



Nanoscience and Nanotechnology at McMaster University

A Model for an Interdisciplinary Approach

**Arizona Nanotechnology Symposium: Small is
Big**

April 10, 2008







McMaster University

- Established in 1887
- 65 km SW of Toronto / 70 km SE of Waterloo
- 21,000+ undergraduate and graduate students
- 1,170+ full-time faculty (96% with PhD)
- 6 Faculties – health sciences, engineering, business, humanities, science, social science
- 140 undergraduate degree programs
- Students & faculty from 70+ countries
- 40+ international exchange agreements
- Among the Top 10 best places to work in academia (*The Scientist*)



McMaster
University



M. I. N. I.

MCMaster INITIATIVE in NANO INNOVATION



CEDT

Centre for Emerging Device Technologies

Devices

Systems

Materials

**Micro- and Nano-
systems Laboratory
(CFI/ORF RI 2007)**



ONTARIO
PHOTONICS
CONSORTIUM

 Brockhouse Institute
for Materials Research



ccem

Canadian Centre for Electron Microscopy



FACILITIES

Materials Growth

- **Molecular Beam Epitaxy**
– **AlInGaAsPSb(N)**
- **ICP-PECVD with *in-situ* Ellipsometry**
- **ECR-PECVD**
- **RF-Magnetron Sputtering**
- **Laser Ablation**
- **Pulsed Laser Deposition**

**Photonic and
Optoelectronics
Integration and
Packaging**

Materials Characterization

- **Photoluminescence**
- **Electroluminescence**
- **Electron Microscopy**
 - **X-ray Diffraction**
 - **Hall Effect**
- **Positron Annihilation**
 - **Spectroscopic and Scanning Ellipsometry**
- **Thin Film Stress Measurement**
- **Surface Profilometry**
 - **Scanning Photoluminescence and Reflectance**
- **Nuclear Magnetic Resonance**

Device Fabrication

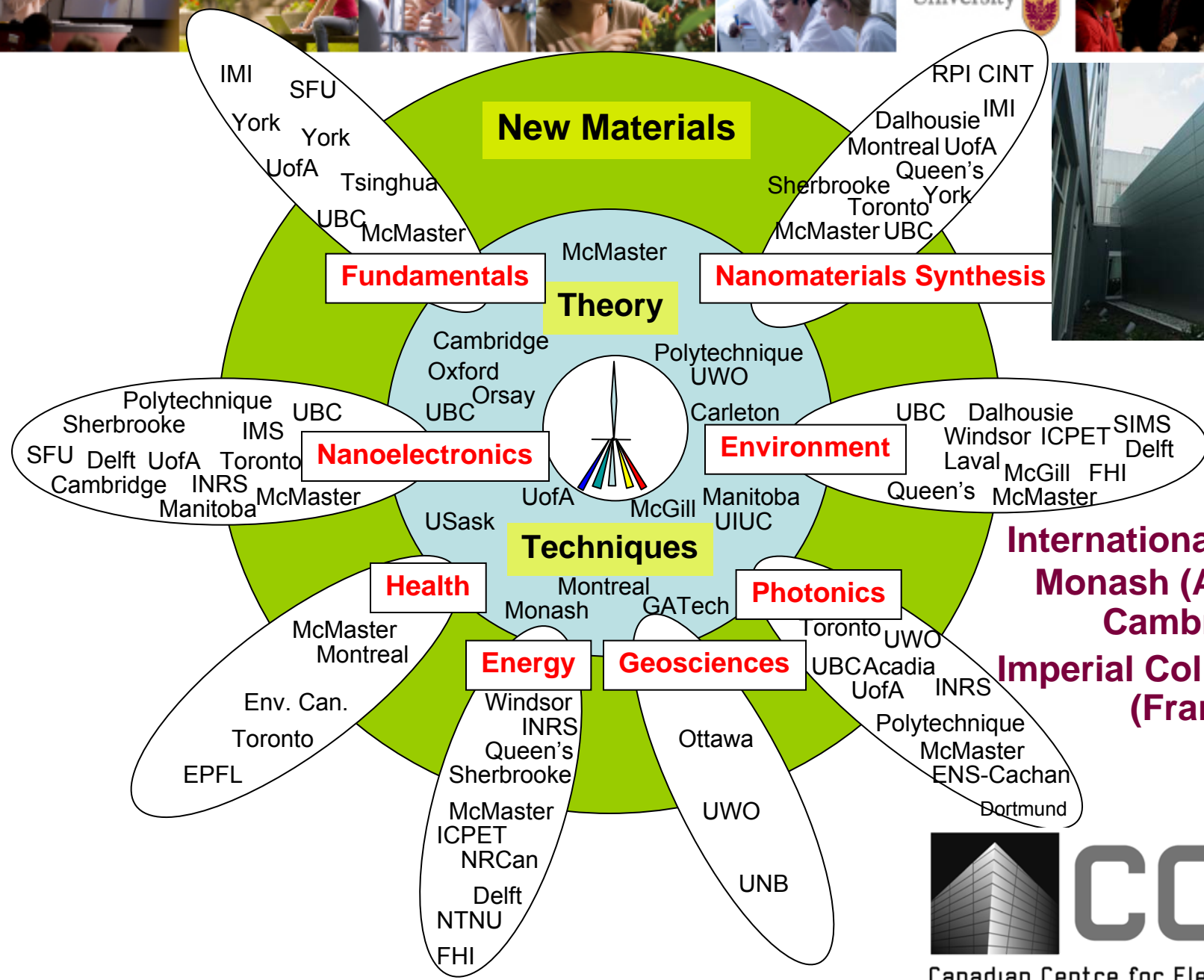
**Mask Design
Device Modelling**

Clean Room Facilities:

**Photo- and e-beam
lithography
FIB
Metallization
Reactive Ion Etching
Holographic Gratings**

Device Testing

**High-speed/high-
frequency
Reliability Studies
Bio-electromagnetics
“Quiet” Environments**



International outreach:
Monash (Australia),
Cambridge,
Imperial College, Rouen
(France)

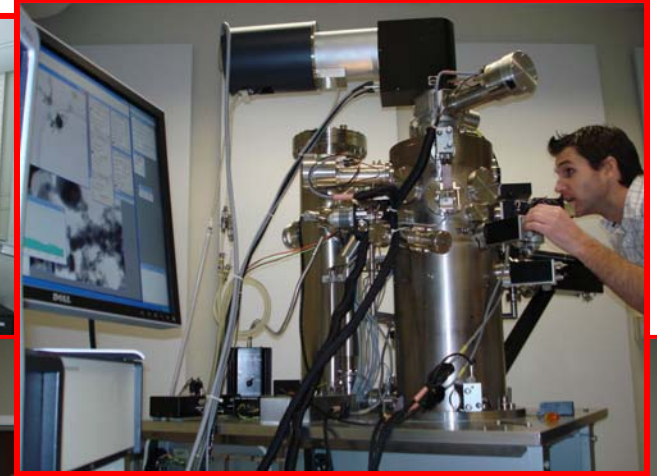


ccem

Canadian Centre for Electron Microscopy



The Canadian Centre for Electron Microscopy



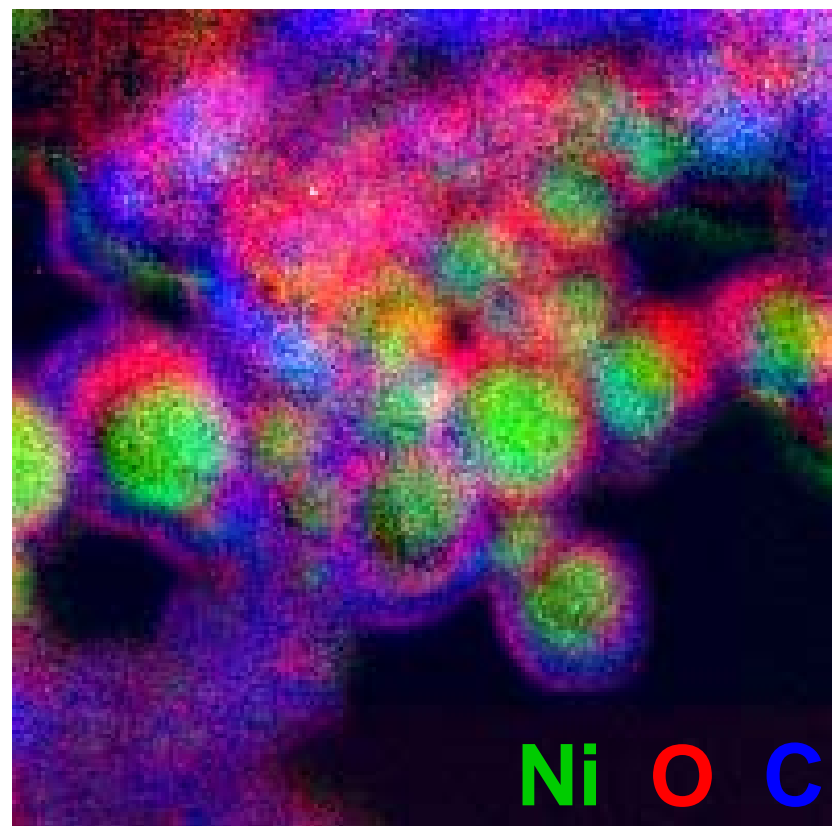
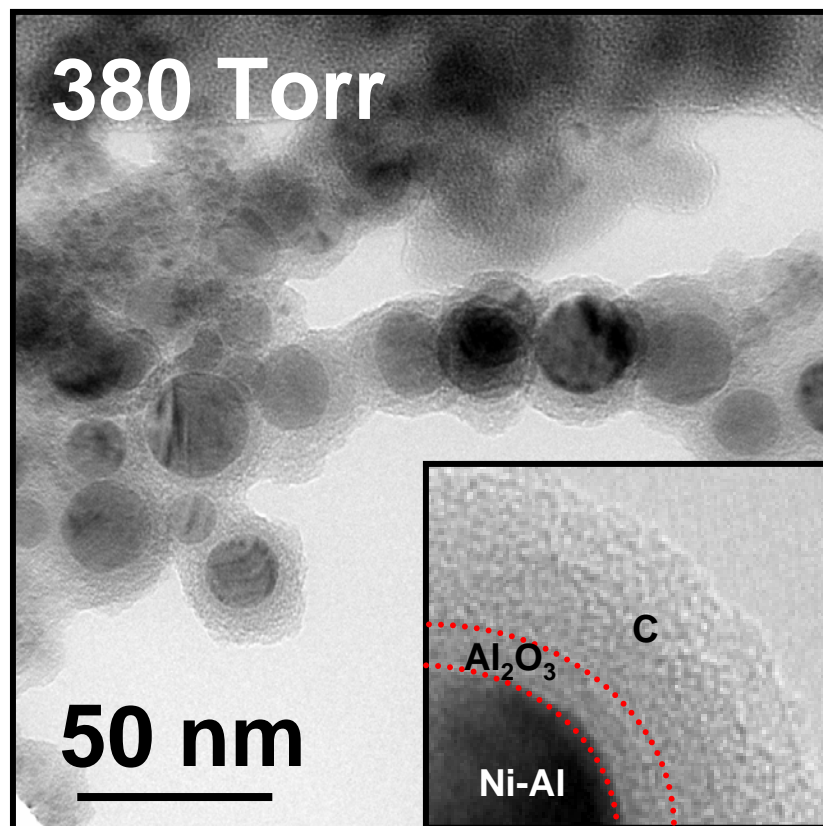
2 FEI Titans:

