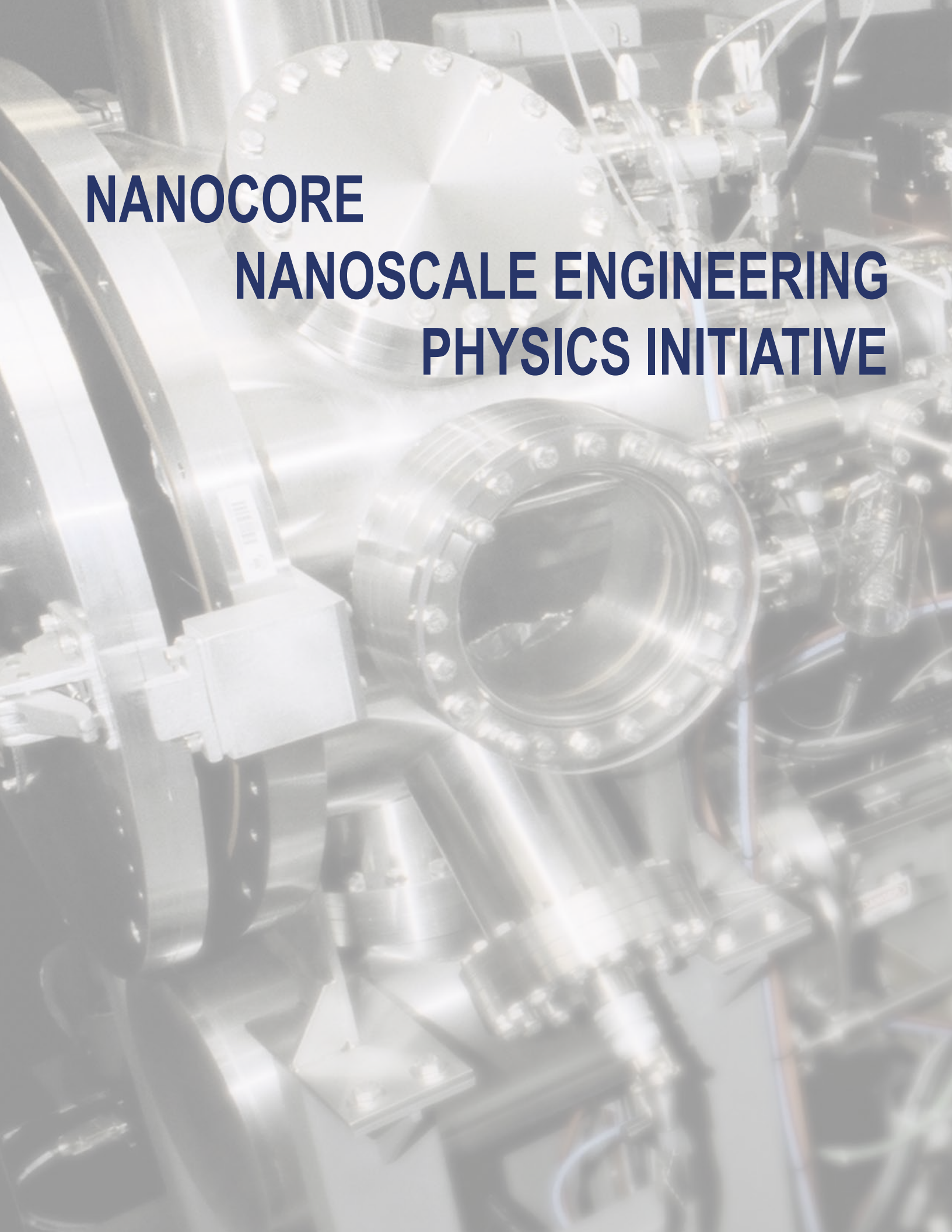
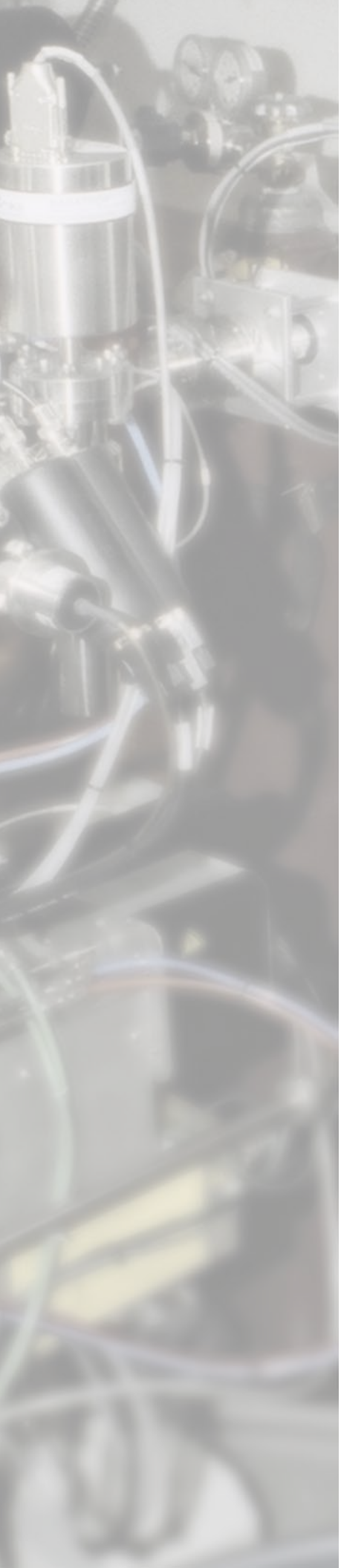


