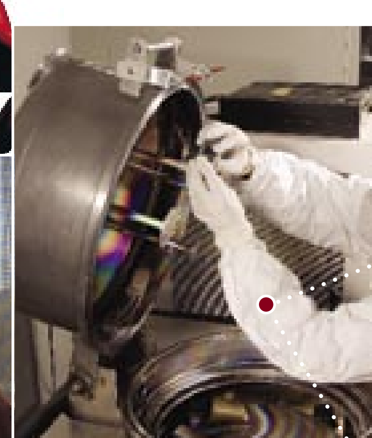
Pioneering Tiny, Powerful Technology

The fifteen researchers in ICICS' young, dynamic Microsystems and Nanotechnology Group are making quantum leaps in the development and fabrication of these emerging technologies.



The prefixes micro and nano have become buzzwords for powerful technology so small that it seems to belong to the realm of science fiction, not science (one nanometre is one-billionth, or 10^{-9} of a metre). Yet, the devices under development by ICICS' Microsystems and Nanotechnology (MiNa) group promise a host of real-world applications. "In the next five to fifteen years this will be the dominant technology, so our goal is to be leaders in the design and fabrication of future systems," says ECE's Lukas Chrostowski. The group currently has six main research foci: biomedical devices, nano-devices and computing, energy, optical communications, sensors and actuators, and micro- and nano-fabrication technology development.

Nanotubes, Nanowires and Nano-electronics

Carbon nanotubes are single molecules of carbon rolled up to form tubes, which have unique electronic and mechanical properties. Alireza Nojeh and MiNa colleagues are working on both single-walled and multiple-walled nanotubes (layers of cylinders inside each other) to better understand their intriguing properties in order to apply them to an array of potential industrial uses.

One potential application for single-walled nanotubes is electron emitters for flat-panel displays, which combine high quality visuals with long product lifetime and low cost. "It's the best of both worlds," says Nojeh. "This technology provides the high brightness and wide viewing angle of old cathode ray tubes with the thinner and lighter structure of the flat-panel technology." Other applications include high-resolution electron microscopes, electron beam lithography, high frequency transistors, and chemical and biological sensors.

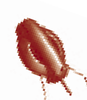
Nanowires are similar to carbon nanotubes, in that they are very long only in one dimension. However, nanowires can be fabricated from both organic materials, such as carbon and DNA, and inorganic materials, such as metal oxides. One of the main attractions of nanowires, and nanotechnology in general, is that their electrons are confined in two dimensions, and the tighter the confinement, the more marked the quantum-mechanical properties. Nanowires of silicon and other inorganic composites have applications in integrated circuits, photonics, solar cells, and displays. ECE professor Peyman Servati has fabricated photo detectors from silicon composite nanowires that exhibit extremely promising light sensitivity, and which could be used for developing future solar cells.

