro-magnetic simulations (dashed line) increase rapidly above 104 T/m as distance z to the domain wall decreases. (b) Variation of axial force F_z determined from "point charge" model on a magnetic bead (susceptibility $\chi = 0.85$) lying 1.42 µm above domain wall with external field H_z. (c)–(f) potential energy profiles transform from attractive (c, d, e) to repulsive (f) by changing H_z further negative. Calculated maximum force F_x^{max} along length of wire shows its tunability with H_z.

Designed Magnetic Disks:



T-Lymphocyte Cells(labeled with 1um spheres) transported in unison with directed forces on platform

References:

G. Vieira, T. Henighan, A. Chen, A.J. Hauser, F.Y. Yang, J.J. Chalmers and R. Sooryakumar, Magnetic Wire Traps and Programmable Manipulation of Biological Cells, Physical Review Letters 103, 128101 (2009).

T. Hengihan, A. Chen, G. Vieira A.J. Hauser, F.Y. Yang, J.J. Chalmers and R. Sooryakumar, Manipulation of Magnetically Labeled and Unlabeled Cells with Mobile Magnetic Traps, Biophysical Journal 98, 412 (2010).

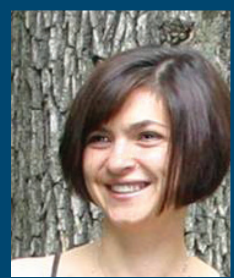
G. Ruan, G. Vieira, T. Henighan, A. Chen, D. Thakur, R. Sooryakumar, J.O. Winter, Nano Simultaneous Magnetic Manipulation and Fluorescent Tracking of Multiple Individual Hybrid Nanostructures, Nano Letters DOI: 10.1021/nl1011855 (online); to appear in print (2010).

Facilities Updates

New Electron Gun Evaporator at Nanotech West

In late April, Nanotech West Laboratory received shipment of a new CHA Industries Solutions Systems® electron gun evaporator, which is now being installed in Bay 4 of the class 100 cleanroom. The new evaporator (named EVP03 in the Nanotech West tool database) is completely oil-free, pumped by an 8" cryopump and dry pump combination. The system can hold up to seven 100mm wafers, and when put into service it will also have the ability to evaporate onto small parts. The evaporation hearth has six pockets and is motor-driven, and can be controlled by a programmable Inficon automated deposition controller. The new tool will be reserved for evaporations such as transistor gates, ohmic contacts, and other depositions that demand the cleanest of processing, while the existing Denton system (EVP01) will continue to remain in service in Bay 3. The CHA purchase was enabled by capital funds available from the Wright Center for Photovoltaics Innovation and Commercialization (PVIC), in turn funded by the Ohio Third Frontier Program. For more information about the facilities and services available to researchers at Nanotech West Laboratory, visit **http://nanotech.osu.edu/**.

New Technical Staff Member at ENSL



The ENCOMM NanoSystems Laboratory (ENSL) welcomes Dr. Camelia Marginean, who joined ENSL as a Technical Staff Member in April 2010. Dr. Marginean is a recent graduate of The Ohio State University department of Physics, and her thesis focused on studies of charge transport through metal/molecular layer/semiconductor and metal/quantum dot structures using Ballistic Electron Emission Microscopy (Advisor: Professor J. Pelz). Dr. Marginean is now the primary contact at ENSL for training and operation of the Veeco Dimension 3000 Scanning Probe Microscope, Quantum Design MPMS-5 SQUID magnetometer and various instruments in the photolithography laboratory. Dr. Maginean can be reached at **cmarg@mps.ohio-state.edu**. For more information about ENSL and the extensive facilities and services it offers researchers, visit **www.ensl.osu.edu**.

2010 IMR Materials Week

Monday, September 13 — Wednesday, September 15, 2010
Ohio Union at OSU's Columbus campus

Join us for this 3rd annual event showcasing the full breadth of materials-allied research at The Ohio State University and beyond, including plenary sessions on Energy and Materials Storage, Innovation and Entrepreneur-ship, Bio-Materials, and technical sessions highlighting recent research findings including: Epitaxial control of complex oxides, Materials for Solid State Lighting and Solar Energy, Computation for Structural and Soft Materials, Spintronics/Graphene, and more.

More details coming soon on IMR's website, via email, and mail!
See our Flickr page for photos from 2009 IMR Materials Week, go to www.flickr.com and search for osu imr.

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