Center for Nanoscale Systems

Impacting and Hastening the Development of Future Information Technologies

For more than a third of a century, some of the most important technological advances of modern society have originated from the successful efforts of engineers and scientists to repeatedly shrink the scale and increase the performance and capabilities of information technology components and systems. These continuing advancements in electronics, information storage, optoelectronics, and photonics have revolutionized technology, creating whole new industries and affecting major societal change.

Much of nanotechnology had its origins in the development and advancement of sophisticated tools and micro- and nanofabrication techniques, which enabled this swift evolution of information technologies. These tools and techniques are now finding rapidly increasing application in broad arenas of science and engineering that extend far beyond the information technology field that has motivated and driven their initial development. But from the viewpoint of potential economic and societal impact, it is the prospective application of still further advances in nanoscale science and engineering that continues to expeditiously enhance the capabilities of information technology. This field, arguably, remains the most important aspect of current nanotechnology research.

The Center for Nanoscale Systems in Information Technology (CNS) was established at Cornell in 2001 as result of a nationwide competition held by the National Science Foundation (NSF). In this new program, the NSF established an array of interdisciplinary Nanoscale Science and Engineering Centers (NSECs) to address some of the exciting challenges that clearly are to be found in nanotechnology research and development. Cornell's NSEC program is expected to be a major leadership component of the overall federal effort collectively known as the National Nanotechnology Initiative. The Cornell NSEC proposal was one of more than 70 submitted by academic institutions from across the nation and was one of six selected for funding, with CNS receiving the largest award. Of the six centers, CNS is the only one with a focus on developing nanoscale science and nanoscale technology for application in future high-performance information technology systems.

To carry out its research program, CNS has assembled faculty teams from five Cornell departments, four other academic institutions, and leading industrial research laboratories. The CNS teams are organized into research thrust groups. The overarching mission of the groups is to understand and control the properties of materials at the nanoscale, and to enhance and exploit these materials systems and the associated nanoscale device phenomena in three areas. These areas are nanoelectronics for information processing and sensing, nanophotonics for communications, and nanomagnetics for information storage.


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The center's objective is to advance the capabilities of nanoscale science and engineering in these areas and, in particular, to develop nanoscale devices and systems that are revolutionary solutions for the requirements of future information technology systems. Seeking to develop new and effective nanoscale science and engineering technologies that will support and enable these advances, the three technological thrusts are supported by a fourth research thrust. The focus of this thrust is to develop critical and promising "enabling" nanoscale science and engineering technologies that will extend and strengthen the nanotechnology foundation of the program. In addition, a seed and exploratory projects initiative has been established as a means of bringing new ideas and opportunities, and new participants, to CNS's research program. A key aspect of the CNS strategy is the utilization of strong industrial partnerships to advance the research and to speed the results to application.

Following is an overview of the interdisciplinary research thrust groups that comprise the center's research organization.

Nanoelectronics

While scaling down the size and scaling up the performance of integrated silicon (CMOS) circuits continues today in a seemingly seamless manner, workers in this field can clearly see the time, often referred to as the "brick wall," approaching when this process will come to a halt due to fundamental materials limitations. Because of the economic and technological importance of continuing the improvement of electronic circuits as far as possible, much attention is being devoted to research that will make it possible to get around or through this brick wall.

To enable a post-CMOS transition, the CNS nanoelectronics team seeks to contribute to the effort by developing and demonstrating a new, different type of silicon circuitry. In this new approach, the physics of charge confinement and electrostatic energy in nanostructures can provide unique benefits for electronic systems that employ *embedded memory elements* as logic. In a manner that will allow devices to be assembled very densely into circuits and systems, researchers are employing nanostructures that will provide the means to *software configure* interconnects between circuit elements. This corrects for unavoidable variability in nanoscale systems, due to imperfect fabrication and defects. Initial studies from this effort, led by Sandip Tiwari, Electrical and Computer Engineering and director of Cornell Nanofabrication Facility, indicate that a new type of silicon dual-gate transistor nanostructure can effectively address critical problems in shrinking silicon circuits to the nanoscale.

In a parallel and somewhat more exploratory effort, other members of the nanoelectronics team, led by Paul L. McEuen, Physics, are working to combine methods developed separately in the fields of microelectronics, polymer chemistry, solid-state physics, and inorganic chemical synthesis to create and probe new types of *carbon-based* nanoscale electronic devices. This research includes work on developing transistors that function through the voltage-controlled flow of electrical charge through organic molecules and work on electronic devices that utilize the marvelous electrical properties of carbon nanotubes. The potential outcome is a future generation of nanoscale devices with new capabilities, including powerful ways of interfacing nanoelectronics with chemical or biological systems.