- 1) double correctors and monochromator
- 2) image corrector and monochromator, laser

JEOL 2010F, STEM HB601 Cryo, JEOL 7000F SEM, CM12, Zeiss NVision FIB/SEM



Elemental Analysis of Nanoscale Structures



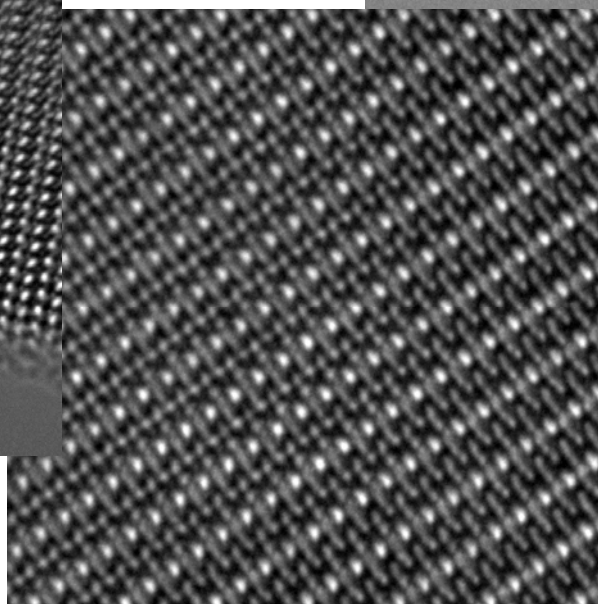
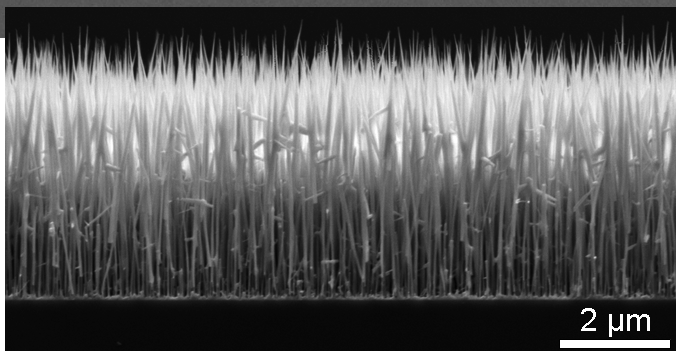
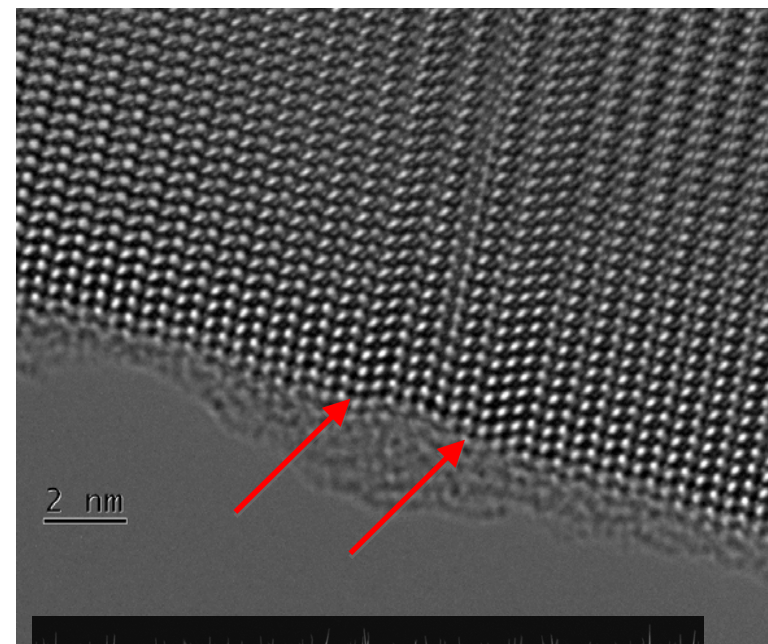
G. Botton's Group: N. Braidy, PhD student, C. Andrei, PDF
Collaboration with R. Hughes and J. Preston, PLD Laboratory, BIMR



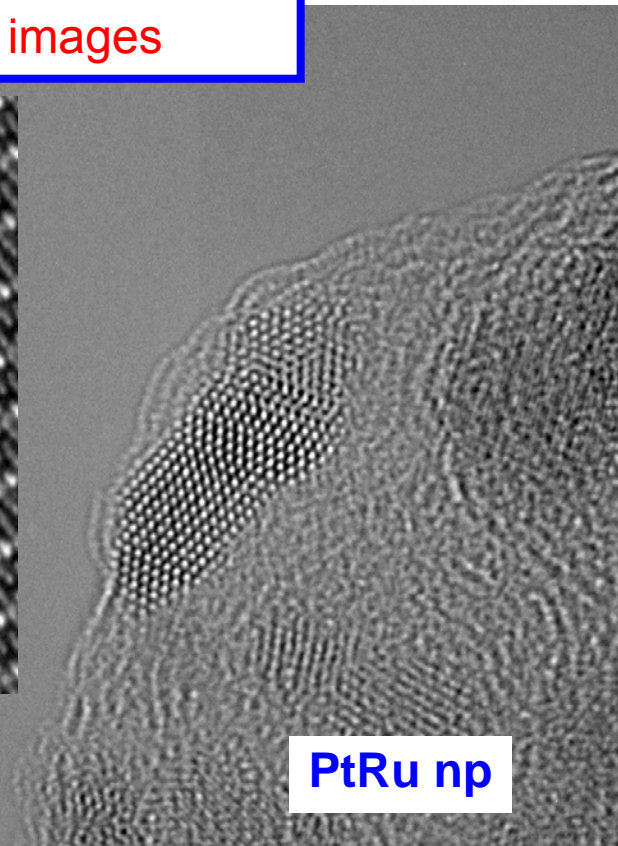
GaAsP Nanowire

Aberration-corrected Imaging

Cs (image) corrected Titan
HRTEM images



LaBaCuO



PtRu np

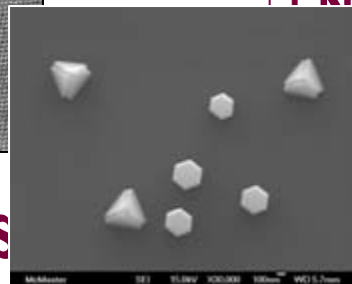
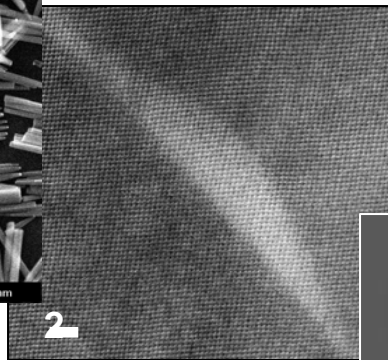
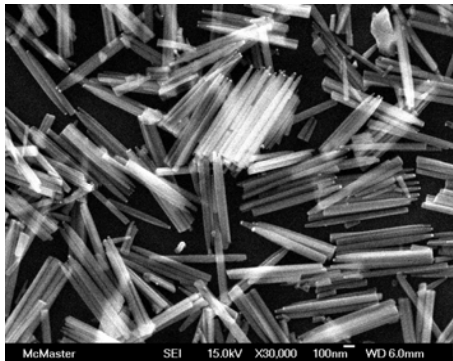
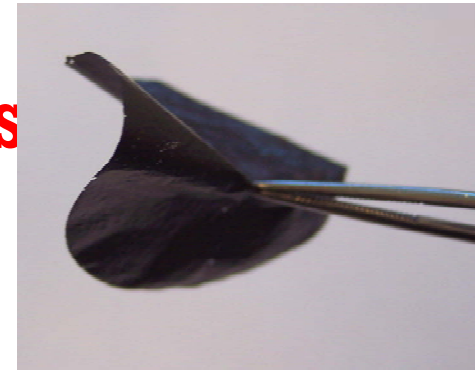
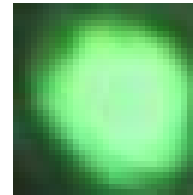
Collaborations between synthesis and characterization experts



MAJOR FOCUS AREAS

❑ ELECTRONIC AND OPTICAL MATERIALS

- ❑ Functionalized Carbon Nanotubes
- ❑ Silicon Nanostructures
- ❑ III-V and II-VI Quantum Structures



