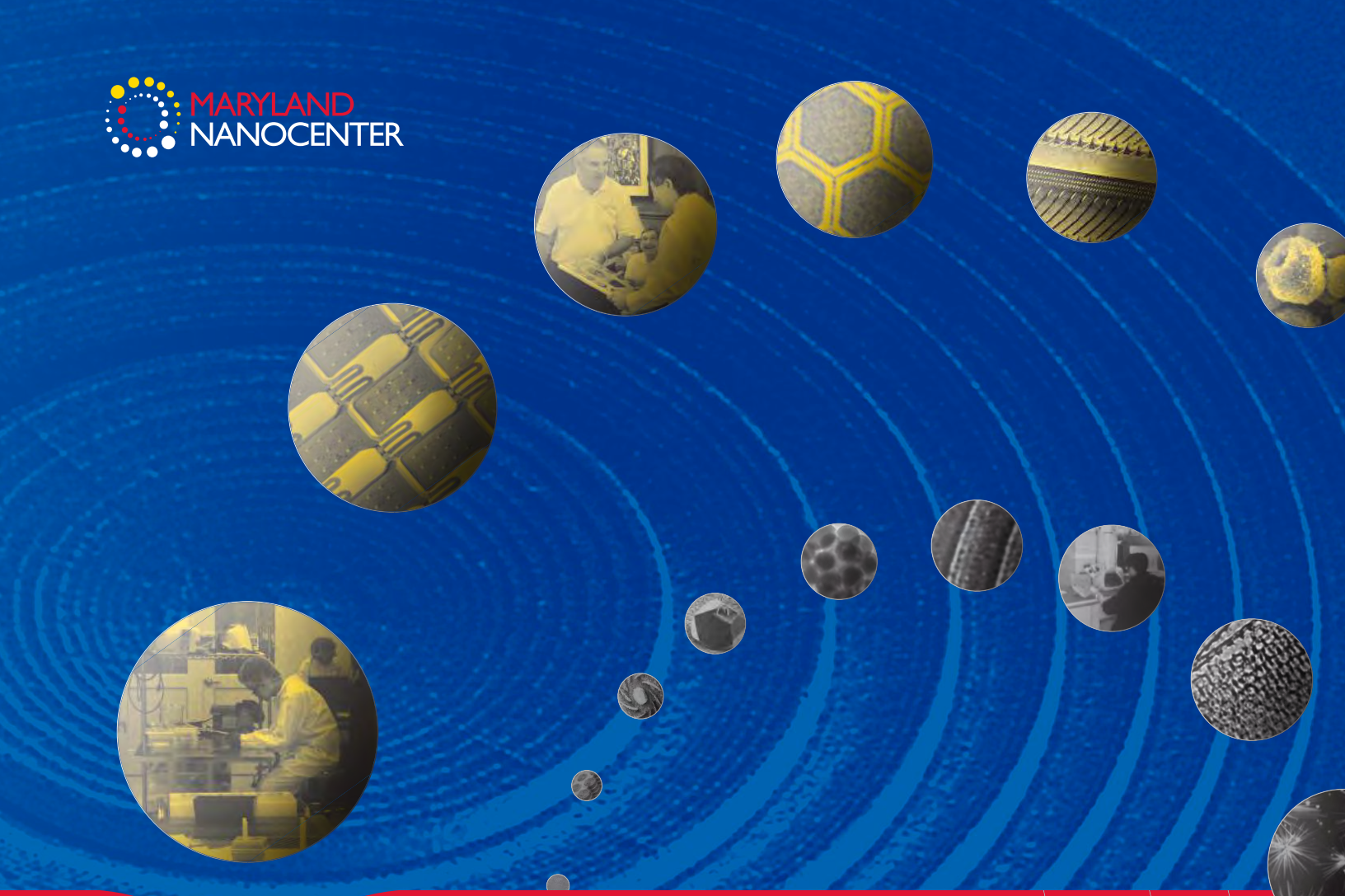
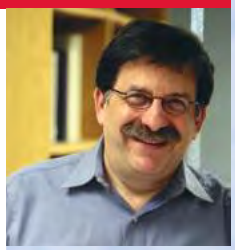


MARYLAND NANOCENTER

JOIN US FOR
A FUTURE OF
BOUNDLESS
OPPORTUNITY.



