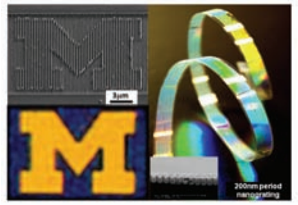
A Snapshot of Current Research by Associated Faculty Members

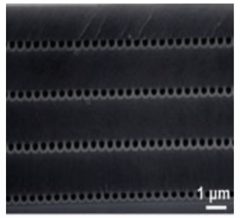
Nanofabrication Technologies for Optoelectronics, Imaging, Sensing, and Displays

Professor Jay Guo's group is conducting research in nano and microphotonics and developing nanofabrication technologies. They have exploited light confinement and enhancement effect of plasmonic nanophotonics for applications in organic solar cells, nanolasers, flexible displays, optical metamaterial structures, photo-acoustic imaging, and biochemical sensors. They have also developed a polymer microresonator as a novel platform for ultrasound detection with high sensitivity and broadband response. In addition, his group has been pushing the frontiers of high-throughput fabrication technologies to bring these nano- and microphotonic structures to practical applications, most notably through the development of nanoimprint and roll-to-roll nanoimprint techniques.



High-efficiency, high-resolution plasmonic color filters using nanostructured metaldielectric-metal stacks (left). Nanogratings on a flexible substrate fabricated by high-speed and continuous roll-to-roll Nanoimprint process.

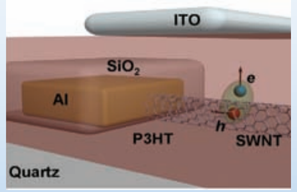
Professor Stella Pang's research group has developed nanofabrication technology for microelectromechanical, biomedical, microelectronic, and optical devices. They have developed novel 3-D reversal nanoimprint and dry etching technology for high performance sensors and single molecule microfluidic systems.



4 levels of 200nm-wide nanochannels formed by reversal nanoimprint in SU-8.

Carbon Nanotubes

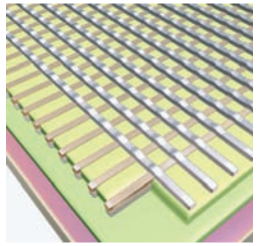
Single-walled carbon nanotubes are unique one-dimensional nanomaterial with exceptional electrical, mechanical, and optical properties. **Professor Zhaohui Zhong's** group has developed a unique one-step direct transfer technique for fabricating pristine nanotube electronic and photonic devices. In addition, they are working on understanding the fundamental exciton dissociation and charge transfer process at nanotube/polymer heterojunction, aiming to develop low-cost, high-efficiency, nanotube-based, hybrid organic photovoltaics. They are also working on exploring high-frequency response of nanotube nanoelectronics biosensors for point-of-care detection.



Single-walled carbon nanotube high-efficiency hybrid photovoltaics.

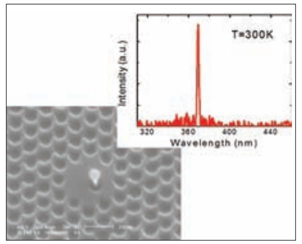
Nanowire Research

Professor Wei Lu's group focuses on the application and fundamental understanding of nanostructures and nanodevices, specifically electrical devices and circuits based on two-terminal resistive switches (memristors) and semiconductor nanowires. Current projects include high-density memory based on resistive devices; memristor-based reconfigurable circuits and neuromorphic circuits; high-performance nanowire transistors and 3-D device integration; nanowire-based flexible and transparent electronics; spin injection into 1-D systems and nanoelectromechanical systems.



High-density memory and logic circuits can be utilized using the memristor-based crossbar circuit illustrated above.

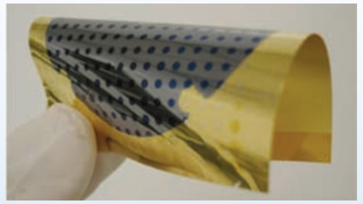
Professor Pallab Bhattacharya's group has developed a technique to grow defect-free InGaN/GaN nanowires on (001) silicon substrates without the use of a foreign catalyst by plasma-assisted molecular beam epitaxy. The nanowires are extremely uniform in diameter and the In composition can be varied to give luminescence in the visible range. More uniquely, InGaN/GaN dot-in-wire heterostructures with additional quantum confinement have also been grown and these heterostructures exhibit strong luminescence in the visible range as well. These defect-free heterostructures and nanostructures are being used to demonstrate high-efficiency, light-emitting diodes and lasers for the demonstration of various strong coupling phenomena.



Single GaN nanowire laser on silicon with photonic crystal cavity.