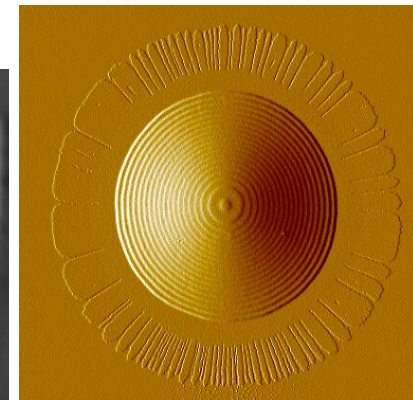
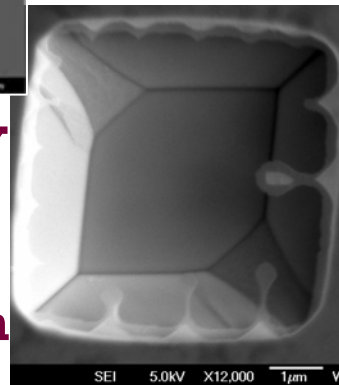
❑ NANOSTRUCTURED DEVICES

- ❑ Wireless Sensors
- ❑ Superlattice Photodetectors
- ❑ Nanoelectronics-based Bio-imaging
- ❑ Nanowire-based Photovoltaics
- ❑ Silicon Photonic Circuits

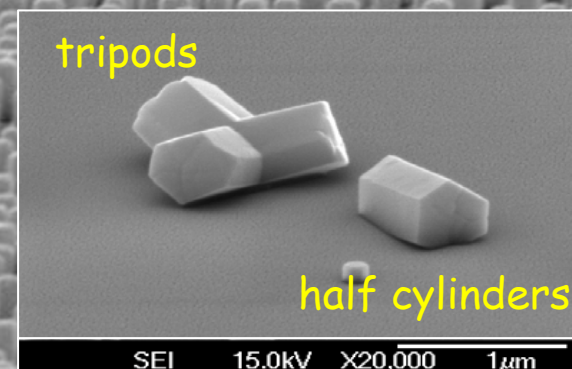
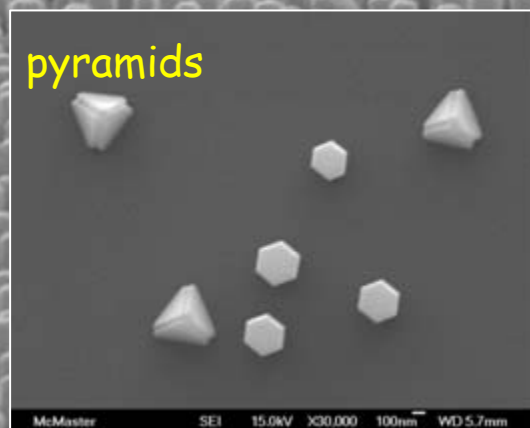
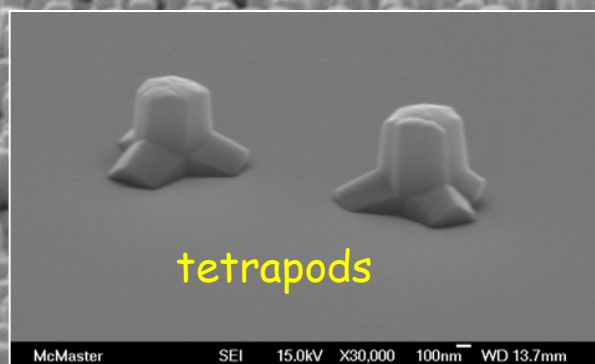
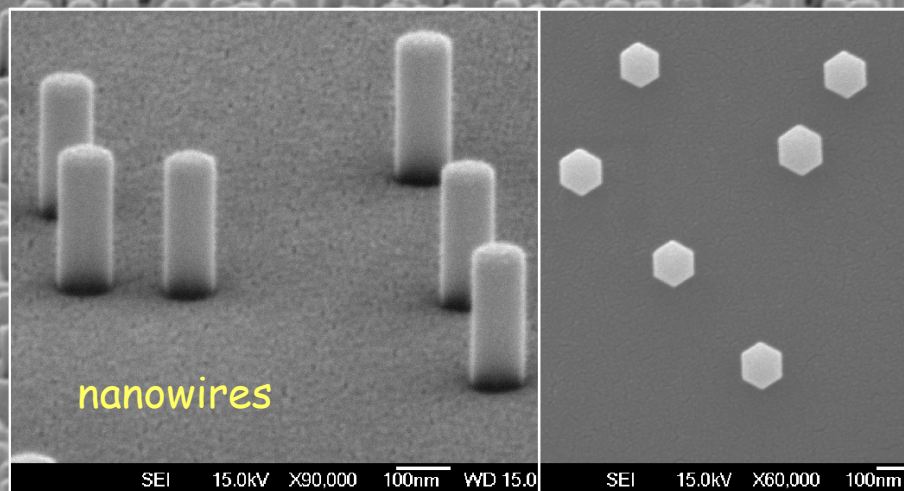
❑ MEMS and BIO-MEMS

❑ POLYMER NANOTECHNOLOGY

- ❑ Crystallization
- ❑ Confinement
- ❑ Self-assembly and Pattern Formation



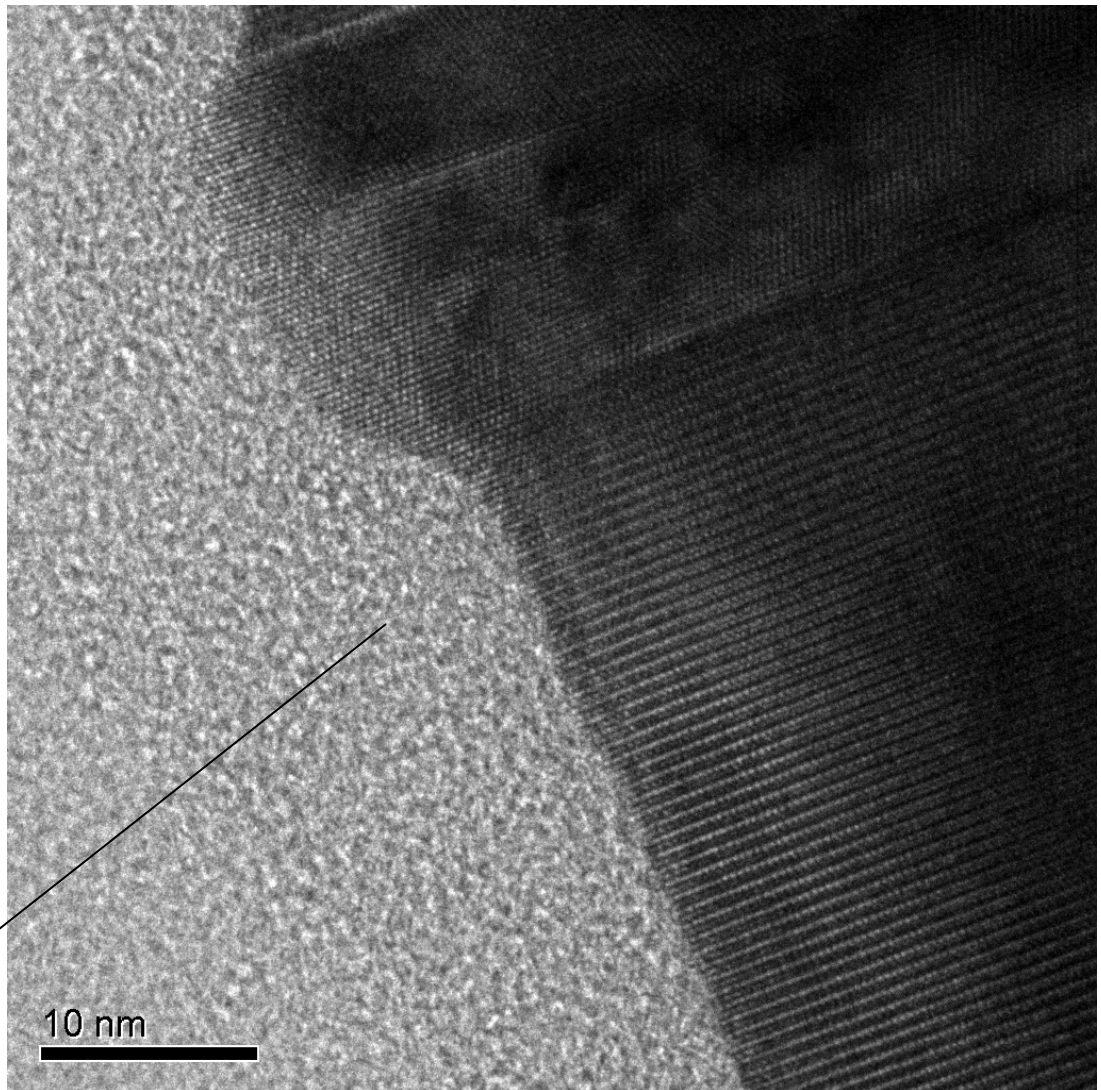
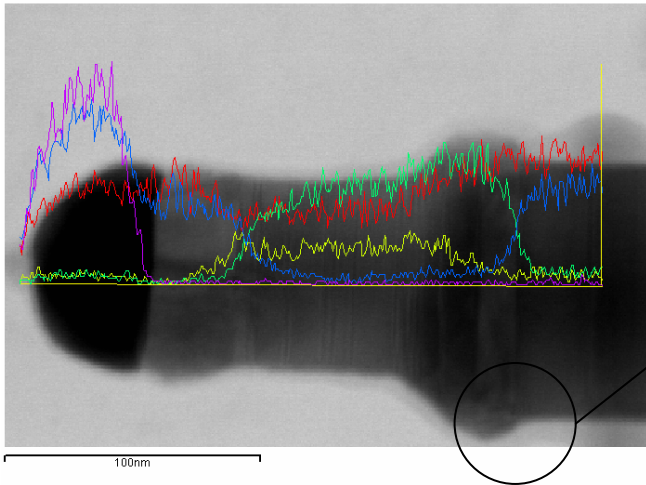
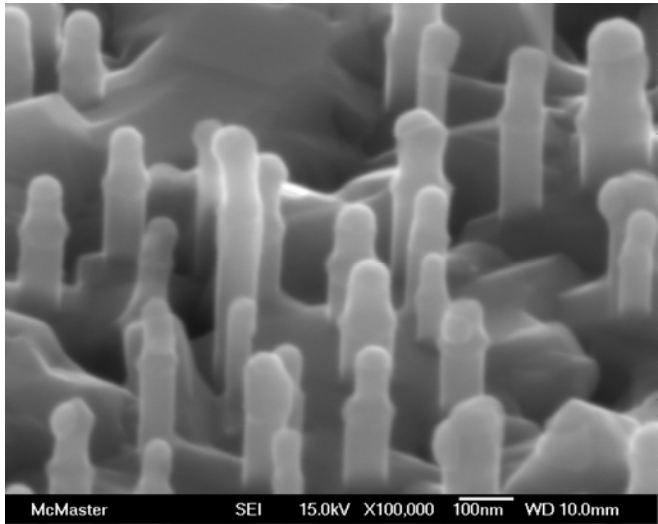
CdTe Nanowire Structures





