TRANSFORMATIVE NANOTECHNOLOGY RESEARCH AT THE UNIVERSITY OF ALBERTA

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Building the new world and training the next generation of nanotechnology pioneers

The Province of Alberta finds itself at the centre of the nanotechnology revolution. Designated as an industrial priority, the Provincial Government recently announced a $130-million investment in nanotechnology, focusing on health care, energy, information communications technology, agriculture, forestry, and technology commercialization. A significant part of the funding package, included within the Alberta Nanotechnology Strategy, provides $15 million over the next five years to support graduate students and scholarships at Alberta's universities. We're training the next generation of nanotechnology pioneers.

Alberta's researchers are now among the leaders in the world, developing new ways to engineer structures at the molecular scale – making advancements that have the potential to transform society in medicine, energy, manufacturing, information processing, sensing and the environment.

Our University – one of Canada's largest and most research intensive universities – is at the core of this provincial strategy, and is now the nation's largest recipient, on a per-faculty member basis, of Natural Sciences and Engineering Research Council of Canada funds.

Building on those successes, we have attracted more than $153 million in nanotechnology-related research funding since the 2000-2001 academic year. Over 500 principal investigators, post-doctoral fellows and graduate students are now well supported.

Their work is intimately tied to the National Institute for Nanotechnology (NINT), established in 2001 as a collaborative project linking the University, the National Research Council of Canada and the Province. It is one of only six major nanotechnology research facilities of its kind in the world; three of the others are in the U.S., with the rest being in Europe and Asia. Today, as Canada's flagship nanotechnology institute, NINT has created a unique multidisciplinary environment in which research and knowledge creation thrive.

NINT is housed in a $63-million, 20,000-square-metre building in the heart of the University campus, and is world-renowned for its research facilities. It includes specialized spaces for laboratories in chemical and biochemical synthesis and analysis of the material structure at the atomic scale, as well as a Class 1000 Clean Room for the production of nanostructured systems. It is also equipped with the latest generation of scientific equipment, including electron and scanning probe microscopes, and chemical and material analysis instruments. And it is home to one of Canada's quietest laboratory spaces, ideal for conducting cutting-edge, collaborative work.

NINT provides opportunities for multi-disciplinary, cross-faculty collaboration. Researchers come from fields as diverse as physics, engineering, chemistry, biology, informatics, pharmacy and medicine. They join forces in a fertile, interdisciplinary environment, collaborating on studies ranging from photovoltaics to the building of a mass sensor that may be the most sensitive in the world.

And although NINT is at the core of much of the collaborative nanotechnology research at the University, the work fans out across our campus and it ranges from the highly theoretical to the markedly practical. As a consequence, we have been able to dramatically increase the number of faculty members involved in nano-related research. In a few short years, we have doubled our staff from 47 to 99 researchers.

We have also given them the tools to do the job by building and acquiring equipment and facilities unmatched in Canada. For example, we now have state-of-the-art micromachining and nanofabrication facilities, known on campus as the NanoFab. About 200 researchers are regular users of the lab, and some 800 people have used the facility over the last seven years, working with almost 100 pieces of essential equipment worth more than $20 million. Work conducted in the lab is predictably diverse: one project, undertaken by a group from mechanical engineering, is developing anti-wetting coatings to help water wick off spacecraft windows when they re-enter the atmosphere. A group of researchers from electrical engineering and oncology is...
Nanotechnology finds a home at the U of A

When the National Government of Canada went looking several years ago for an academic neighbour and home for the country’s National Institute for Nanotechnology (NINT), they looked, naturally enough, to the University of Alberta. The U of A had firmly established itself as a place where some of the country’s top nanotechnology researchers were doing exciting new work.

Established in 2001, NINT is operated as a partnership between the National Research Council and the University of Alberta, and is jointly funded by the Government of Canada, the Government of Alberta and the University.

NINT researchers are focused on the revolutionary work being done at the nano-scale, the world of individual atoms or molecules. The main focus of our research is the integration of nano-scale devices and materials into complex nanosystems that are connected to the outside world.

