Cutting Edge Research

Maryland has long been a leader in key areas relevant to nanotechnology, and exciting new directions are emerging and developing rapidly through strikingly cross-disciplinary research teams. Some examples are described below. Click on a topic to see an overview of advances in that area along with some of the faculty involved.

- **Focus Areas**
- **Components and Applications**
- **Nano's Impact**

Scanning nanoprobe techniques

Following the invention of the scanning tunneling microscope (Nobel prize 1986), Maryland and its NSF MRSEC (Williams, Phaneuf, Wellstood, et al) have been perhaps the primary driver in developing and applying a multitude of **scanning nanoprobe techniques** to investigate surface and nanoscale behavior down to the level of individual atoms. These methods reveal surface properties such as atomic structure, topography, electronic, optical, magnetic, mechanical, and chemical properties in detail, enabling new levels of fundamental understanding of many nanoscale phenomena.

Where and How

Want to see where it all happens? Learn more about Maryland NanoCenter's **centers and institutes**, and the top-notch facilities they use, including the **FabLab**, our microfabrication clean room facility; the **Nanoscale Imaging, Spectroscopy, and Properties Laboratory (NispLab)**; and the **Keck Laboratory for Combinatorial Nanosynthesis and Multiscale Characterization**.

You can find information about these and many other excellent shared experimental facilities, collaborative research laboratories, and partner laboratories on the **Laboratories** page.

You may also browse our **extensive equipment collection**.
Particle synthesis and nanomanufacturing

The fabrication of nanoscale particles, tubes, and wires is another area of exceptional expertise. Maryland NanoCenter researchers have mastered approaches to fabricate nanoparticles, nanotubes, and nanowires with exceptional controllability and reproducibility, using multiple nanosynthesis approaches. These include spontaneous nucleation and growth (Zachariah, Ehrman), template-based synthesis from self-assembled nanostructures (Lee), and design of specific nanocomposite structures from polymers and ceramics (Kofinas). These capabilities underpin an Maryland NanoCenter interest on understanding the health and environmental impact of nanoparticles, since fundamental insights can best emerge from careful experiments involving highly controlled nanoparticle structures.

Locating, measuring and controlling nanoparticles

While scanning nanoprobe techniques are powerful means for characterizing properties and behavior on the nanoscale, the ability to identify and actively control the location of nanoparticles, nanotubes, and nanowires is essential if construction of nanosystems is to be viable. Liquids provide a useful medium for transporting nanoparticles. Tiny beams of light provide an effective means not
only to visualize and measure nanoparticles (Davis, English) but also to move them on the nanoscale using "optical "tweezers" (Losert). Alternatively, electrical forces associated with electrokinetic phenomena can act of particles in liquids (Shapiro) to enable particle transport. Maryland NanoCenter researchers are already developing methods to scale up and systematize these techniques for nanomanufacturing and metrology (Gupta). The creation and control of various sorts of nanoparticles has major promise for applications from new catalysts (Eichhorn) to drug delivery (DeShong).

**Nanoelectronics**

Our faculty are pursuing several scenarios for the introduction of nanotechnology into next-generation electronics. Carbon nanotubes, a descendent of "buckyballs" (Nobel Prize 1996), have incredible electrical, mechanical, and thermal properties which have stimulated enormous interest for nanotechnology applications. Maryland researchers (Fuhrer) achieved the world record for electron mobility in carbon nanotubes, a major step toward their use as the revolutionary transistors of the future. Other groups have made some of the tiniest semiconductor transistors known (Yang). And cross-disciplinary teams are pursuing other nontraditional approaches to nanoelectronic devices. One is based on organic materials (Williams) which will allow manufacturing of semiconductor
devices on flexible substrates at low cost. Another is aimed at using special nanodevice structures to probe and exploit the properties of individual molecules (Sita). And while we usually think of advanced electronics in terms of traditional semiconductor chips and computers, Maryland's researchers see nanoelectronic devices in other contexts as well, coupling their properties to other nanostructures to create biosensors, drug delivery vehicles, environmental sensors, and chem-bio detection systems for security.

Nanomanufactured systems

Ultimately, nanomanufactured systems will be the vehicle from which we derive nanotechnology benefit. Building such systems is a tremendous challenge. Maryland NanoCenter researchers are pushing the technologies for nanomanufacturing, along with metrology (i.e. measurements) to guide it, in several directions. One is through continuous advance of nanofabrication, using highly focused ion and electron beams (Melngailis, Fuhrer), scanning probe and electron microscopies, and atomic-layer control of materials construction (Oehrlein, Takeuchi, Rubloff). Another is through novel processes such as nanostamping or nanoimprint lithography (Williams, Hines) and nanowriting or dip pen nanolithography (Gomez).