Nanowire structures: $\text{InP}/\text{InGaAs}/\text{InP}$

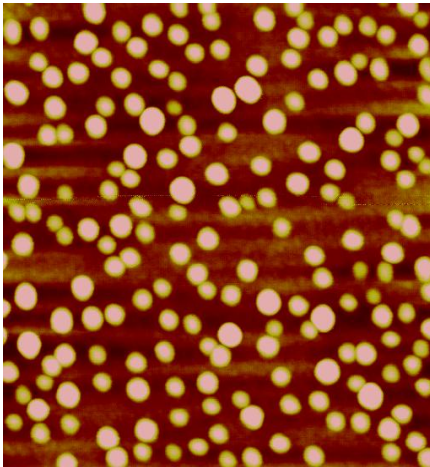
R.R. LaPierre
G. Botton



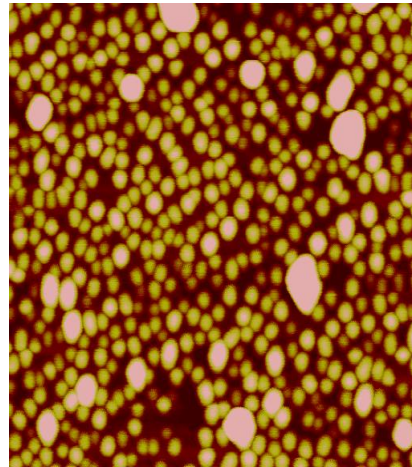


InAs Quantum Dots (GS-MBE)

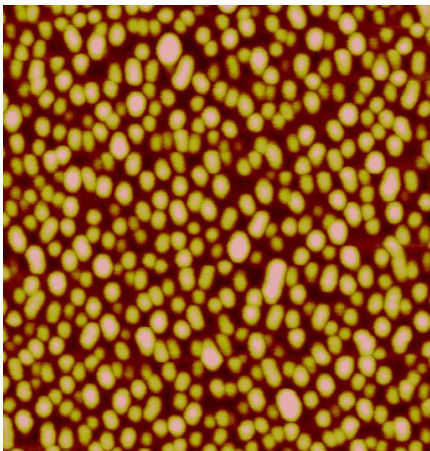
D.A. Thompson and S. Tavakoli



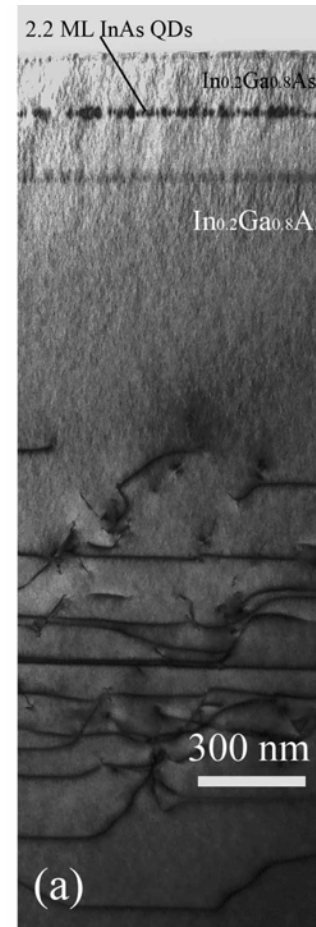
D (Diameter) = 22.1 ± 0.15 nm
H (Height) = 10.03 ± 0.70 nm
 ρ (Density) = 8.04×10^{10} cm⁻²



D = 16.36 ± 0.08 nm
H = 9.14 ± 0.65 nm
 $\rho = 1.30 \times 10^{11}$ cm⁻²



D = 19.34 ± 0.10 nm
H = 9.23 ± 0.65 nm
 $\rho = 1.87 \times 10^{11}$ cm⁻²

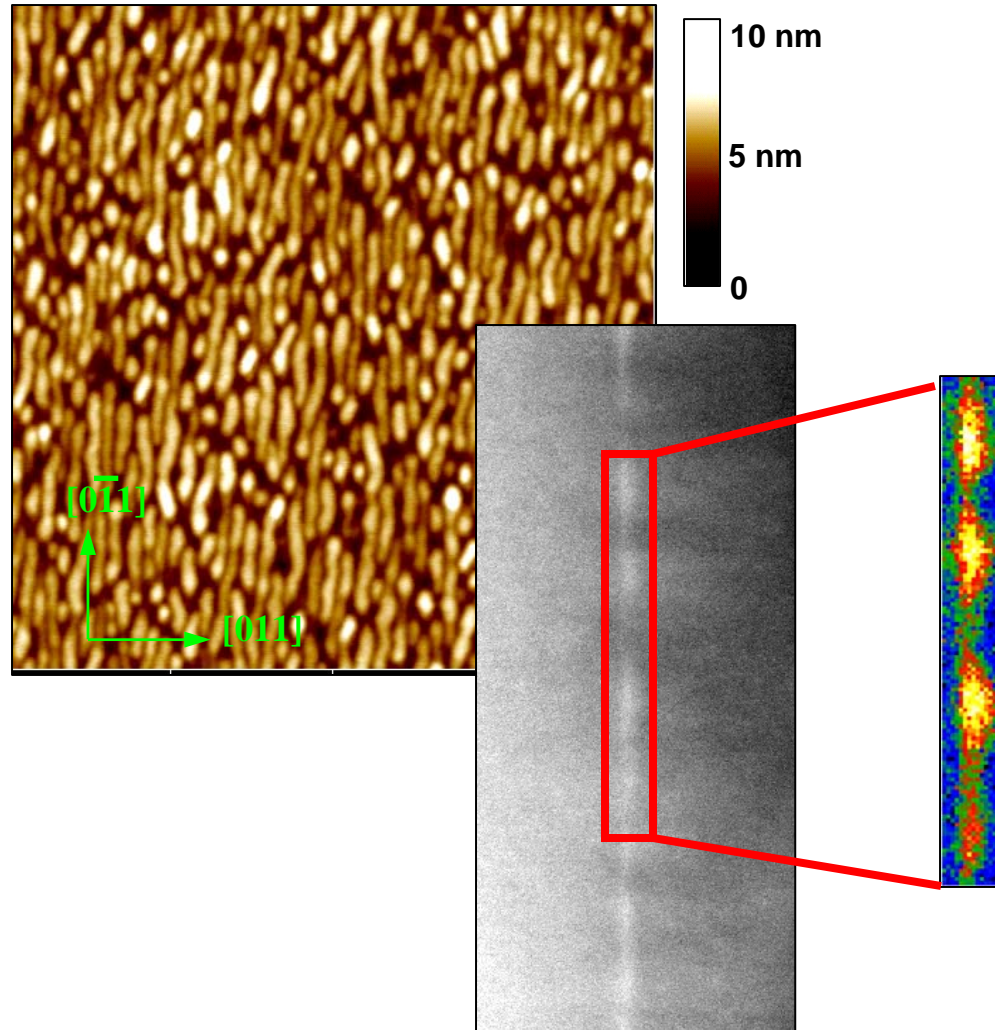
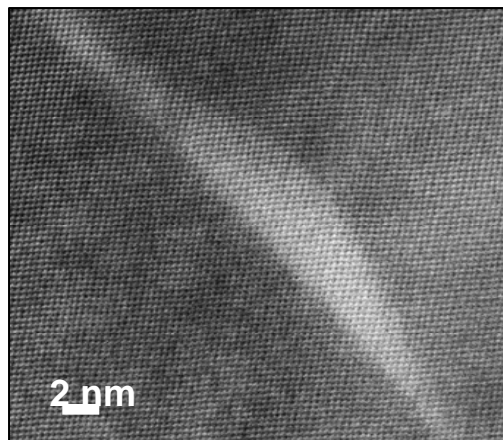
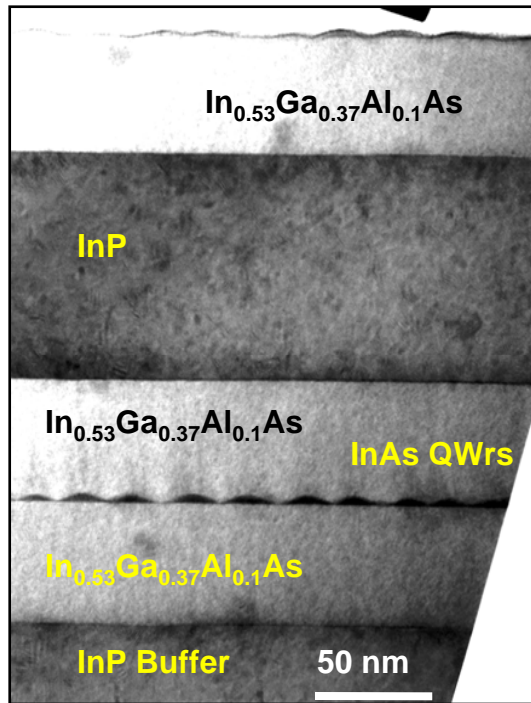