NANOCORE
NANOSCALE ENGINEERING PHYSICS INITIATIVE



MICHAEL BRETT

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The principal mission of Nanocore is to build upon existing strengths in nanoscale engineering physics to develop world-class expertise in selected areas of nanotechnology. Specifically, the areas can be summarized as nanofabrication methods related to thin film technology, and advanced characterization of nonequilibrium physical properties of nanosystems relevant to future ICT.

EXECUTIVE SUMMARY

The goals of the NanoCore and the iCORE/NSERC/Micralyne Industrial Research Chair are to develop world class expertise in selected areas of nanotechnology and develop device applications of nanoengineered materials, with assistance from industrial partner Micralyne. These goals are accomplished in parallel with the training of a large number of personnel at the forefront of nanoscience and engineering. Continued success in recruitment of research trainees has led to an outstanding group of graduate students. Of 18 graduate students directly supervised by Brett or Freeman, 13 have been awarded major scholarships from NSERC, or Alberta Ingenuity. Another measure of whether Nanocore/ICE are accomplishing their goals is the ongoing activity in Alberta by former Nanocore/ICE trainees. Over the past year, six trainees have taken their skills into the growing local Alberta nanotech industry.

Brett and Freeman continue their leadership in establishment, facilitization and operation of the University of Alberta Micromachining and Nanofabrication Facility (NanoFab), having received awards over the past two years (as principal or co-investigators) of infrastructure and operating support exceeding $20M from CFI, NSERC, ASRIP, and Western Diversification. As a result, the NanoFab facility is the best in Canada and now boasts in excess of 490 users from 109 research groups including 21 Alberta based ICT-related industries. Through Nanofab support and leadership, iCORE funding has played a key role in enabling the nucleation of 8 ICT-related firms in Alberta. Nearly 1/3 of Nanocore

funds are used to support personnel developing nanofabrication processes critical to other users

Within the scientific and engineering communities, Brett and Freeman each made several prestigious appearances at international conferences, such as invited talks at the Materials Research Society Symposium (Brett) and the American Vacuum Society (Freeman). Brett was recognized with ASTech Award for Outstanding Leadership in Alberta Technology, in part for establishing the University of Alberta NanoFab. In professional service, Freeman completed his term on the NSERC Grant Selection Committee for Condensed Matter Physics as Chair for 2003-04.

RESEARCH PROJECTS

Continuous upgrading of infrastructure is essential, and there are spectacular examples again this year. The showpiece $2M Raith electron beam writing tool was installed late in the year as part of the 2002 $8.3M CFI/ASRIP award (PI Brett), complemented by an upgrade of the existing modified scanning electron microscope. Raith now operates an office out of Edmonton to bolster their North American presence in this market. Our leadership in nanofabrication will be further solidified by the Integrated Nanosystems Research Facility (PI: Lynch with co-investigators Dew, Brett, Freeman), funded by CFI/ASRIP at $10.8M. Pursuing the ultimate physical limits of "top-down" nanofabrication, an ultrahigh vacuum, cryogenic (liquid helium) scanning tunneling microscope has been installed, allowing Alberta to enter the era of manipulation of individual atoms and molecules on surfaces. This cluster of nanofabrication expertise fostered by the NanoFab and by Brett and Freeman was an influential factor in locating the National Institute of Nanotechnology in Edmonton.