Microsystem platforms for nanoscale research and technology

www.nanocenter.umd.edu/research.php
Maryland NanoCenter researchers are also pursuing a more radical approach to nanosystem manufacturing uses **microsystem platforms for nanoscale research and technology**. Such platforms are already in common use, e.g. in chips which couple mechanical and electrical functions in air-bag deployment devices in cars or in cochlear implants for the hearing-impaired. We are developing microfluidic systems as a vehicle for transporting and assembling nanostructures into small systems for important tasks. Maryland NanoCenter research along these lines includes: capture, maintenance, and use of cells as intelligent sensors for chemical and biological agents (Smela, Abshire); single-molecule detection (DeVoe); replication of multi-step biomolecular reactions for metabolic engineering and drug discovery (Bentley, Yi, et al); separation and concentration of species for chemical analysis (Ghodssi); and bio-assisted assembly of nanoelectronic circuits and systems. UMD has placed a major emphasis on microsystems research, developing a very strong group of faculty in the area and a strong infrastructure to support the research. Maryland NanoCenter sees microsystem platforms as a key enabling technology for much of its nanotechnology aspirations: to a great extent, microsystems will become the laboratories and factories of the future.

**Biomolecular engineering**

A major component of Maryland NanoCenter research lies in
**Biomolecular engineering** and its broad applications to biomedical diagnostics and therapeutics, agriculture and environment, and ultrahigh selectivity approaches to nanosensors and nanoassembly. Maryland NanoCenter faculty exploit complex biochemical reactions to tailor biomolecules for specific applications, such as revealing the fundamentals of metabolic processes in living systems (Bentley) or promoting specific bioreactions, developing new means to identify and control viruses (Culver). Other efforts focus on using biopolymers to create active sites for biomolecular reactions (Payne, Yi), a key element in metabolic engineering and the discovery of new drugs and therapy strategies.

Maryland NanoCenter enjoys strong overlap with the UMD Bioengineering Program, with numerous faculty members participating in both. The [University of Maryland Biotechnology Institute](https://www.umd.edu/umbi) (UMBI), part of the UM System, has several campuses, including the [Center for Biosystems Research](https://www.cbrc.umd.edu) (CBR) on the College Park campus, and the [Center for Advanced Research in Biotechnology](https://www.carb.umd.edu) (CARB), a joint venture with NIST and Montgomery County MD. The new [Kim Engineering and Biosciences Research](https://www.umd.edu/kim) buildings add substantially to bioengineering laboratory facilities at College Park.

**Nano-bio technology**

The connection between nanotechnology and biology
presents some of the most exciting opportunities on the nano landscape, and indeed **nano-bio technology** constitutes a primary attraction for Maryland NanoCenter researchers. Piggybacking biology on nanostructures is a particularly promising avenue for research, such as manufacturing tiny carriers for drugs and modifying the carriers so that they localize at disease sites (DeShong, Lee). The reverse is true as well: the exquisite selectivity of biology, reflected in both DNA and proteins, presents a powerful means to direct the assembly of nanostructures. For example, Maryland NanoCenter researchers are working to decorate nanotubes with biological species, transport the nanotubes through microfluidic environments to complementary targets, and use inherent bioselectivity and other means to put the nanostructures together into circuits and systems. This highly cross-disciplinary marriage between nano and bio promises tremendous advances spanning the spectrum from new paradigms in fundamental scientific inquiry to health, security, and consumer applications we see everyday.

**Combinatorial materials science and discovery**

Demand is rapidly increasing for new, complex materials for a wide variety of materials applications. Since these materials may include 3-4 different atomic constituents, discovery and optimization of these materials sets requires a more efficient approach nontraditional in materials science,
and combinatorial studies which address a range of combinations in parallel is extremely efficient. Maryland has been a pioneer in combinatorial materials science and discovery, with major international partnerships in place which couple a variety of nanomaterials production methods to rapid scanning probe techniques. These research activities include work on functional inorganic materials in the UMD MRSEC, combinatorial experimentation and materials informatics in CoSMIC, an NSF International Materials Institute (Takeuchi, Rubloff), and in international collaborations.

Complex multifunctional and smart materials

Together with the Center for Superconductivity Research, the MRSEC has also led in the discovery and understanding of complex multifunctional and smart materials (Takeuchi, Venkatesan, Wuttig, et al) which contain three or more different kinds of atoms, from high temperature superconductors to materials with other unusual functionality, such as the huge coupling of electrical and magnetic properties that cause the "giant magnetoresistance" now employed in advanced data storage devices, or novel shape memory alloys, materials that "remember" their shape after they have been profoundly distorted.

Keck Laboratory for Combinatorial Nanosynthesis and Multiscale
Characterization

Advanced methodologies of scanning probe nanocharacterization and combinatorial synthesis merge to are converging to a new frontier in the Keck Laboratory for Combinatorial Nanosynthesis and Multiscale Characterization, a new laboratory facility in the Kim Building. Here materials are constructed on an atomic scale in a superclean environment that enables scanning probe techniques to reveal intrinsic structural, electrical, magnetic and chemical properties of very complex materials at the nanoscale (Takeuchi, Williams, Rubloff).