Room temperature PL from QDots:
Growth on meta-morphic layers



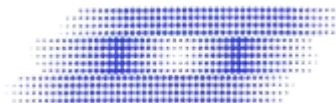
InAs Quantum Wires (GS-MBE)

D.A. Thompson, K. Cui and G. Botton



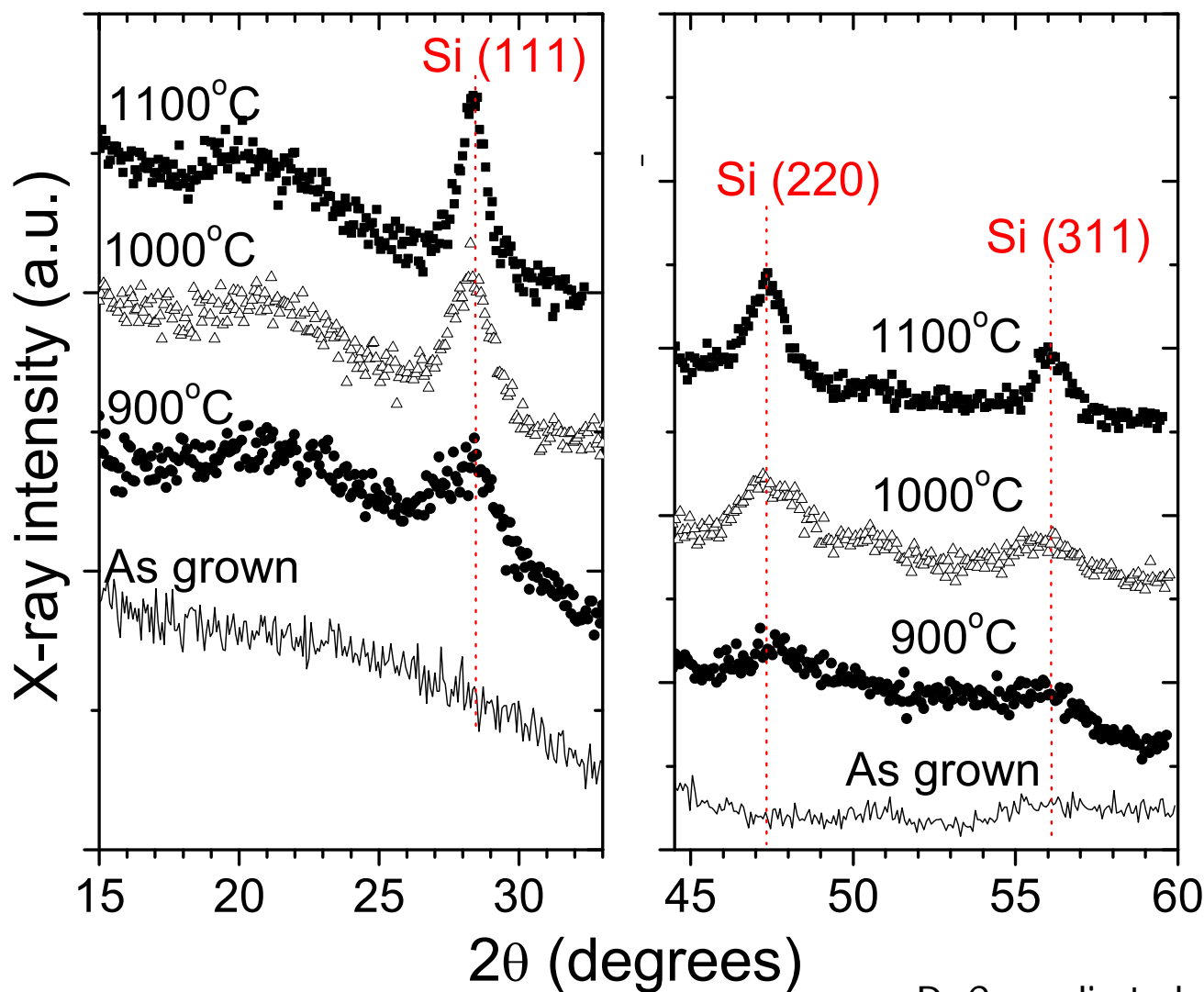


Si nanocrystal formation



CEDT

Centre for Emerging Device Technologies



$a\text{-Si}_y\text{O}_{1-y}$
 $y=0.45$

$t=2\text{ h}$

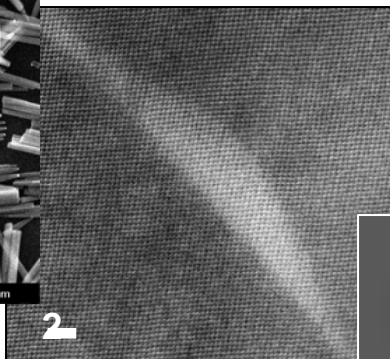
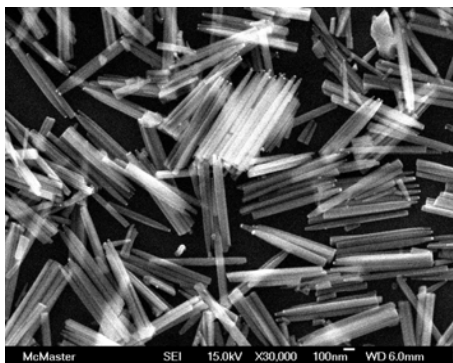
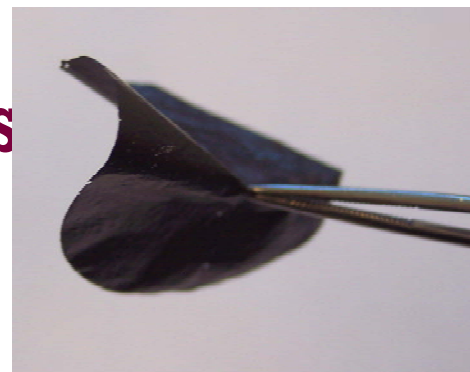
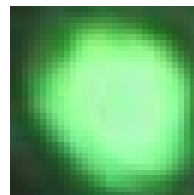
Glancing-
angle X-ray
diffraction



MAJOR FOCUS AREAS

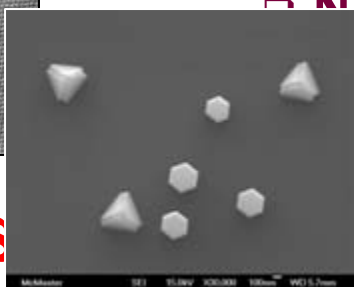
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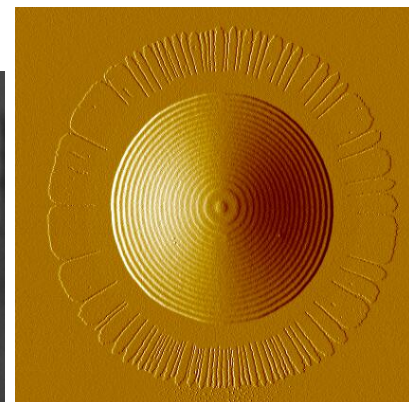
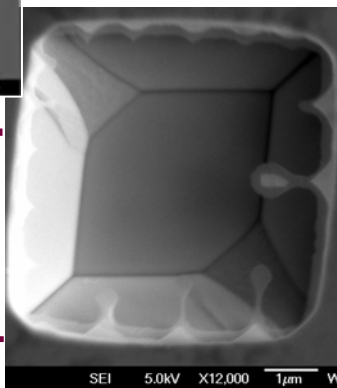
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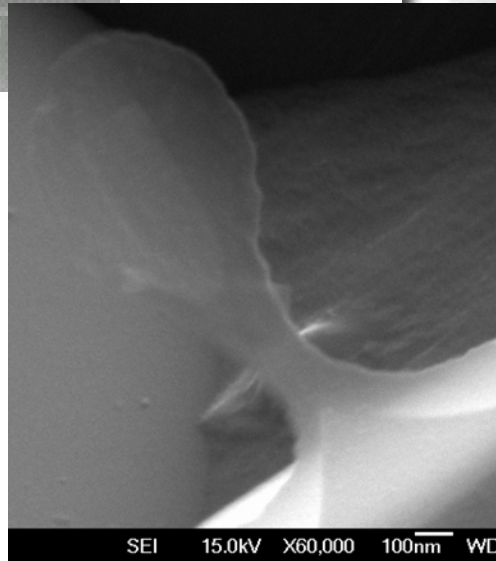
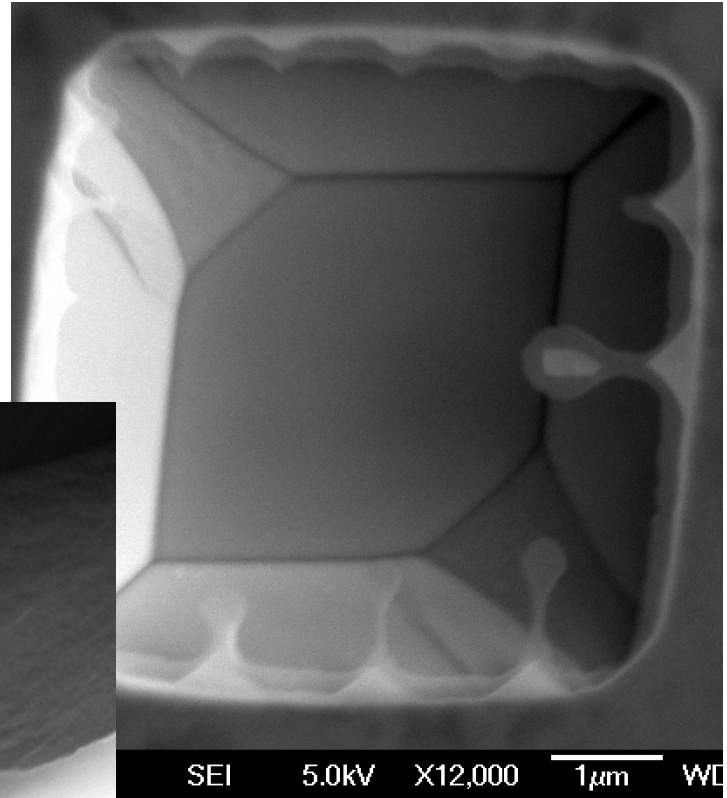