Nanophotonics

The CNS objective in the nanophotonics area is to develop, study, and advance photonic system components that exploit nanoscale phenomena. These components would provide functionality to satisfy the full spectrum of requirements for future *all-optical* circuits and networks for telecommunications. By exploiting nanostructures (e.g., quantum dots), scientists can control the electronic properties (e.g., refractive index) of composite materials through the control and variation of their composition at the nanoscale level.

Alexander L. Gaeta, Applied and Engineering Physics, leads the nanophotonics thrust group. Initial results include the successful fabrication of the first waveguide structure (incorporating PbS quantum dots, single crystal particles of approximately seven nanometers in diameter), which could function as active optical amplifier elements over the entire telecommunication band. If successfully implemented, this could greatly enhance the capacity of fiber optic systems in the future. Another promising

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Alexander Gaeta, Physics, works with high school physics teachers at CNS workshop

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Malcolm Thomas, CCMR (l.), and John Silcox, Applied and Engineering Physics (r.)

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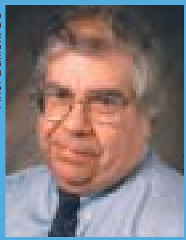

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Information Processing and Sensing

Nanoelectronics
Overcoming materials limitations to fabricate the next generation of electronic circuits—scaled down in size, scaled up in performance (Sandip Tiwari, Electrical and Computer Engineering, and Paul L. McEuen, Physics)

Communications

Nanophotonics
Exploiting the nanoscale phenomena to provide all-optical circuits and networks for telecommunications (Alexander L. Gaeta, Physics)

Information Storage

Nanomagnetics

Providing high-performance, ultra-high density, nonvolatile, on-chip nanoscale memory cells, going beyond the current approach of storing information magnetically (Daniel C. Ralph, Physics)

Innovative Instrumentation

Enabling Science and Technologies

Meeting the needs of advanced nanofabrication through the development of unique analytical tools and innovative scanned probe instrumentation (John Silcox, Applied and Engineering Physics)


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start in the nanophotonics effort is the successful fabrication of glasses containing magnetic nanostructures, which is a step toward the development of a new class of magneto-optic devices that could provide new and powerful means of manipulating light.

Nanomagnetics

Just as electronic circuits have been regularly decreased in size and increased in performance over the last several decades, the ability to store information magnetically at higher and higher density has also been increasing at a very rapid pace. In recent years, the storage capacity (bits/square inch) of magnetic hard drives has been doubling every year.

Another important development is a major industrial R&D effort to integrate magnetic memory cells (magnetic RAM or MRAM) directly onto silicon chips for high-performance, low-power, and nonvolatile memory applications. The CNS nanomagnetics group, led by Daniel C. Ralph, Physics, seeks to apply nanoscale science and engineering to further advance the development of memory, logic, sensor, and other device technologies that take advantage of the electron's intrinsic magnetic moment—its spin—as well as its charge.

A major focus initially is to utilize the recently discovered potential to reversibly switch the orientation of nanoscale thin film magnets by employing spin-polarized electron currents. This has the potential of providing high-performance, ultra-high density, nonvolatile, on-chip nanoscale memory cells that can go well below the capabilities achieved by scaling down current approaches. Spin-polarized currents may also be employed to control the dynamics of nanomagnetic moments in the 10 to 100 GHz regime. This could have applications in high-frequency mobile communication systems. The nanomagnetics group is also pursuing the study of spin-conserving electron transport across heterogeneous interfaces and the interfacing of ferromagnetic and semiconducting materials in novel geometries for applications, including possible quantum computing applications that utilize spin-dependent transport and spin-coherence phenomena.

Enabling Science and Technologies

To successively fabricate, understand, and develop functional nanoscale devices and systems requires the development and effective application of a broad array of nanoscale science and technologies. To meet this need, John Silcox, Applied and Engineering Physics and Vice Provost for Physical Sciences and Engineering, leads the CNS thrust group in advanced nanofabrication (including both conventional top-down lithographic approaches and bottom-up chemical techniques such as nanoscale synthesis and assembly) and in nanocharacterization using unique analytical tools and innovative scanned probe instrumentation. The analytical scanning transmission electron microscope (STEM) investigation of quantum dot samples for the nanophotonics effort is an important early contribution. Another major component of the group's activities is the development of a powerful array of new types of scanned tip instruments that can enable the measurement study—the electrical, topological, and magnetic properties—of materials and devices with sub-nanometer scale resolution.

The Center for Nanoscale Systems is only in its first year of existence, but a strong team of highly interactive Cornell researchers has come together and is working in concert with the faculty at Cornell's partnering institutions and with industrial collaborators. The CNS research team is already making very good progress toward the goal of developing nanoscale systems and nanoscale solutions that can substantially impact and hasten the development of future information technologies. CNS is also educating some of the very best students in the country, equipping them to become future research leaders of the rapidly advancing field of nanoscale science and engineering—a field that has been identified by the federal government as centrally important to maintaining the nation's leadership position in science and technology.

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