Michael Brett

Alberta is closely connected to national developments in nanotechnology through the Nanoelectronics Program of the Canadian Institute for Advanced Research. According to Chaviva Hosek, CIAR President and CEO, the University of Alberta enjoys the highest participation in this program of any university in the world (CIAR also admits foreign associates.) The Alberta members are Brett and Freeman from Nanocore, and Robert Wolkow, the iCORE Chair recruited through Nanocore in 2002-03. Brett and Freeman continue to work on planning within the National Institute for Nanotechnology, as members of a small group of existing University of Alberta researchers selected for this role in the formative years of the Institute.

Nanofabrication continues to be a key focus of the research programs. The patented Glancing Angle Deposition (GLAD) process developed in Brett's lab provides a remarkably simple way to engineer complex structures in thin film coatings on the nanoscale. These novel coatings are providing opportunities for team researchers to explore device applications where the nanoengineered structure and surface area provide advantages over conventional materials.

A high profile development was the demonstration of the first three-dimensional photonic crystal in a square spiral geometry by PhD students Scott Kennedy and Martin Jensen. This work, in collaboration with Dr Sajeev John of the University of Toronto, is exciting because of the potential promise for integrated optics capabilities, potentially leading to application in optical computing. This architecture of photonic crystal may be more readily manufactured and more amenable to intentional defect incorporation than other competing photonic crystal technologies. In related work involving ultrafast optical switching, Dr Jon Holzman and Dr Abdul Elezzabi have demonstrated integrated opto-electronic structures utilized to broadcast ultrahigh frequency signals. These devices are capable of broadcasting well into the terahertz regime, gaining international recognition for this capability.

Also utilizing nanoengineered structures in photonics, PhD student Andy Van Popta, with co-supervisor Dr Jeremy Sit and collaborator Dr Dick Broer of Philips Research Labs, has been optimizing the optical performance of helical structures with a goal of developing superior technology for energy efficient flat panel displays. PhD student Peter Hrudey has been

developing luminescent chiral materials, which are also a potential component for flat panel displays, and has demonstrated that nanostructuring can be utilized to improve the intensity of light coupled out of the coating.

Recent developments in nanofabrication include the ability to precisely fabricate nanofibres of 20nm diameter over lengths exceeding 5 μm, by PhD student Martin Jensen. The first polymer materials with chirality controlled on the sub-micrometre scale have been demonstrated by PhD student Anastasia Elias, in collaboration with Dr Kees Bastiaansen of the Technical University of Eindhoven. Dr Maria Stepanova, with Dr Steven Dew, has invented and implemented a new process to fabricate self-assembled metal dots, networks, and nanowires on non-metallic substrates. Each of these processes bring new flexibility and control to nanomaterials engineering.

Two projects have applied ICT-developed nanotechnology to the energy field. Dr Gregory Kiema and graduate student Mike Colgan have fabricated Graetzel solar cells based on porous nanostructured TiO_2 infiltrated with organic dye, and achieved conversion efficiencies up to 5 percent. Because of potential ease of fabrication and low cost, a further increase in efficiency could lead to a competitive product. Dr Jim Broughton with graduate student Barb Djurfors is utilizing the GLAD fabrication processes to develop porous electrode structures for application in supercapacitors, and have achieved state-of-the-art capacitance per unit mass. Such supercapacitors combine the energy storage capability of batteries with the fast discharge of capacitors, and can provide energy load-levelling in technologies such electric or hybrid cars. It is hoped that the GLAD process can enable cost-efficient fabrication.

In research with close involvement with industrial partner Micralyne, MSc students John Steele and Shufen Tsoi have demonstrated the operation of sensor devices with nanostructured surfaces that have been treated chemically or functionalized to optimize performance. For example, their humidity sensors afford greater sensitivity and significantly faster response than current commercial devices.

Sasha Krichevsky in Physics, in collaboration with Dr Brett, has tested ideas for streamlined procedures to fabricate magnetic memories exploiting the techniques of glancing angle deposition. Our pursuit of advanced methods of nanofabrication continued, focused on the goal of "routine" methods for patterning in the single-digit-nanometre regime.