WHAT IS THE MARYLAND NANOCENTER?

Imagine having **labs full of the state of the art equipment** you could just walk into and use as your own, organized and staffed to make your work efficient. Then envision a **research community** of faculty and students who **work with you**, energizing your research through **collaborations** on shared and new interests, and **facilitated by staff and infrastructure.**

That's the mission of the Maryland NanoCenter—providing outstanding **research infrastructure** amidst a **collaborative community** to enable top-notch research and innovation, benefiting the University of Maryland, the region, and the nation.

INFRASTRUCTURE

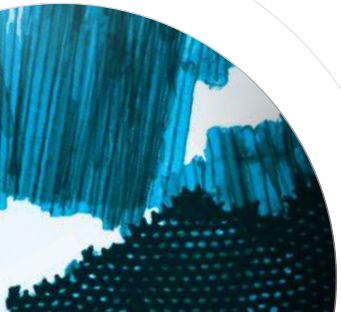
- synthesis of nanoscale **materials and structures**
- **patterning** at the nanoscale
- **imaging and characterization** to atomic scale
- microsystems **fabrication**
- experienced **technical staff** to support equipment, projects, and training
- serving **undergrad and graduate** courses as well as research users
- **online equipment scheduling** with reasonable user fees

Gary Rubloff
DIRECTOR, NANOCENTER
UNIVERSITY OF MARYLAND


PHOTO MIKE MORGAN

Ellen D. Williams
DISTINGUISHED UNIVERSITY PROFESSOR
UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS
DIRECTOR, ARPA-E

During my term as researcher and MRSEC Director, I saw firsthand the profound impact the NanoCenter provided to our research efforts. The NanoCenter deserves major credit for moving nano and micro research at Maryland to the top tier.



OUR EVOLUTION

PAST

The opening of the Jeong H. Kim Engineering Building in 2005 stimulated the campus to consolidate experimental facilities and build a launchpad for leadership in micro and nano research. The result was formation of the Maryland NanoCenter, with **two primary goals:**

(1) Infrastructure goal: to organize and manage a portfolio of experimental facilities—particularly fabrication in the FabLab clean room, and nanoscale microscopy in the AIMLab—as shared user facilities.

(2) Research development goal: to leverage these capabilities for leading-edge nano research, driven by a collaborative community on campus and beyond.

From the beginning the NanoCenter has been supported by multiple colleges and the campus, supporting an experienced and effective staff. An early investment by the Maryland Department of Business and Economic Development significantly enhanced the equipment portfolio, making infrastructure available to Maryland companies, laboratories, and universities.

RESEARCH DEVELOPMENT

- **colleagues and venues** to create big ideas and new directions
- **collaborations** across a broad scientific community
- **access to leaders** in nano science and technology
- **infrastructure** for developing programs, proposals, publicity and outreach
- **implementation support** for multi-investigator programs

The Maryland NanoCenter opens its doors to faculty, researchers and businesses from all over the **Mid-Atlantic region.** It has supported work on materials from semiconductors to polymers and biomaterials, structures from nanodevices to microsystems and labs-on-a-chip; and applications from information technology, energy and environment, defense and security, to nanomedicine, agriculture, food safety, and cultural heritage preservation. From this **diversity within a common environment,** new research teams convene to pursue ambitious projects and big ideas, broadening the stroke of science's paintbrush.

The NanoCenter is a **pivotal resource** enabling its members at UMD to generate **hundreds of millions of research dollars** and to play strong roles in nanoscience, from fundamental to applied.

Brian Jamieson
PRESIDENT
SCIENTIFIC BIOMEDICAL MICROSYSTEMS
CUSTOMER SINCE 2009

The success of our company is in large measure attributable to our cooperation with the NanoCenter's FabLab.