NINT’s building is one of the world’s most technologically advanced research facilities. Its researchers are focused on development and applications in the areas of:

- Synthesis and characterization of nanocrystals and nanowires
- Synthesis of supramolecular-based nanomaterials
- Fabrication and characterization of molecular-scale devices and nanosensors
- Development of nano-scaled materials for catalysis and directed chemical reactions at semiconductor surfaces
- Development of nano-electronic and nano-fluidic systems to interface devices to the outside world
- Theory, modeling, and simulation of nanosystems on multiple length scales
- Development of quantitative imaging and characterization techniques that support nanotechnology research
- Examination of the ethical, environmental, economic, legal and social issues of nanotechnology
- Research on nano-bioengineering such as protein design and genetic engineering of novel behaviours
- Development of nano-electrical mechanical systems (NEMS), such as lab-on-a-chip devices

The researchers’ work is focused around these interdisciplinary research groups: devices and sensors, engineered materials for energy, materials and interfacial chemistry, molecular scale devices, nano life sciences, supramolecular nanoscale assembly, electron microscopy and theory and modeling.

Some University of Alberta faculty members are cross-appointed to NINT and are conducting research that connects to and enhances these eight areas. The long-term objectives of NINT’s research plan are to discover ‘design rules’ for nanotechnology, and develop platforms for building nanosystems and materials that can be constructed and programmed for a particular application.

The realization of NINT’s goals, both long and short-term, will lead to important new applications and commercial opportunities, and will establish Edmonton as an internationally-recognized centre of nanotechnology research and industrial activity, attracting young scientists and graduate students of high calibre to continually increase the capabilities of the institute.
University of Alberta researchers are among North America’s leaders in interdisciplinary, cutting-edge nanotechnology innovations. Much of the driving force behind the building of tiny devices and features at the nanoscale is their importance for existing and emerging technologies such as microelectronics, nanoelectromechanical systems (NEMS), sensors and diagnostics which communicate directly with cells, viruses and bacteria, and a host of other applications.

Combining knowledge from fields as diverse as oncology, orthodontics and electrical engineering, approximately 100 U of A faculty are involved in nanotechnology-related research. They are poised to make historic changes in fields ranging from health care to microelectronics and the environment.

Many of the University’s nanotechnology researchers work in partnership with the National Institute for Nanotechnology (NINT), which is based at the University of Alberta. NINT is an integrated, multi-disciplinary institute involving researchers in physics, chemistry, engineering, biology, informatics, pharmacy and medicine. Established in 2001, it is a partnership between the National Research Council and the University of Alberta, and is jointly funded by the Government of Canada, the Government of Alberta and the University.

Here are some of the University’s top nanotechnology researchers and their key projects:

Dr. Robert Wolkow, U of A physicist and Principal Researcher at NINT:

- He and his team have proven the potential for constructing electronic circuitry on a molecular scale, a breakthrough that could remove the limitations of conventional transistor technology and pave the way for smaller, faster, and more environmentally friendly microelectronic devices. The study was published in the June 2005 issue of the scientific journal *Nature*. This advancement has long-term implications for electronics and sensors, including medical diagnostic devices.

Dr. Jillian Buriak, Department of Chemistry, internationally known expert in semiconductor surface chemistry and Senior Research Officer at NINT:

- He and the Molecular Scale Devices Group he leads at NINT have also created the world’s sharpest object – a tungsten needle tapering down to about the thickness of a single atom. In 2006 the American Institute of Physics named this achievement one of the top physics developments in the world. The team is also well along the way to constructing what it hopes will be the first holographic/tomographic microscope that has the ability to see atoms – an idea that was put forward by Dennis Gabor, Nobel laureate and inventor of holography, over half a century ago. However, until now, the ideal source he envisaged didn’t exist and wasn’t thought to be possible. The nanotip appears to be that ideal source of electrons.