Professors Hegmann and Meldrum are continuing to explore the potential of nanomagnetic systems. The nanomagnetic universe is remarkably rich and many possibilities for future devices remain to be explored. Magnonics aims to control the generation and propagation of very short (to less than 10 nm) wavelength magnetic oscillations by means analogous to the control of light in photonic crystals. These very small scales challenge us to develop new tools and methods required for their successful realization, a process which is always fertile with opportunity for other applications as well. In the case of magnonics, our "dream"

Michael Brett and Mark Freeman with some research team members at the 2004 Banff Informatics Summit

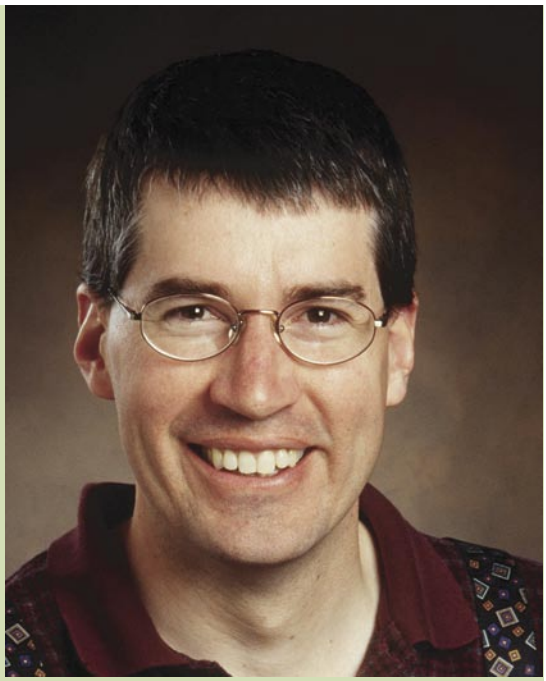
characterization tool is an ultrafast stroboscopic spin polarized scanning tunneling microscope(!). Already this goal has led to an additional project funded by the NSERC Nano Innovation Platform (Hegmann, PI; the only project in Alberta so funded) to explore the nature of electrical conduction through molecules at high speeds. Molecules are the building blocks for all of Nature's nanotechnology. Projects such as this one are conceptually related to our other activities by sharing the premise that the operation of all active devices is determined by the dynamic characteristics of the components. The speed of molecular conduction will not dictate whether or not molecular electronics has applications, but will play a pivotal role in determining which applications it may be suited for.

The extension of the building-block theme to include molecules and structures engineered on the sub-20nm scale over large areas is a natural evolution as the program continues and capabilities evolve to address smaller and smaller structures. A first project involving a linkage between magnetic and molecular systems was completed in 2003, in collaboration with Dr Ian Manners' group at the University of Toronto. This project investigated magnetic properties of nanostructures produced by direct electron beam exposure of an iron-bearing organometallic precursor material. The project involved participation of an undergraduate engineering physics major Jason Sorge, who has since gone on to graduate studies with Dr Brett.

A great deal of progress in the area of nanomagnetic building blocks has been made by postdoctoral fellow Xiaobin Zhu, recruited directly into Nanocore in 2003 and now also the holder of an Alberta Ingenuity Fellowship. He is elucidating the dynamic behaviour of a variety of configurations of magnetostatically-coupled magnetic nanostructures. Dr Zhu has been comparing the dynamic behaviour of nanodisks and nanorings. Both are of interest for applications on account of their circulating magnetization patterns, which minimize the stray-field coupling between adjacent particles. However, the fact that the disk supports a vortex core but the ring does not, leads to a fundamental difference in the dynamic response.

Dr Won Kee Kim, a Nanocore-supported postdoc working with Dr Marsiglio, is performing theoretical studies of related phenomena.

We have continued measurements of the ultrafast response of nanocrystalline composite magnetic materials. The emphasis has been on materials created through ion implantation and annealing, continuing the experimental work of Kristen Buchanan who has concentrated on theoretical and numerical modeling of these systems while writing her PhD dissertation during the past year. Buchanan has captured the essential details of the ultrafast response in a simple model. Using a material from Dr Meldrum, our present record response time of 16 ps has been demonstrated (at room temperature in zero magnetic field bias, the environmental conditions necessary for a sensor application.)