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Rafael Kleiman's Group

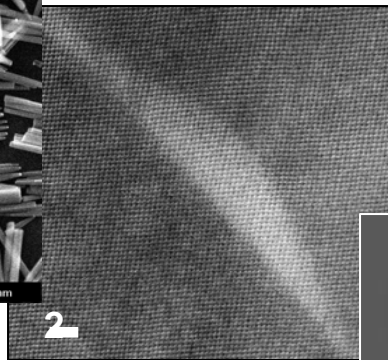
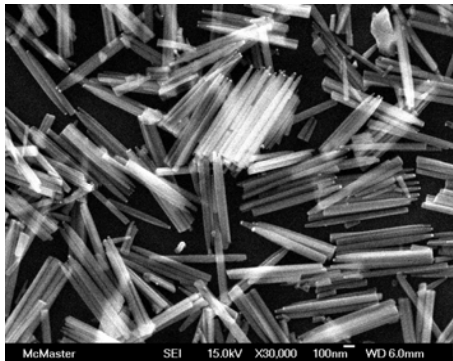
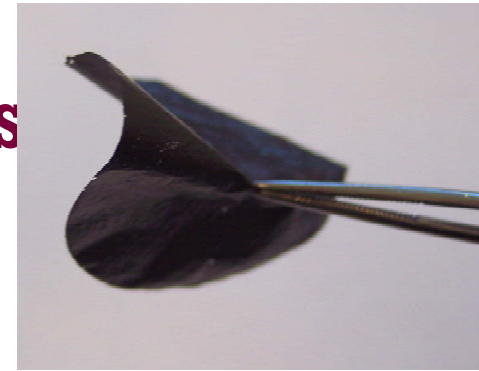
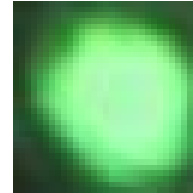




MAJOR FOCUS AREAS

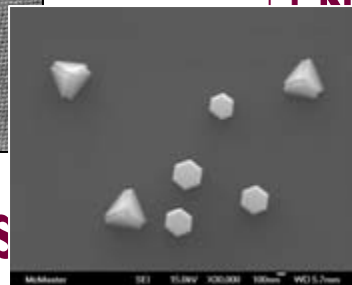
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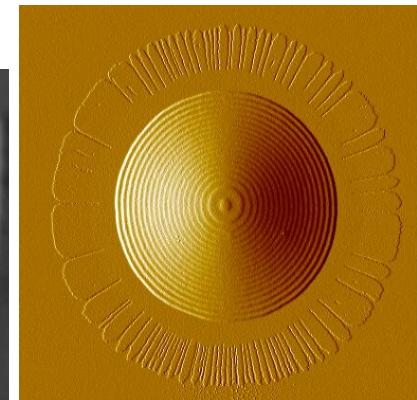
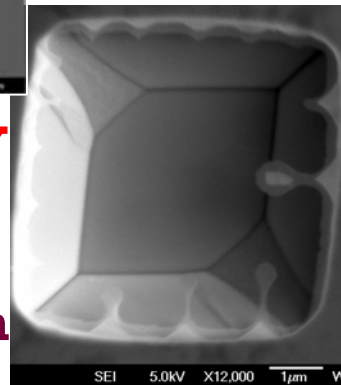
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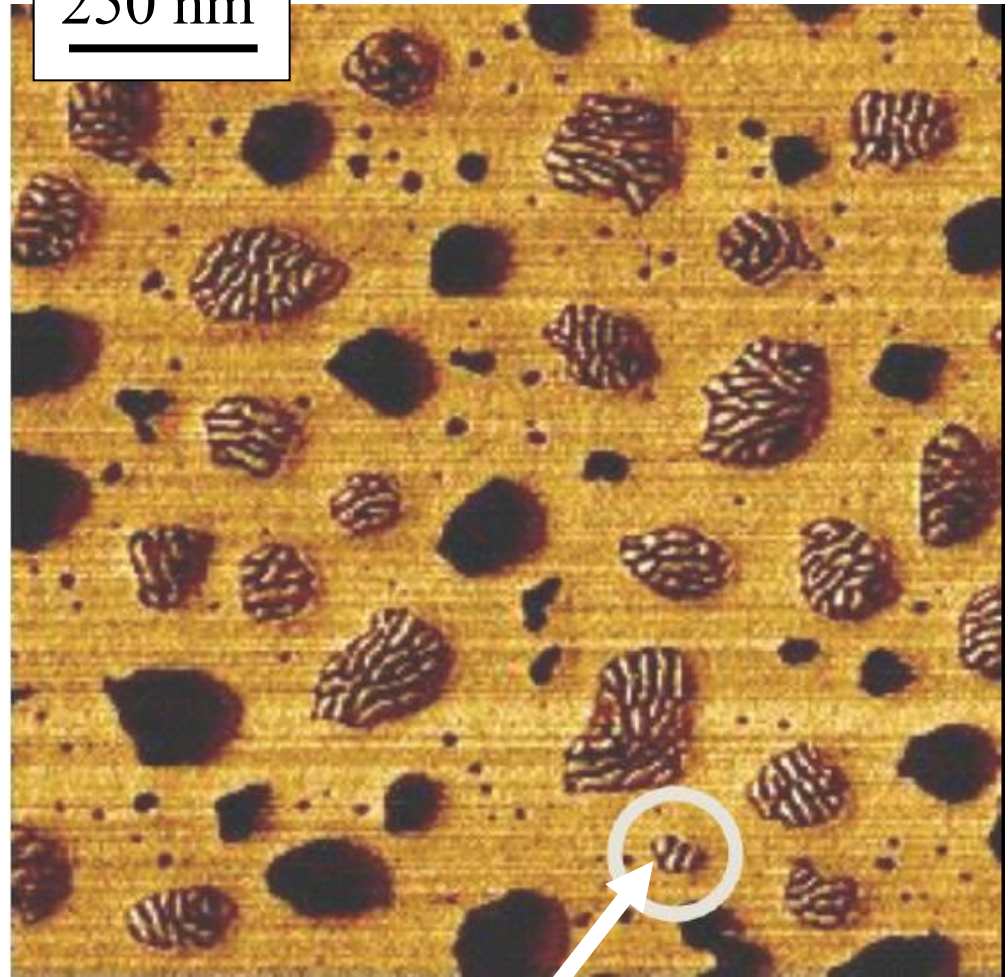




How does crystallisation start?

These are droplets of PEO on a substrate imaged with AFM. The black droplets have not yet crystallised (i.e. they are liquid), the striped droplets are crystalline and show their lamellae. Note that the small droplet has just 10 molecules!

250 nm



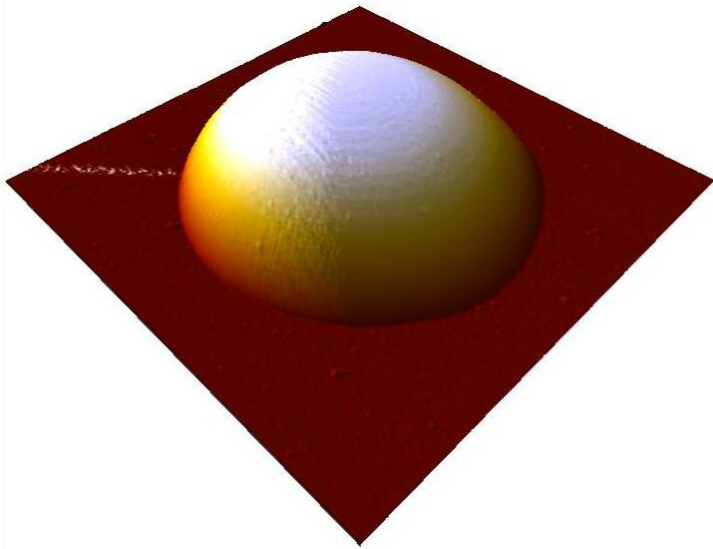
Kari Dalnoki-Veress

only ~10 chains (370 kg/mol)!!!

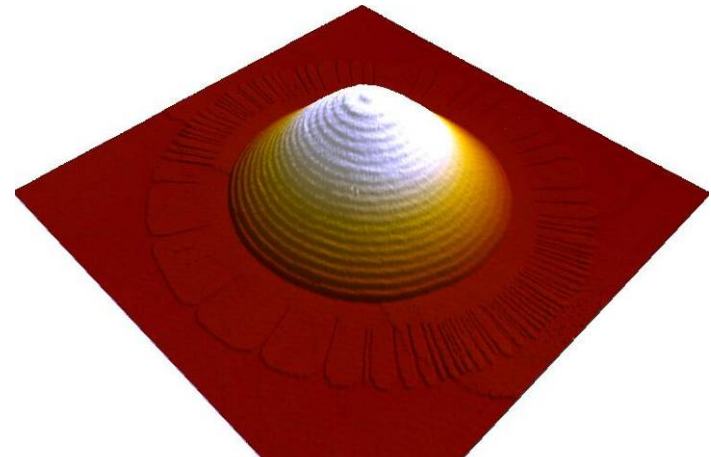


Droplets in an anisotropic liquid

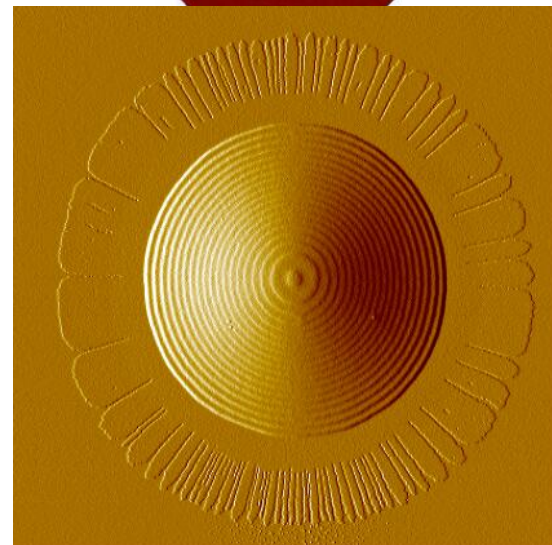
Expected spherical cap



Hyperbolic cap that is layered!