- He is involved in another venture with U of A physicists Dr. Frank Hegmann and Dr. Mark Freeman. Hegmann is leading an inter-disciplinary project to combine the ultra-fast capabilities of lasers with the ultra-small capabilities of scanned probe microscopes. Hegmann’s goal is to make a scanned probe microscope that can probe molecules with ultra-fast time resolution – a very important capability when working at nanoscale.

Dr. Jillian Buriak, Department of Chemistry, internationally known expert in semiconductor surface chemistry and Senior Research Officer at NINT:

- She and her group are investigating ways to harness the properties of nanomaterials by “bonding” organic and nanoscale materials with silicon to allow for interfacing of computer-based technology (silicon chips) with biological tissues, functional nanoparticles and nanowires – for a range of applications.

- She and her group are exploring ways to manufacture the minuscule components in demand by today’s computer industry. Her team has demonstrated an innovative technique for producing conductive nanowires on silicon chips. The technique can produce wires that are 5,000 times longer than they are wide and meet the need for connecting ever-smaller electronic components. While the new process could provide the solution for computer manufacturers looking for ways to increase the speed and storage capacity of electronics, it could also mean cheaper electronics as well.

- She is working with Dr. Fabrizio Giuliani of the University of Alberta Hospital to understand what happens with neurons (electrically stimulated cells) in patients suffering from multiple sclerosis, a disease of the nervous system. The team is attempting to grow neurons on silicon chips so they can measure electrical activities in these cells and understand the basis of MS, a degenerative disease, with the hope of eventually finding a cure.

- She is conducting research in the area of photovoltaics – the conversion of solar energy into useable energy, such as electricity and hydrogen. She is using nanoscience to control matter on the atomic and molecular scale to produce cheap and efficient solar cells that can be produced via inexpensive manufacturing, and assembled anywhere.

Dr. Richard McCreery, chemist and specialist in the field of molecular-scale electronics, who is a Principal Researcher at NINT and teaches chemistry at the U of A:

- His group is investigating the behaviour of molecules or single-molecular layers as electronic circuit components, with the goal of developing new technology platforms for microelectronics. Such research could usher in an entirely new era in computer technology. Using organic molecules as active elements of microelectronic devices, possible application areas include:
• Computer memory (higher-performance memory chips)
• Computer logic (for example, processors)
• Chemical and biological sensing
• Interactions between electronics and photons (for example, display devices, fibre optic telecommunications, solar energy conversion)
• Molecular circuit components are potentially more versatile than existing microelectronics, and may lead to reduced cost and lower power consumption. A nano-sized memory device – a molecular “nanochip” – that was developed by McCreery’s team at NINT has been licensed to a Colorado-based, high-tech company, ZettaCore Inc., to integrate with silicon memory devices. ZettaCore researchers are testing the nano device in their memory prototype chip. It potentially has greater capacity, longer retention and lower cost than existing computer memory. The company is currently evaluating whether such devices can be reliably manufactured for commercial use.
• McCreery’s group is also building a unique facility for “hybrid electronics” in the NINT clean room, which draws on existing strengths in the U of A’s NanoFab lab as well as the resources of a national lab.

Dr. Linda Pilarski, oncology professor, and Dr. Chris Backhouse, engineering professor:
• They have developed a “lab-on-a-chip” for use in the treatment of cancer and detection of infectious agents. The device is in fact a microfluidic chip made of polymer and glass on a transparent rectangle about the size of a regular microscope slide. Pilarski has begun testing the device on clinical samples from patients with blood cancers, with results that accurately match those obtained using conventional methods; she and Backhouse have established a test using this novel technology that can detect genetic changes which lead to adverse drug reactions in children suffering from leukemia.
• They have established “FISH on a Chip,” a test that detects abnormalities in chromosomes – the cellular structures that contain our genetic material. Chromosomal abnormalities are found in many cancers and genetically transmitted diseases. FISH on a Chip can perform 10 different tests on a cancer sample for a total cost that is at least 10 times lower than the conventional “FISH” test – making this clinically important test widely available in any health-care facility, no matter how remote.
• With U of A medical microbiology and immunology professor Dr. Jutta Preiksaitis, Pilarski and Backhouse have developed microfluidic-chip tests that can inexpensively, accurately and quickly detect pathogens. The technology is being developed as a self-contained, automated device that could be used in any health facility, even those with irregular power supplies and limited or no access to clean water or sterile conditions.
• Dr. Backhouse is also collaborating with Drs. Duncan Elliot and Jim McMullin from the Electrical and Computer Engineering Department to put much of the functionality of a medical diagnostic lab on a single USB key. This requires a combination of photonics, nano-biotechnology, electronics, microfabrication and programming. They are working with Canadian industry leaders in the field, such as such as DALSA, Micralyne and iLOC.