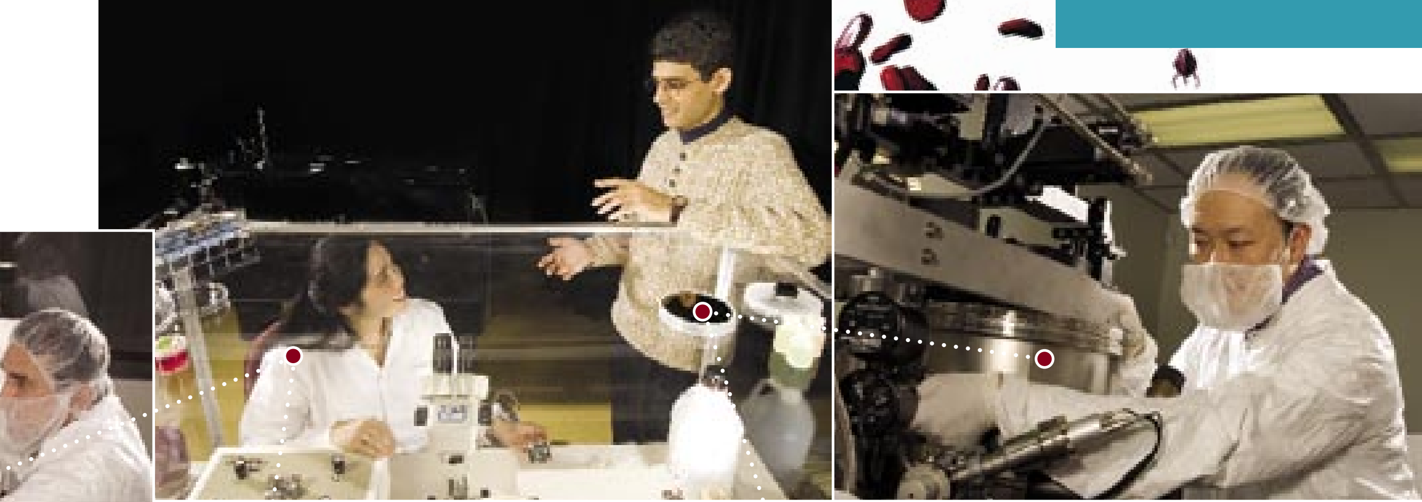
Advances in Nano-computing

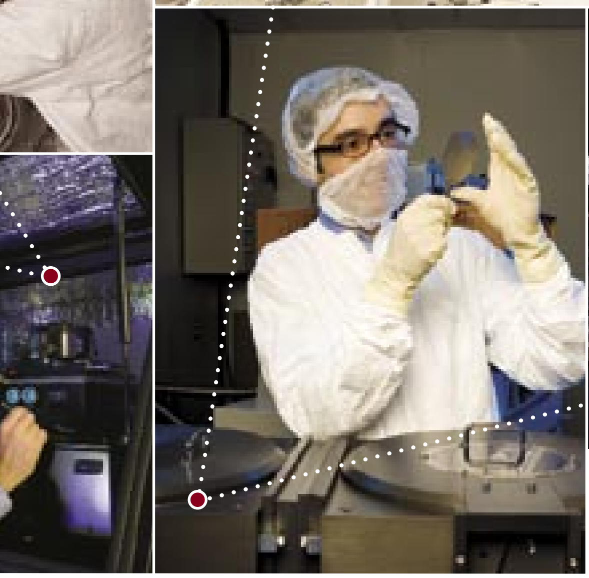
In current computer hardware, logic gates and wires a fraction of a micron wide are fabricated onto a silicon chip. However, as these components become smaller—the size of a few atoms—the laws of classical physics break down and the rules of quantum mechanics take over. Group members are working on several aspects of nano-computing, including device simulation (ECE/ICICS' Nojeh, Konrad Walus, David Pulfrey), device fabrication (Nojeh, Servati) and nano-device circuit and systems simulation (Walus). In another complementary and essential area, Walus and ECE/ICICS colleague André Ivanov are researching the design and testability of nanoelectronic circuits. "Many of these nanoscale devices have relatively poor reliability and exact fabrication and connection of the 100 million or more components that are in current computers may not be possible," notes Walus. "It is imperative that we develop new methodologies to design and test these future circuits."

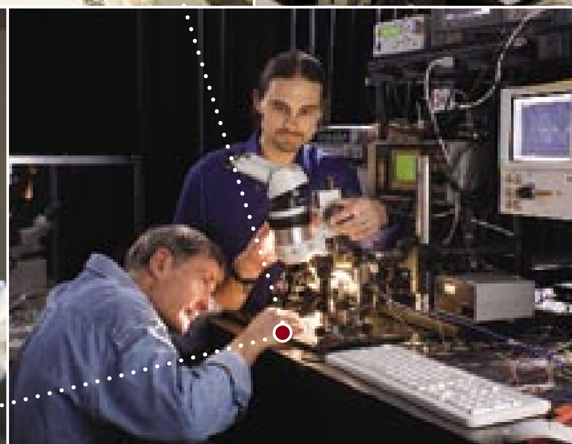
Inkjet Technology "Prints" Bio-materials

One exciting research direction in the MiNa group is the application of inkjet









technology for printing organic electronic circuits and biological materials. “The advantage of this method is the very low cost of circuit/sample fabrication and the fast turnaround time,” says Walus. Inkjet printing allows researchers to print and pattern organic polymer-based devices, or even living cells, in specific orientations and on multiple layers—the same way that a paper document is printed. “We think we will be able to use this not only for printing circuitry, or flat structures, but for tissue scaffolds as well,” says colleague Karen Cheung (ECE/ICICS). “This is the first step in growing tissues such as artificial retinas or skin to replace scar tissue in burn patients.”