These droplets can be used to make lenses that have unique optical properties because they are hyperbolic in shape. They can also be used as building blocks in nano-devices



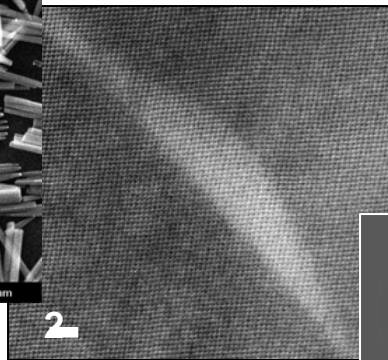
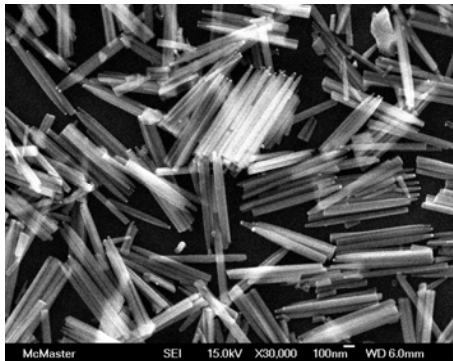
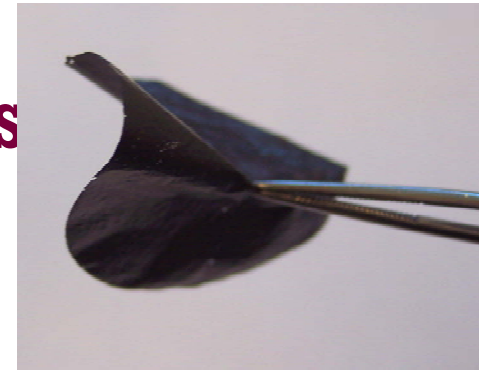
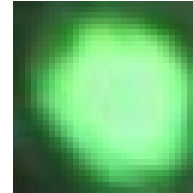
Kari Dalnoki-Veress



MAJOR FOCUS AREAS

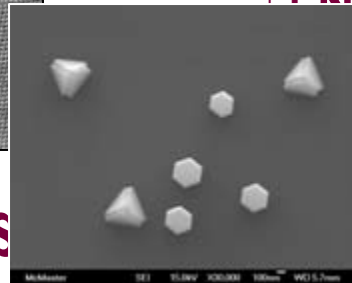
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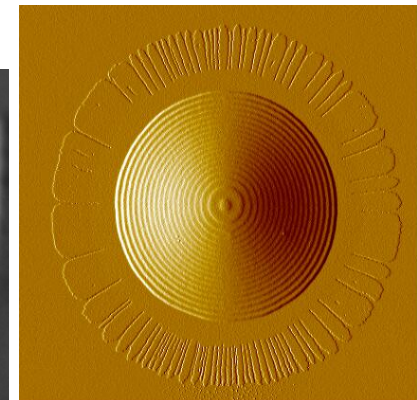
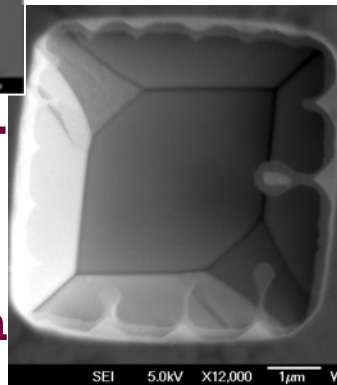
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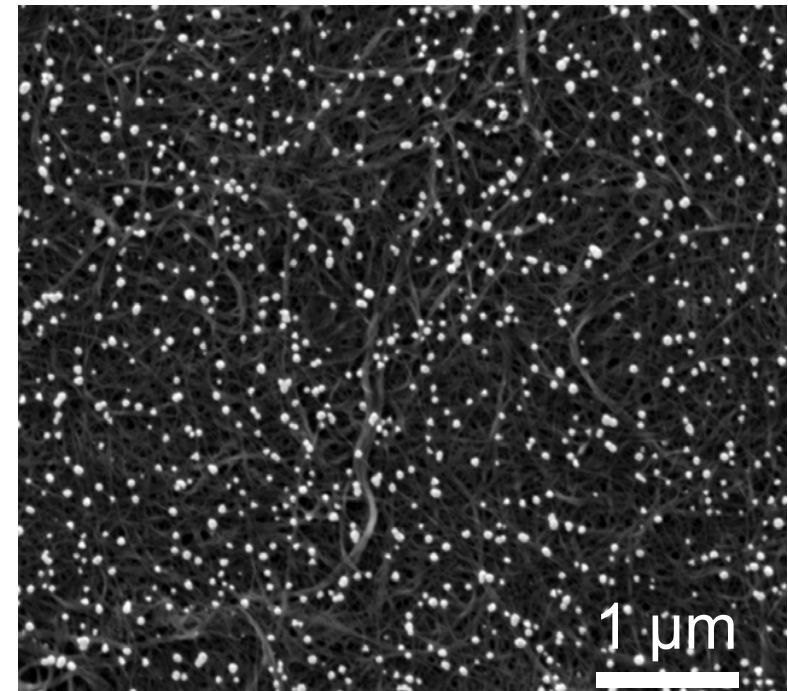
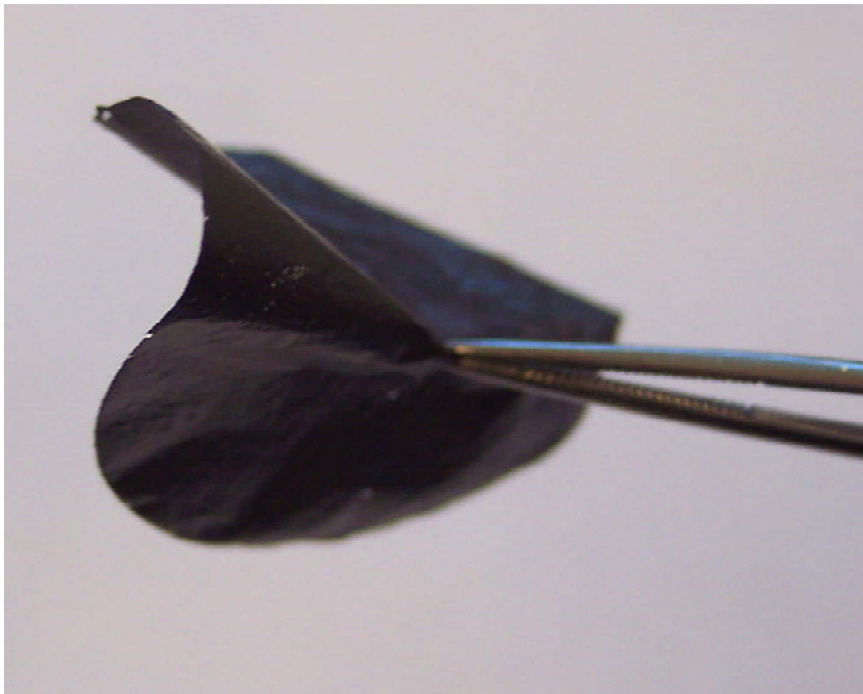
- ❑ Crystallization
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Ray LaPierre (Engineering Physics) and Alex Adronov (Chemistry)

» ADRONOV FABRICATES FLEXIBLE, CONDUCTIVE FILMS OF STACKED SWNTs, FUNCTIONALIZED WITH AU NANOPARTICLES



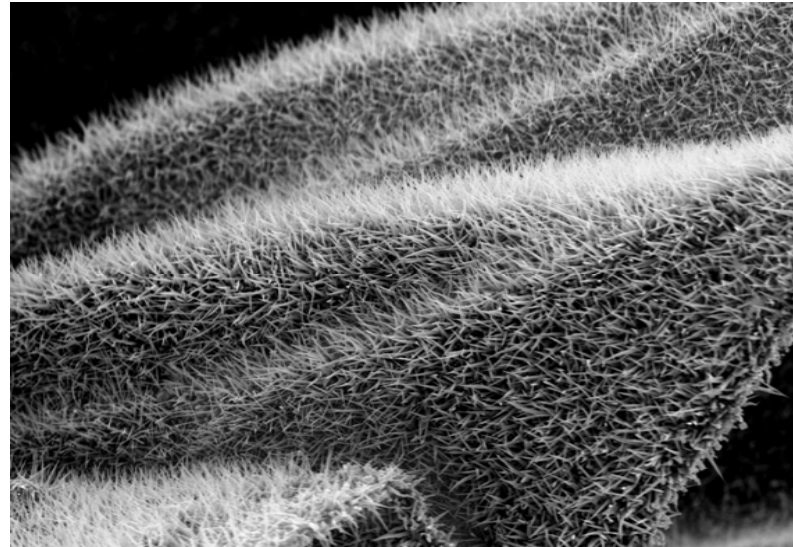
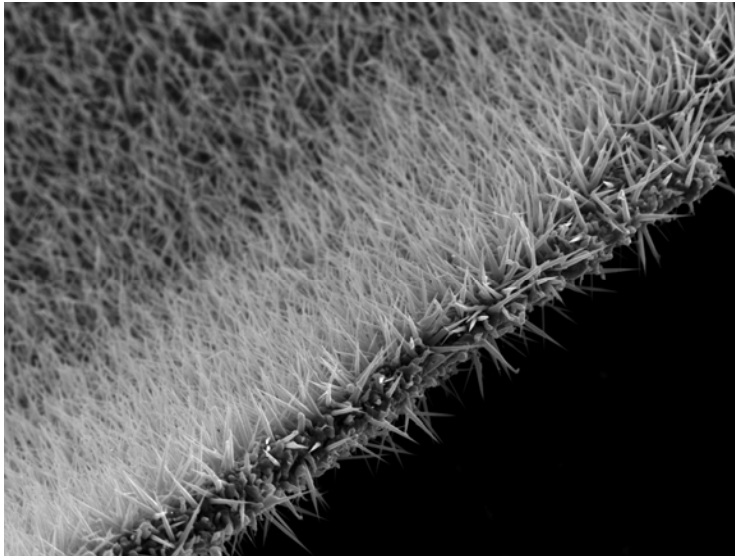
CEDT
Centre for Emerging Device Technologies