Dr. Michael Brett, Electrical and Computer Engineering and a Principal Researcher at NINT:

His team and the Edmonton company Micralyne – which develops MEMS (micro-electro-mechanical systems) for specialized instrument makers worldwide – have developed a technology called GLAD, which stands for Glancing Angle Deposition.

This proprietary technology – voted one of the top 25 microtechnology/ nanotechnology innovative products for 2007 – is used to fabricate porous, thin films composed of engineered nanostructures. The technology can be applied to make a wide range of next-generation devices, including solar cells, optical devices and gas sensors.

Dr. Tarek El-Bialy, orthodontist, and Drs. Jie Chen and Ying Tsui, Department of Electrical and Computer Engineering:

They have created technology to regenerate human dental tissue, using low-intensity pulsed ultrasound housed in a miniature system-on-a-chip that offers a non-invasive means of stimulating jaw growth and dental tissue healing. The miniature wireless device can fit inside a patient’s mouth, beaming ultrasound waves to the area needing repair. The device can be used to prevent mechanical injury to teeth in patients who wear braces, a condition called progressive root resorption or shortening of the roots, and it can stimulate lower-jaw growth in patients with craniofacial problems. TEC Edmonton, the U of A’s tech transfer service provider, has filed a U.S. patent on the device and the researchers are working on turning their prototype into a market-ready model by the end of 2009. The team’s work has been quoted by many authors around the world.
Dr. Mark Freeman, physics professor and a member of the Devices and Sensors group at NINT:

He conducts research in experimental condensed matter physics and materials science at the micro- to nanoscale level, focusing on nonequilibrium physics in small structures, with an emphasis on magnetic systems. He was part of the first team to make direct, ultrafast time-resolved observations of ferromagnetic dynamics and has continued this work using specially developed instruments. Dr. Freeman is strongly interested in the development of ultra-fast scanning probe techniques to examine dynamic nanoscale processes, and has developed methods to extract picosecond-scale (one trillionth of a second) information from tunnelling microscopy.

Dr. Larry Kostiuk, chair of the Department of Mechanical Engineering:

Dr. Kostiuk’s general research interests are in the area of premixed turbulent combustion. Practical concerns for premixed combustion are in the efficient use of fossil fuels, formation of pollutants and the hazards from fires and explosions. Scientific concerns relate the understanding of the complex coupling that exists between fluid mechanics, thermodynamics and chemistry. His work has addressed important issues for both practical and scientific problems in combustion. Past research has been to develop models for the effect turbulence has on the burning rate and extinction of premixed flames, the dynamics and evolution of flame surfaces and effects of gravity on flames. This work has resulted in a strong interest and involvement in the associated areas of laminar combustion and non-reacting turbulent flows. Currently Dr. Kostiuk is working with industry on the development of Low NOx, high turn-down gas fired burners. He recently published, with Dr. Daniel Kwok, a study involving a new method of generating electric power by exploiting the natural electrokinetic properties of a liquid, such as ordinary tap water, by pumping fluids through tiny microchannels – creating a new source of clean, nonpolluting electric power with a variety of possible uses, ranging from powering small electronic devices to contributing to a national power grid.