Organic Semiconductors and Nanostructures

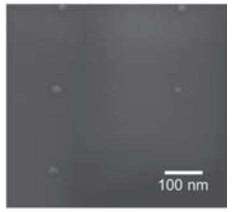
Professor Stephen Forrest's group is involved in the investigation of both organic and III-V semiconductor materials at the nanoscale, and how nanostructures influence optoelectronic device properties. Of particular interest is using nanostructures to create entangled interfaces in organic solar cells, thereby achieving very high power conversion efficiencies. Also, work on light emitters such as organic LEDs and lasers, as well as photodetectors are a focus of intense research. Recently, using growth technologies such as organic vapor phase deposition, Professor Forrest and this team have observed the first systematic correlation between nanostructure and exciton diffusion length in crystalline organic semiconductors. Also, the group is working on exceptionally low-cost, ultra-thin film InP and GaAs solar cells cold welded to flexible plastic sheets for economical solar to electrical energy conversion applications.



Epitaxial lift-off allows for the transfer of thin matIII-V layers onto flexible substrates. An array of InP-Indium tin oxide is shown mounted on a Kapton substrate.

Nitride-Based Quantum Dots

Professor P. C. Ku's group focuses on utilizing nanoscale materials and structures grown by MOCVD InGaN/GaN (e.g., ordered quantum dots) to improve the energy efficiency of the generation, manipulation, transportation, and detection of photons, aiming for applications in solid-state lighting, solar energy utilization, quantum information processing, sensing, and on-chip optical communication. Current projects include high-efficiency, light-emitting diodes and delivery of incoherent photons, low-threshold nanoscale lasers, nanostructured third-generation photovolatics, and infrared sensors.

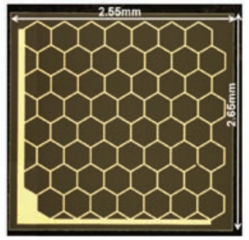


Site-controlled InGaN/GaN quantum dots for single-photon emission.

Professor Pallab Bhattacharya's group is involved in the epitaxy and characterization of *self organized* InGaN/GaN quantum dots by plasma-assisted MBE and is investigating the properties of quantum dot LEDs emitting in the green and, in particular, the phenomenon of "efficiency droop".

Multifunctional Materials

Research conducted by **Professor Jamie Phillips** and his group is focused on compound semiconductor and oxide materials for optoelectronic and electronic devices. Current research efforts are in the areas of II-VI compound semiconductor heterostructures and nanostructures for intermediate band solar cells, ZnO for thin-film electronics and solid-state lighting, ferroelectric thin films for microwave electronics, and HgCdTe infrared detectors.



Microscope image of II-VI ZnTe:O intermediate band solar cell.

Spintronics Research

The groups led by **Professors Pallab Bhattacharya** and **Wei Lu** are involved in the investigation of spin-based phenomena in nano- and microscale semiconductor heterostructures. Examples are ferromagnetic Mn-doped InAs quantum dots for high-temperature spin injection, spin transport in nanowires, lateral and vertical spin valves, spin amplifiers and quantum dot spin lasers, and spin polarized single-photon sources. These light sources are useful for cryptographic optical communication and biomedical sensing applications.

Quantum Dot and Quantum Ring Lasers and Detectors

Professor Bhattacharya's research group has done pioneering work in the development of high-performance InAs/GaAs lasers emitting at 1.0, 1.3, and 1.55μm. Currently, they are working with Intel to develop a QD laser based WDM communication system for computer applications. They have also recently demonstrated detection of 1–3THz radiation with intersublevel detectors having quantum rings in the active region.

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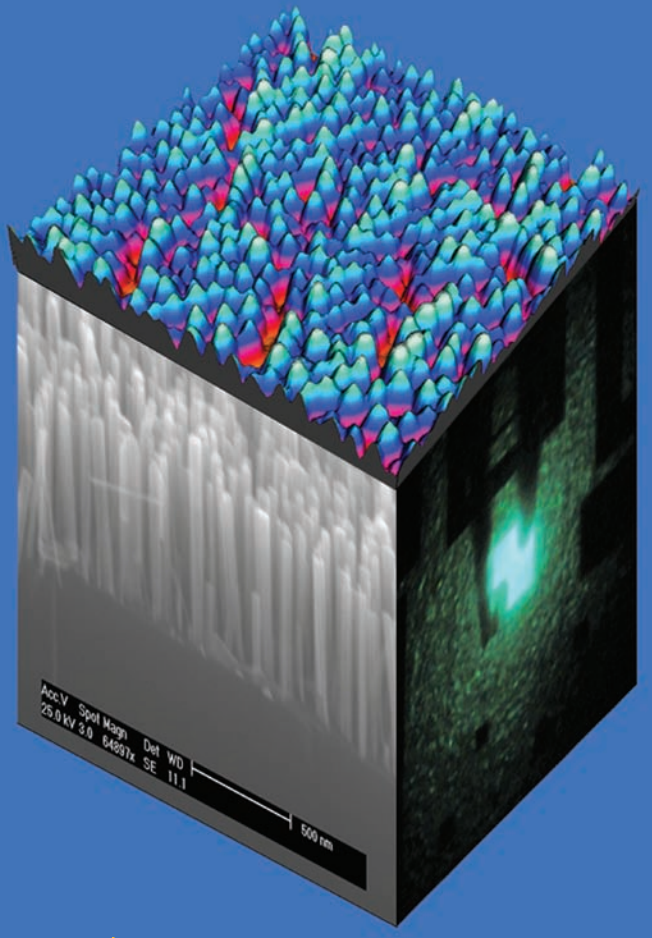