PRESENT

The NanoCenter infrastructure—centered around its shared user facilities—has paved a robust pathway for long-term success. More than 100 research groups use these facilities, coming from the University of Maryland and universities, companies and laboratories in the region. The equipment portfolio enables synthesis, fabrication, and characterization at the micro and nano scale for a wide variety of materials and applications, supported by nine technical staff members who provide hands-on training and assistance. This environment has proven a strong attraction for recruiting faculty and students to UMD and for bringing outside users to the NanoCenter facilities.

A sign of its collaborative culture, some NanoCenter members make selected equipment in their research labs available to other NanoCenter members, using NanoCenter administrative services to manage scheduling and billing for these partner labs, and thus expanding the capabilities of the nano community.

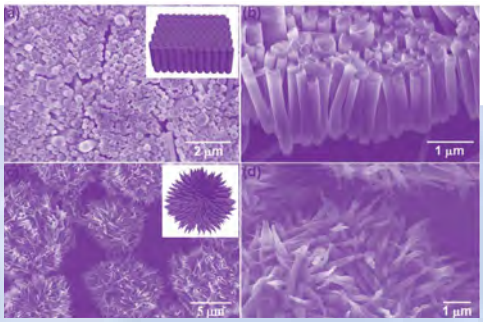
The NanoCenter's research development goal builds on its technical and administrative infrastructure and the informal culture of its community. Students meet in NanoCenter facilities, faculty interact without regard to organizational boundaries, and the NanoCenter sponsors events and opportunities to stimulate new research themes and approaches. NanoCenter staff provide support for everything from workshops and conferences, to major proposal development and preparation, and to subsequent grant management.

FUTURE

The NanoCenter has established an effective environment to promote nano and micro research. With an excellent technical and administrative infrastructure, scientists and engineers can concentrate on research goals that can change the world. They can enlist new combinations of colleagues to create novel ideas and transform them into strategic plans and reality. We look forward to an increasing array of big ideas and advances to emerge from the NanoCenter and its partners.

Ian White
ASSOCIATE PROFESSOR, UNIVERSITY OF MARYLAND
FISCHELL DEPARTMENT OF BIOENGINEERING

The resources provided by the Nanocenter were a major factor in my decision to join the School of Engineering as a junior faculty member at the University of Maryland, and they have made a major contribution to the development of my group's research program.



ENABLING A WORLD OF RESEARCH

DESIGNER NANOMATERIALS

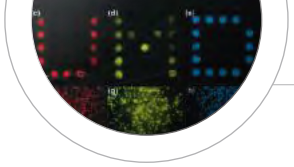
New materials promise major advances across the spectrum of nano applications, as techniques created through nano research enable atom-scale control in making materials for particular properties. NanoCenter researchers are adept at making new materials by mastering their chemistry and in optimizing multi-component materials through rapid-discovery strategies, including modeling from molecular to macro scales and combinatorial experiments which interrogate the performance across a spectrum of material parameters simultaneously. Related efforts build on this to create nanostructures from multiple materials, aiming the design of both the materials and structures made from them at the functions needed for important nano-technology applications.

NANO FOR ENERGY

Nano science and technology offers the paradigm shifts needed for major changes in energy capture, conversion, and storage and in stewardship of the environment. NanoCenter researchers pursue new materials, and related structures and architectures, to exploit nanotechnology for major advances. Topics include solar cells and photocatalytic conversion of sunlight to energy, capture of energy from heat through thermoelectric devices and from vibration through micro-devices, new battery configurations based on nanostructures and nanomaterials, fuel cell configurations for more efficient, cleaner use of fuels, and nanomaterials as the basis for new concepts in cooling. The associated research landscape spans the full range from fundamental research to next-generation technology. This is exemplified in energy storage research. NanoCenter researchers are involved in Nanostructures for Electrical Energy Storage, a DOE Energy Frontier Research Center, that pursues design and under-standing of electrochemical nanostructures as well as major applied programs and commercialization efforts aimed at enhanced electrode materials and solid state battery configurations for batteries and fuel cells.