Biomedical Devices Improve Diagnosis and Treatment

Cheung’s research in biological microelectromechanical systems (bioMEMS) focuses on implantable microelectrodes for recording and stimulation, such as neural implants for prosthetics. Implantable devices record signals directly from the motor cortex at the cellular level. These signals have the potential to enable real-time control of prosthetic limbs. Cheung is also researching the use of neuro-implants to administer drugs such as antibiotics or agents that promote neuronal growth. ICICS colleagues Mu Chiao (ME) and Boris Stoeber (ECE) also investigate MEMS and microfluidics, the behaviour of fluids at the microscale, which is important in the development of cell- and molecule-based systems for drug delivery, genetic assays and high-throughput screening.

Kenichi Takahata (ECE/ICICS) is designing implantable stents to prevent arteries from collapsing after bypass surgery. The stents have wireless interfaces that can also monitor blood pressure, blood flow and body chemistry to communicate regular updates on the status of the patient. In related research, fellow ECE professor and ICICS member Vikram Krishnamurthy is modelling carbon nanotube interactions with cells for potential drug transport.

Breakthroughs in Biophotonics

In the area of biophotonics, ECE professor Shuo Tang is working on medical imaging at the cellular and tissue level. The technology focuses optical waves to submicron resolutions to provide extremely detailed images and determine chemical specificity. These measurements can establish cell function, structure and chemical composition essentially in vitro, by taking an optical sample—without the need for biopsies or invasive surgery.

Lukas Chrostowski is making very small lasers, detectors and sources for spectroscopy, DNA sequencing and optical lab-on-a-chip applications. Along with his ECE/ICICS colleague Nick Jaeger, he is also working on developing next-generation devices for high-speed networks, ranging in distances from centimetres for on-chip applications, to kilometres for long-distance communication (*FOCUS* Spring 2006).

Nanoscale “Sensor Perception”

Several MiNa researchers are developing nanoscale sensors and actuators for a wide array of applications, from environmental monitoring to robotic surgery. ECE professor and ICICS member Edmond Cretu is working on micro- and nanosensors to detect movement and vibration, and to help in precise navigation and positioning of micro-surgery tools. Current solutions lack the resolution to do accurate 3D imaging, so it is difficult for a surgeon to pinpoint a specific area. Combined with the optical core sampling technology mentioned above, such micro/nano sensor clusters will enable further steps in minimally-invasive surgery.

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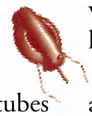
Once a tumour is located, a tiny accelerometer on the head of the scalpel would guide the surgeon to the exact site," explains Chrostowski. "On screen you could see where the tool is relative to the arterial wall, tumour site, etc."



Silicon nanowires and carbon nanotubes can also be used in biosensors to detect toxic substances, such as anthrax. The use of embedded nanosensors to measure load, temperature, pressure, moisture, and chemical emissions has broad application for forestry, mining and other industries. Environmental monitoring is an important area of interest for MiNa research. Carbon nanotube sensors can have several advantages over conventional sensors: they are compact, safe to operate, have low power consumption, and can potentially be very stable in a wide range of temperatures, humidity and gas flow variations.

Nanotubes can also be used for actuation. ICICS member John Madden (ECE) is making molecular actuators by spinning yarn from thousands of single-walled nanotubes (*FOCUS* Fall 2003). These "artificial muscles" are leading to breakthroughs in artificial organs, robotics and nanosystem fabrication. Madden's work also has applications for energy storage devices, such as batteries and automotive fuel cells. "Once you learn how to handle these nano materials, you can make all sorts of devices," notes Chrostowski.

With funding from NSERC, CFI and CIHR, MiNa researchers are using state-of-the-art facilities in AMPEL and ECE to develop novel methods to fabricate these emerging devices and to control fabrication at the nanoscale. "We are developing new methods of 3D fabrication and new ways of making nanodevices," Chrostowski states. Sounds simple. However, creating tiny powerful technology based on quantum properties of matter is anything but.

Lukas Chrostowski can be reached at 604.822.8507 or lukasc@ece.ubc.ca