ELECTRICAL AND COMPUTER ENGINEERING – EECS DEPARTMENT

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About the Center for Nanoscale Photonics and Spintronics

The quest to explore the properties of materials and devices, when their dimensions are shrunk to the nanoscale, has led to an explosion of research in the fields of nano-science and nanotechnology. The resulting research and development will continue to impact several disciplines in the coming decades, especially engineering and medicine. The Center for Nanoscale Photonics and Spintronics (CNPS) is a center based in the College of Engineering that serves to unify the research and teaching activities at Michigan in these areas.

Faculty in Electrical and Computer Engineering at Michigan have the expertise to conduct CNPS-related research in the specialty areas of photonics, optics and optoelectronics, spintronics, and microelectronics. This research impacts the application areas of quantum information processing, secure communication, quantum optics, spin-based nano-electronics for logic and memory, and sensing. The research encompasses different materials (semiconductors, carbon nanotubes, quantum heterostructures), different technologies, and ultimately devices for the diverse applications listed above.

An introduction to the research conducted by faculty in the division of Electrical and Computer Engineering in the area of nanoscale photonics and spintronics is provided in this brochure.

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Center Associated Faculty Members

Pallab Bhattacharya
Charles M. Vest Distinguished University Professor and James R. Mellor Professor of Engineering

Research Interests: Molecular beam epitaxy, low-dimensional quantum confined systems, quantum dot lasers and detectors, nanowire devices, optoelectronic integrated circuits, spintronic devices

Stephen R. Forrest
Vice President for Research, William Gould Dow Professor of Electrical Engineering

Research Interests: Organic electronics, photonic integrated circuits, photonic materials

Lingjie (Jay) Guo
Associate Professor

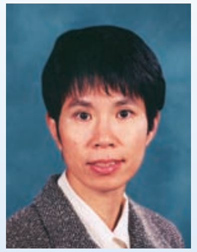
Research Interests: Nanofabrication technology and applications, photonic microresonator sensors, organic photovoltaic, nanophontonics, and nanoelectronics

Pei-Cheng (P. C.) Ku
Assistant Professor

Research Interests: Optoelectronic devices and materials

Wei Lu
Assistant Professor

Research Interests: Nanoelectronics, growth of nanoscale semiconductor heterostructures, novel electronic device structures and device physics, solid-state based spintronics, nanoelectromechanical systems



Stella W. Pang
Professor

Research Interests: Nanofabrication technology, dry etching, dry deposition, microelectronic, optical, micromechanical and biomedical devices

Jamie D. Phillips
Associate Professor

Research Interests: Compound semiconductor and oxide materials for electronic and optoelectronic devices

Zhaohui Zhong
Assistant Professor

Research Interests: Nanoelectronics and nanophotonics, microwave and terahertz frequency nanoelectronics, solar cell technology, chemical and biological sensing, nanomaterial synthesis

Resources

Solid-State Electronics Laboratory (SSEL)

The SSEL is home for 27 faculty members and 127 graduate students conducting research in microelectronic, optoelectronic and spintronic devices, materials growth and characterization, micro-and nanofabrication, and micromachined devices, circuits, and microsystems (MEMS). Faculty members in SSEL offer a variety of undergraduate and graduate courses in these areas. The **Lurie Nanofabrication Facility (LNF)**, a state-of-the-art materials processing and device and circuits fabrication facility, is an integral part of SSEL and a national resource.

National Nanotechnology Infrastructure Network

The National Nanotechnology Infrastructure Network (NNIN) is an integrated networked partnership of 13 user facilities, supported by the National Science Foundation since March 1, 2004. The NNIN provides users across the nation open access to leading-edge tools and capabilities to help enable their individual research projects. The NNIN also has extensive education, training, and outreach activities, as well as programs on societal and ethical issues involving nanotechnology.

Facilities, Equipment, and Laboratories

The SSEL and LNF provide among the most extensive facilities in the nation for research in nanoscale photonics, electronics, spintronics, and in the other diverse areas listed above (including solid-state circuits, MEMS, displays). Highlights are:

- Over 11,000 sq. ft. class 1000/100/10 cleanrooms
- Dedicated areas for:
  - Silicon processing
  - Compound semiconductor devices
  - Thin films deposition
  - Wet and dry etching
  - Electron beam lithography
  - Metrology
  - III-V materials growth by MBE and MOCVD
  - Organic semiconductor growth and device fabrication
  - Synthesis and processing of carbon nanotubes and spintronics materials
- Laboratories for packaging and testing
- Laboratories for optical, electrical, and magnetic measurements on materials and devices including nanoscale structures and devices
- Laboratories for time-resolved optical measurements in the visible and near-infrared wavelength ranges
- Facilities for nanoimprint technology