NANO-BIO SCIENCE AND TECHNOLOGY

Opportunities to dramatically enhance biomedical technology drive strong partnerships between biology and engineering experts in the NanoCenter, addressing goals including targeted drug delivery and localized therapeutics that minimize side effects, novel antimicrobial therapies to combat antibiotic resistance, biomaterials and scaffolds for tissue regeneration, microdevices to medical implants, and understanding of how cells communicate to modulate evolution of colonies and tissues. Techniques to pursue these goals range from single-cell studies with "optical tweezers" to biochips that replicate biological interactions within platforms that dramatically enhance research advances in understanding and controlling biology. The breadth of impact is illustrated in research in viruses, which ranges from understanding pathogens that threaten humans to using viruses as nanoscale scaffolds for batteries. NanoCenter bio-related research is closely linked to other University of Maryland institutions, including medical and pharmacy schools in Baltimore and the Institute for Bioscience and Biotechnology Research, as well as NIST, FDA, and other federal labs and small companies.



NANOELECTRONICS AND INFORMATION PROCESSING

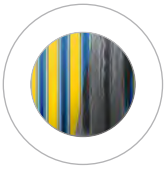
Electronics has long been in the nano regime and remains a major driver of nanotechnology. Down-scaling of size has become a profound obstacle to further advance, stimulating alternative approaches to information processing. Several NanoCenter researchers have played important roles in carbon nanotube and graphene based alternative electronics, while others are pursuing information processing based on electron spin, not charge. Significant NanoCenter work is aimed at exploiting the special properties of quantized systems for quantum information processing. The UMD-NIST Joint Quantum Institute is pursuing several physical embodiments of these phenomena (photonics, superconductivity) in concert with the NanoCenter.

UNDERSTANDING AND PRESERVING SIGNS OF OUR HISTORY

NanoCenter researchers exploit its facilities to characterize geological materials from earth and from space to gain insight into their history. They also investigate materials and processes that today drive the earth's geophysical and environmental activity, in part to anticipate what may be ahead. Maintenance of man-made artifacts is a related theme, embodied in NanoCenter research to use nanoscale processes to preserve priceless artifacts of cultural history residing in museums.

FUNDAMENTAL SCIENCE AT THE NANOSCALE

The NanoCenter community includes a strong focus on fundamental science, enabled particularly by advances in experimental techniques and increas-ingly by computational sciences. The invention of the scanning tunneling microscope, a primary driver for nanoscience, stimulated UMD researchers to lead the development of a portfolio of related scanning nanoprobe techniques, and the NanoCenter benefits from its members who created this legacy.



NanoCenter researchers have also pushed the forefronts of in-situ electron microscopy, nanoparticle synthesis, spin-polarized electrons and magnetic phenomena, low-dimensional carbon nanostructures (nanotubes, graphene), nano-confined electrochemistry, and single-molecule and single-cell studies. New scientific challenges are also emerging at the meso scale —bridging nano to micro—from phenomena that appear when nano-structures are massively aggregated as required for key applications.

MICRO AND NANO SYSTEMS

Microsystems (or MEMS) play a major role in the NanoCenter. Arising from the merger of microelectronics fabrication and its application to arenas well beyond electronics (chemical sensing, mechanical sensing and actuation, fluidics, and others) appli-cations. The NanoCenter boasts a broad cadre of microsystems researchers with interests including biomedicine, combustion, energy, unmanned aerial vehicles, robotics and security. They seek to exploit microsystems as components in these systems and as powerful platforms for fundamental experimental research. NanoCenter interactions between microsystems and nano research offer new opportunities as nanoscale constructs are incorporated into microsystems . Microsystems researchers exploit close interactions with systems and control engineering experts featured in the Institute for Systems Research.

NANOMANUFACTURING

Manufacturing of nanotechnology components is a challenge typically requiring a merger of "top-down" conventional manufacturing methods (e.g., for microsystems) and "bottom-up" nanosynthesis processes. NanoCenter researchers are addressing a variety of approaches to nanomanufacturing for specific applications. Nanoscale scaffolds for nanodevices are being explored in the forms of cellulose (e.g., paper) and self-assembled nanostructures (e.g., catalytically grown nanowire "forests", nanopore arrays by anodization), and in dimen-sionally/spatially hierarchical scaffolds (e.g., nanobatteries formed on virus particles anchored to micropillar structures). Nanomanufacturing benefits by borrowing lessons from microelectronics fabrication (e.g. using self-aligned structures to align different material components with each other), by new combinations of nanomaterials and nanoprocesses (e.g., graphene and atomic layer deposition), and by inserting improved nanomaterials into more conventional manufacturing processes (e.g., fast ion conductors for solid state batteries).