Mark Freeman

RESEARCH TEAM MEMBERS

Team Leaders

ROLE	TOPIC	AWARDS/SPECIAL INFORMATION
Dr Michael Brett	iCORE Professor and iCORE/NSERC/ Micralyne Industrial Research Chair, Canada Research Chair	ASTech Award for Outstanding Leadership in Alberta Technology (2003) Associate Member, CIAR Program in Nanoelectronics (2002)
Dr Mark Freeman	iCORE Professor, Canada Research Chair	Associate Member, CIAR Program in Nanoelectronics (1999)

Faculty Team Members

ROLE	TOPIC	AWARDS/SPECIAL INFORMATION
Dr Chris Backhouse	Microfluidic devices	
Dr Steven Dew	Microfabrication process technology	Killam Annual Professor
Dr Abdul Elezzabi	Ultrafast photonics	McCalla Professor
Dr Jeremy Sit	Nanostructure devices	
Dr Ray Egerton	Electron microscopy of thin films	Distinguished Physical Scientist, awarded by Microscopy Society of America (2004)
Dr Frank Hegmann	Terahertz spectroscopy	
Dr Frank Marsiglio	Superconductivity	
Dr Al Meldrum	Nanoparticles and nanomaterials	

Postdoctoral Fellows

ROLE	TOPIC	AWARDS/SPECIAL INFORMATION
Dr Mark Roseman	Nanoscale Physics	Now at NSERC Nano IP
Dr Xiaobin Zhu	Ultrafast microscopy	Ingenuity Fund Fellowship
Dr Yan Pennec	Temp. dependent magnetic damping	
Dr Jim Broughton	Supercapacitors	
Dr Greg Kiema	Microfluidic materials	
Dr Doug Vick	Nanostructure growth	
Dr Jon Holzman		NSERC PDF, Canada Governor Gen. Gold Medal
Dr Maria Stepanova	Ion beam nanostructuring	
Dr Ken Harris	Perforated materials	NSERC PDF

PhD Students

ROLE	TOPIC	AWARDS/SPECIAL INFORMATION
Grey Arnup	Single-shot ultrafast microimaging	
Miroslav Belov	Spatial control of modal oscillations	AIF Fellowship
Jason Blackstock	Molecular electronics	NSERC Julie Payette Scholar
Robert Bryce	Colloids in microfluidics	NSERC Industrial Award
Kristen Buchanan	Nanocrystalline magnetic composites	NSERC PDF – Argonne National Laboratory
Sacha Krichevsky	Dynamic switching "astroids"	PDF at Naval Research Lab
Zhigang Liu	Numerical simulation of magnetization dynamics	
Allan MacDairmid	Bio-inspired macromolecular nanowires	NSERC PGS-B
Barb Djurfors	Nanostructure characterization	I. Killam Schol.; D. Killam Schol; DB Robinson Schol
Scott Kennedy	Photonic crystal fabrication	NSERC PGS-B, iCORE
James Gospodyn	Chiral optic ellipsometry	
Peter Hrudey	Luminescent nanostructures	NSERC PGS-A; iCORE
Anastasia Elias	Replica nanostructures	NSERC CGS; Ingenuity; iCORE
Martin Jensen	Photonic crystal devices	Ingenuity; iCORE
Mary Seto	Mechanical nanostructures	AIF Fellowship, Micralyne
Andy Van Popta	Chiral photonic devices	NSERC PGS-A; iCORE

MSc Students

ROLE	TOPIC	AWARDS/SPECIAL INFORMATION
John Steele	Sensor devices	
Mark Summers	Photonic crystal materials	eMPOWR Scholarship

Other Team Members

ROLE	TOPIC	AWARDS/SPECIAL INFORMATION
Dr Mirwais Aktary	Nanolithographic process development	Applied NanoTools, Raith
Dr Mohammed Hedayatipoor	Dielectric measurements of proteins	Visiting Professor
Dr Marek Malac	Patterning of permalloy structures	Now at NINT
Matthew Hawkeye	UG student researcher	
Doug Gish	UG student researcher	Ingenuity studentship
Tze Luck	Summer student researcher	NSERC Summer Student
Bryan Szeto	Summer student researcher	NSERC Summer Student
Cindy Blois	Summer student researcher	
Michael Cook	Summer student researcher	
Jon Klippenstein	Summer student researcher	NSERC Summer Student