Other Noteworthy Research

- The Department of Civil and Environmental Engineering is beginning to look at applying nanotechnology within the forestry sector, including the use of nanocrystalline cellulose (NCC), the basic structural building block of trees. This is spurred in part by widespread interest in the use of renewables as feedstocks for industrial processes and consumer products. To date, the forestry sector has used timber and wood mainly for its macro-scale properties in lumber and panels, and for its fibre-level properties in pulp and papermaking. At a very much finer scale, the NCC building block crystals have a range of remarkable properties. This research could lead to potential new applications and products.
- Nanotechnology is also being applied to construction materials in the Civil and Environmental Engineering Department. Cement-based material, fibre/wood-based material and pavement can be strengthened by:
  - Using an existing nanomaterial
  - Using nanotechnology as a bonding agent to create greater strength
  - Using nanotechnology to improve fibre-crystallized structure
- Dr. Rob Burrell in the Department of Biomedical Engineering is doing work in nanostructured biomaterials. Burrell, who is also a biologist, developed a fast-healing bandage that uses molecule-sized building blocks to heal wounds without leaving scars. He was the primary inventor of Acticoat, a silver-based wound dressing now used around the world. At NINT, he and his team have developed new nanostructures from clusters of silver atoms.
Dr. Tian Tang, assistant professor of Mechanical Engineering and Canada Research Chair in Nanomolecular Hybrid Materials, has research interests that interface with applied mechanics (such as solid mechanics, fracture, contact mechanics and adhesion, and statistical mechanics) and materials science (mechanical behaviour of materials and structures and micro- to nano-scales and in biological systems). Her areas of focus include the physics of carbon nanotubes and CNT-based devices, multi-scale modeling and simulation of nano-biomolecular hybrid materials, adhesion in biological and biomimetic systems, and statistical theory for the failure mechanism of compliant solids.

Dr. Dave Mitlin, of the Department of Chemical and Materials Engineering, is a Principal Researcher at NINT. His team is using nanotechnology to develop micro- and nano-engineered mechanical systems with energy applications.

Dr. Xiaodong Wang, professor in the Advanced Structures and Materials Laboratory in the Department of Mechanical Engineering, focuses on the mechanics of nanostructures and their multi-scale simulation. Current research is focused on the development of multiscale modeling and simulation methods and simulation of multiphenomena for nanoscience and engineering.

A bridge to the arts

The line between hard science and the arts becomes blurred in Nanosonatas, Volume 1, a piano composition written specifically for University of Alberta music professor Milton Schlosser by American composer Frederic Rzewski (pronounced ZHEFF'-skee). Schlosser commissioned the work through the U of A’s internal research grant program. He performed the world premiere of Nanosonatas late last year and the recital was recorded by Canada’s public broadcaster, CBC Radio.

The work reflects Rzewski’s interest in nanotechnology. He composed it after a physicist friend showed him a video of a rotating nanomotor. The composition consists of a series of seven, three-minute pieces which imitate the shifting speeds of the motor. Schlosser describes the avant-garde work as challenging – for both the performer and the listener. The blending of technology and music bridges the chasm between art and science. It also shows that, on a human level, technology has to have its expression in the arts as well, says the music professor.

Additional facts on nanotechnology in Alberta:

The current Alberta cluster of nano/micro companies includes

- Micralyne
- Big Bangwidth
- Norcada
- Quantum Technologies
- Aurora Nanodevises
- Applied Nanotools
- Nucristy Pharmaceuticals
- Umicore Canada
- Chiral TF
- Celnoex
- Dycor Technologies
- Raith
- Scanimetrics
- Sulzer Metco
- Indexable Cuttingtools
- MPB Technologies
- Advanced Integrated Microsystems

Example of excellence: Micralyne

- Created in 1982 as a U of A spin off company
- Privatized in 1998 as a MEMS manufacturer and independent foundry
- Its strengths today include MEMS components, microfluidics and thin film systems
- It employs about 160 people, including 40 engineers; six employees have doctorates, 18 have master's degrees and more than 50 have bachelor's degrees
- Annual revenues are about $20 million