Janice Reutt-Robey
UNIVERSITY OF MARYLAND
CHAIR OF DEPARTMENT OF CHEMISTRY

The Nanocenter positions UMD as a leader in nanotechnology and the nanosciences.

NANOCENTER'S CORE STRENGTH: SHARED EQUIPMENT

NANOCENTER SHARED USE FACILITIES

FabLab The NanoCenter's FabLab is a 10,000 sq. ft. clean room micro and nano fabrication complex. It features four bays (deposition, thin films/CVD, etch, and lithography), a spacious teaching lab and an exploratory materials laboratory.

Designed as a class 1000 environment, the main research area routinely operates at class 100 or better. The FabLab is run by a highly skilled staff of five people, all with many years of industrial clean room and R&D experience.

Several key tools for nanofabrication have been acquired in the past few years, including a Raith eLine 150 electron beam lithography system, an Atomate nanowire growth system, and a Beneq atomic layer deposition system.

Microfabrication tools include: PVD (evaporation & sputtering), CVD, thermal oxide growth, PECVD, dry etching, deep RIE, wet etching, photolithography, wafer alignment and bonding, and rapid thermal annealing.

Inspection and metrology tools include: an SEM, surface profiling, electrical test, Hall measurement, thin film stress measurement, porosimetry, battery fabrication and testing, selected optical characterization, and more.

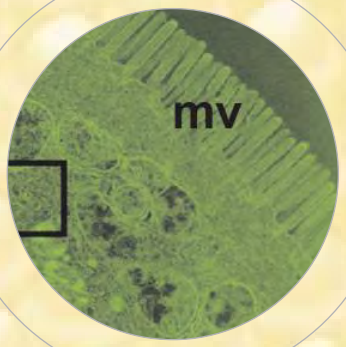
AIMLab The NanoCenter's microscopy facilities, newly renamed the Advanced Imaging and Microscopy (AIM) Lab, is home to electron and ion microscopy instruments, for state-of-the-art analytical and high resolution characterization techniques for research and education in the nano- and bio-sciences. Instruments include: two JEOL 200kV transmission electron microscopes (a LaB6 with EDS, and a FEG-TEM with EDS and EELS), a Hitachi FE-SEM with EDS, and a JEOL WDS and EDS microprobe. In-situ TEM studies are the highlight of research for these instruments.

Two Tescan dual beam FIB's with gallium and plasma beams combine focused ion beam and high-resolution SEM enabling sample preparation, 3D characterization, micromachining, microfabrication and even micro-repair.

An NT-MDT electrochemical scanning probe microscopy system provides a wide variety of scanning nanoprobe modes plus coupling to microRaman, tip-enhanced Raman, and near-field scanning optical microscopy. UV-Vis and FTIR systems, as well as other Raman systems, complement the optical capability.

Yuhuang Wang, ASSOCIATE PROFESSOR OF CHEMISTRY AND BIOCHEMISTRY

My research group heavily uses instruments in the NanoCenter, **and leverages the considerable expertise in its labs** to advance important frontiers **of nanomaterials chemistry.**



NANOCENTER PARTNER LABS

NanoCenter Partner Labs include both departmental and individual laboratories in which at least some of the equipment is available more broadly to NanoCenter users. Specific training, protocols and authorization for use of the shared equipment are determined by the lab owner, while the NanoCenter's scheduler and billing processes support the shared equipment's use. User fees collected by the NanoCenter for the shared equipment are dedicated to its maintenance and upgrades. This Partner Lab arrangement expands the scope and quality of equipment available to the NanoCenter community. Examples from a growing list are:

- **Nano-Bio Systems Laboratory** shares two optical/fluorescence microscopes, one with biological environmental chamber, and a microRaman system
- **Tissue Engineering and Biomaterials Laboratory** shares a sophisticated 3D printer for biological and polymeric materials and also specialized spectrometers
- **Surface Analysis Center (Chemistry Dept)** shares a Kratos XPS system, a Raman microscope, and an AFM
- **ALD Nanostructures Laboratory** shares a Woollam M-2000 spectroscopic ellipsometer, electrical test/probe station, and Kratos surface analysis system