ROLE	TOPIC	AWARDS/SPECIAL INFORMATION
Daniel Salamon	Summer student researcher	Now at NINT
Jason Sorge	Summer student researcher	NSERC Summer Student
Karin Hayward	Administrative Assistant	
Ben Bathgate	Technician	
Stephenie Bozic	Nanofabrication specialist	
Lynn Chandler	Administrative Assistant	
David Fortin	Administrator/Technical	

Nanocore Supported Graduate Students of Affiliated Researchers

ROLE	TOPIC	AWARDS/SPECIAL INFORMATION
Shufen Tsoi	Surface functionalization	
Ken Chau	GHz Optical Modulator	NSERC CGS; iCORE; Ralph Steinhauer Award
Michael Cummings	Ultrafast carrier dynamics	
Lucian Covaci	Numerical simulations of surfaces and nanoscale superconducting devices	
Fatih Dogan	Electron-phonon systems using DMRG method	
Aaron Hryciw	Light-emitting nanocrystalline silicon	
Peng Li	Radiation damage to organic compounds	
Aaron Slepkov	Nonlinear optical properties of organics	NSERC PGS-B
Simona Verga	Researching nanoscale superconductivity	
Feng Wang	Magnetic nanoparticles	Killam

COLLABORATIONS

NATIONAL
Professors Hegmann and Meldrum have made exciting advances related to nanophotonics and optoelectronics in projects with the Canadian Institute for Photonic Innovation and supported by iCORE. Hegmann's group has applied their powerful terahertz spectroscopy method to non-contact measurements of conductivity in quantum dots arrays and quantum wires. Meldrum's group has demonstrated a powerful technology for tailoring the emission wavelength of silicon nanocrystal-based luminescent materials.
Xiaobin Zhu's project on nanomagnetic building blocks includes collaboration with Professor Peter Grutter of McGill University, Director of both the CIAR Nanoelectronics Program and of the NSERC NanoIP. Graduate student Zhigang Liu is providing great micromagnetic modeling support for this project.
A project involving a linkage between magnetic and molecular systems was completed in 2003, in collaboration with Dr Ian Manners' group at the University of Toronto.
We are also collaborating with Prof. Heinrich of Simon Fraser University to understand the dynamic coupling between magnetic elements in structures consisting of multiple vertical layers, alternating between magnetic and nonmagnetic materials.
INTERNATIONAL
Mirwais Aktary is collaborating with Dr Tanaka from Shizuoka, a synthetic organic chemist, to elucidate the "rules of thumb" through which structure determines resolution for electron resists.
Mr Liu has also collaborated with the Brookhaven National Laboratory team of Yimei Zhu (in particular Dr Marco Beleggia, who made an extended visit to Alberta in September) on the analytic computation of stray fields in "non-ideal" geometries.
INDUSTRIAL
Jason Blackstock has continued his collaboration with HP Labs to produce well-defined structures for the study of molecular conduction, using an approach that could ultimately be ported into a production environment (that is, does not require surface preparation in ultrahigh vacuum.) Spin-offs of Blackstock's innovative research are also leading to exciting cross-fertilization with other projects. The methods hold significant promise for qualitatively expanding the range of materials that can easily be introduced into ultrahigh vacuum for fundamental measurements.
Also utilizing nanoengineered structures in photonics, PhD student Andy Van Popta, with co-supervisor Dr Jeremy Sit and collaborator Dr Dick Broer of Philips Research Labs, has been optimizing the optical performance of helical structures with a goal of developing superior technology for energy efficient flat panel displays.

INTELLECTUAL PROPERTY

Opportunities for commercialization of devices developed in the ICE program (sensors, supercapacitors) are being considered by spinoff firm ChiralTF Devices Inc., a joint initiative of the University of Alberta and Micralyne.

FUNDING

The Michael Brett and Mark Freeman teams receive funding from many sources in addition to the iCORE Research Professorships for both Brett and Freeman and an Industry Chair for Michael Brett. The Industry Chair is supported by iCORE ($100K/year), NSERC ($140/year) and the company Micralyne ($115K/year in cash plus additional in-kind contributions). Brett and Freeman both hold Tier 1 Canada Research Chairs, which contribute $400,000 per year to the research team. They are building and supporting NanoFab, which is an open fabrication laboratory that is supported by CFI (~$9M), ASRA (~$8M) and WED (~$1M). They also receive funding from NSERC, CIAR and CIPI and have close links to the National Institute for Nanotechnology ($120M).

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