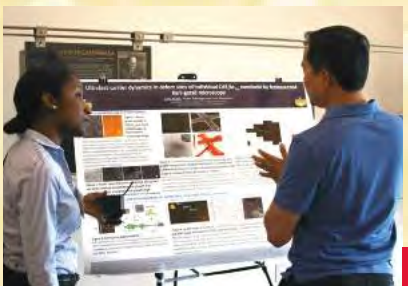
NANOCENTER ALLIED LABORATORIES

NanoCenter Allied Laboratories are **other laboratories at the University of Maryland** that share equipment with interested users. NanoCenter members are encouraged to contact the lab directors or principal investigators to make arrangements to use these instruments. In particular, the **Chemistry Department** operates x-ray, NMR, EPR, mass spectrometry, and optical instrumentation in its shared laboratory.

MAKING RESEARCH EASIER: NANOCENTER SERVICES

The NanoCenter is strongly committed to advancing nano research beyond current boundaries by supporting infrastructure, collaborative research creativity, publicity, proposal development, and program implementation. Supportive activities include efforts to:

- Train students on microscopy and fabrication equipment
- Maintain and manage use of core equipment in shared user facilities
- Assist research in shared user facilities
- Organize staff and faculty for efficient preparation of promising multi-investigator proposals
- Organize and host workshops, seminars, scientific meetings
- Assist with program implementation for multi-investigator contracts and grants
- Promote scientific advances and results to the university community and the general public



Prof. Yi Ji
UNIVERSITY OF DELAWARE
PHYSICS

Our work at the FabLab has generated seven refereed publications in reputable physics journals. Our funding support from Department of Energy was renewed due to our success, which would have been impossible without the Fablab.

FACILITIES

NANOCENTER EDUCATION

The NanoCenter provides educational benefits beyond students' hands-on research experience. Students from different departments and groups see a broader picture of nano research because they have frequent interactions with each other and with outside users while working in NanoCenter facilities or joining NanoCenter discussions.

The **teaching lab** space in the FabLab hosts lab courses from different departments, while the AIMLab supports overview-style microscopy and characterization courses, plus targeted short courses.

Intro to Nanotechnology showcases the roles of various engineering and science disciplines in nanoscience, and helps them decide if they want to pursue the Nano Minor.

The **Nano Minor program** provides undergraduates with a distinct cross-disciplinary nano focus and academic credit in nanotechnology.

A RICH COLLABORATION OF WORLD-CLASS MINDS

CONNECTIONS: OPEN, COLLECTIVE, INTUITIVE, CROSS-DISCIPLINARY, BOUNDLESS

The NanoCenter community is informal, welcoming, and collaborative. Besides open user facilities, faculty research groups often hold joint group meetings, share their expertise and instrumentation, and offer their students regular interaction with collaborating faculty and their students. This is consistent with campus culture, in which novel cross-disciplinary teams are spontaneously generated to meet important research challenges, without regard for departmental, college, or disciplinary boundaries.

THE NANOCENTER EMPLOYS SEVERAL MEANS TO ENCOURAGE THESE BENEFITS, INCLUDING:

The Research Strategy Committee seeks to guide the NanoCenter into its second decade of growth. This representative group of research leaders seeks to advance the NanoCenter and stimulate big things to happen in the community.

NanoColloquia bring leading nano researchers to campus for special colloquia and discussions with relevant research groups.

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THE NANOCENTER IS FOR YOU

The NanoCenter is poised to enable new visions in nano research over the coming years, providing across-the-board support from state-of-art equipment and training in our laboratories, access to research expertise from UMD faculty experts and their groups, and administrative guidance and support to implement programs that realize your vision. **We welcome your inquiries and participation.**

UNIVERSITY OF MARYLAND

A. JAMES CLARK SCHOOL OF ENGINEERING

COLLEGE OF COMPUTER, MATHEMATICAL, & NATURAL SCIENCES