Brockhouse Institute
for Materials Research



» THE AU NANOPARTICLES ACT AS SEEDS FOR SEMICONDUCTOR NANOWIRE GROWTH. LAPIERRE GROWS III-V NANOWIRES ON ADRONOV'S CNT FILMS FOR PV APPLICATIONS



CEDT

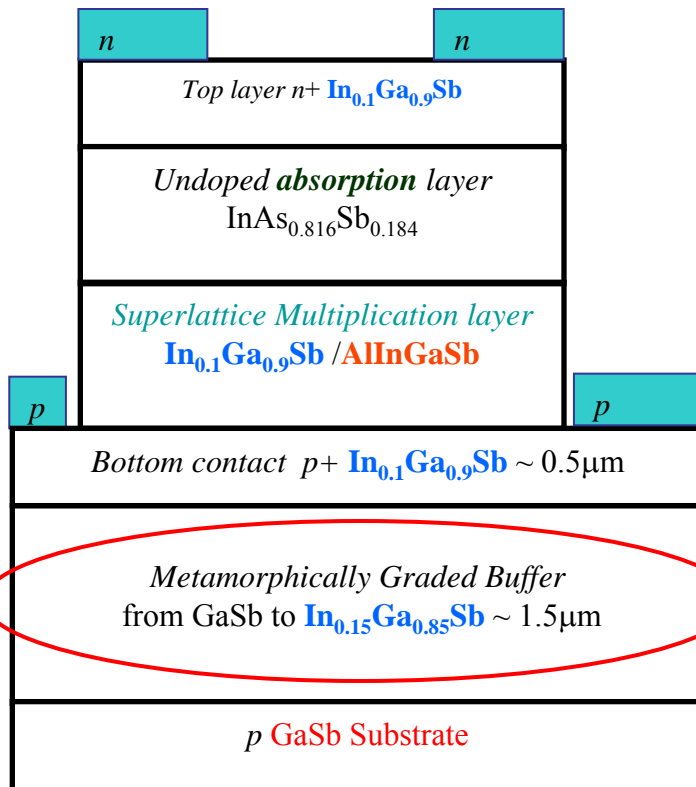
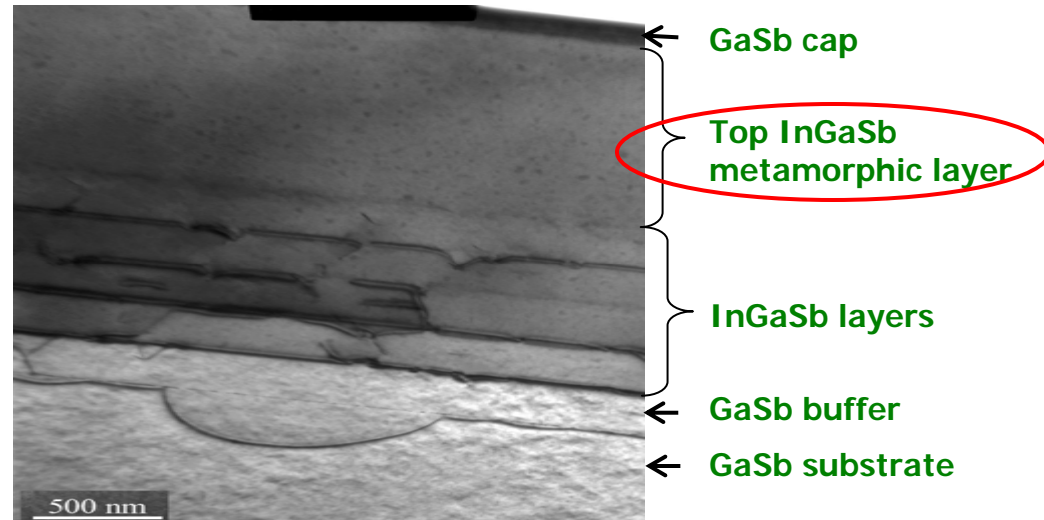
Centre for Emerging Device Technologies



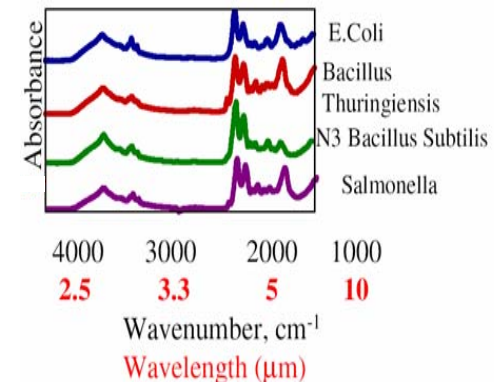
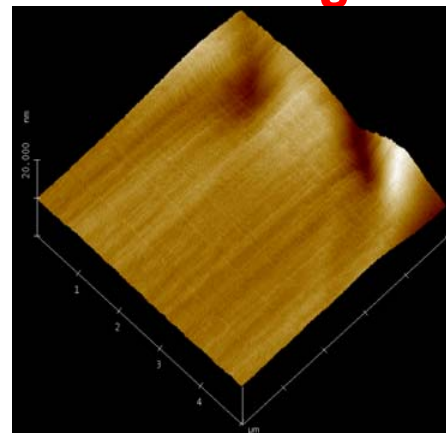
Superlattice Photodetectors

TEM images

- Antimonide materials
- Mid Infrared lasers/detectors for
 - Biomedical applications
 - Defense and security applications
 - Next generation non-silica fibers



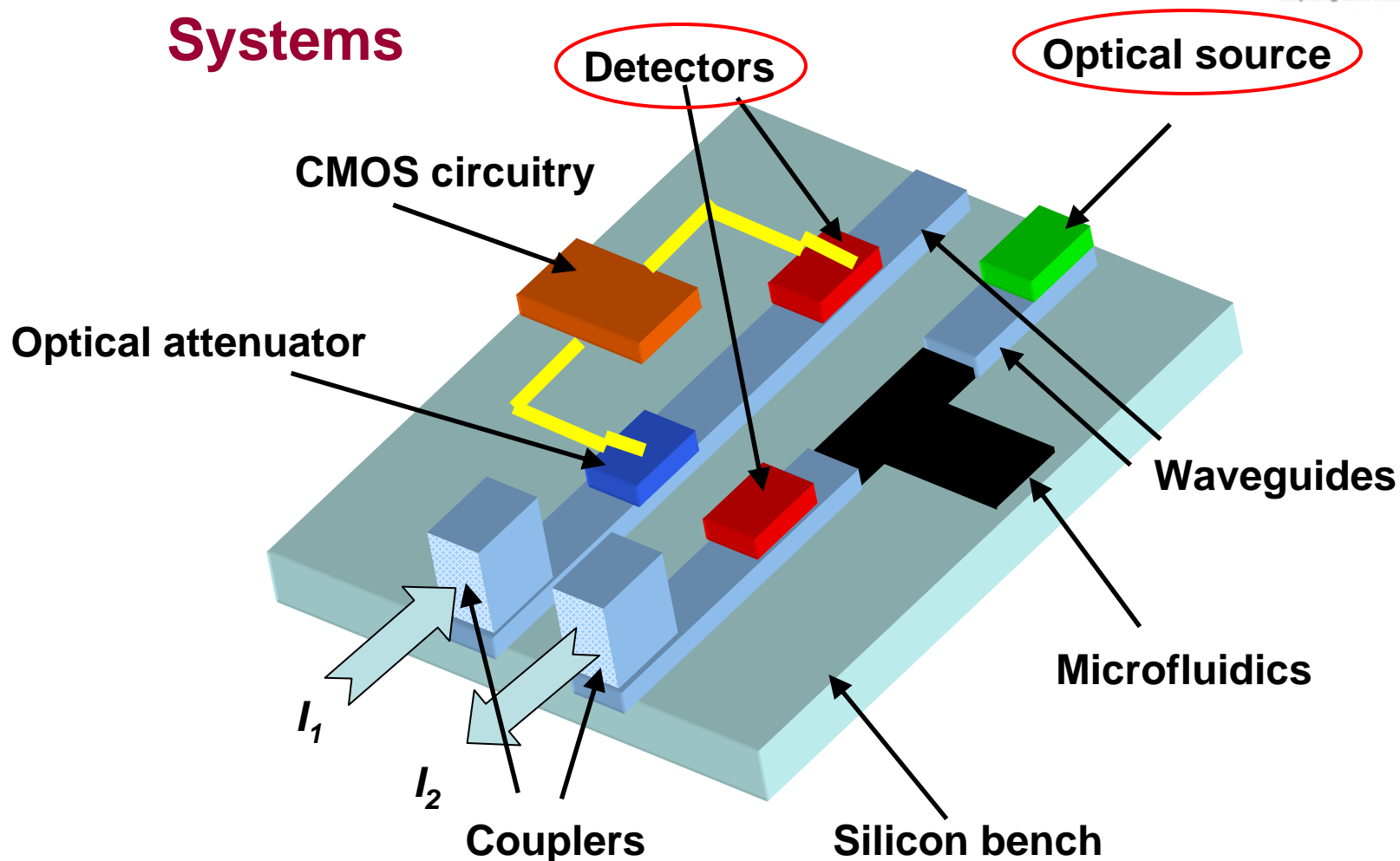
AFM image



Surface roughness: 0.175nm; Dislocation density: $\sim 3 \times 10^8 \text{ cm}^{-2}$

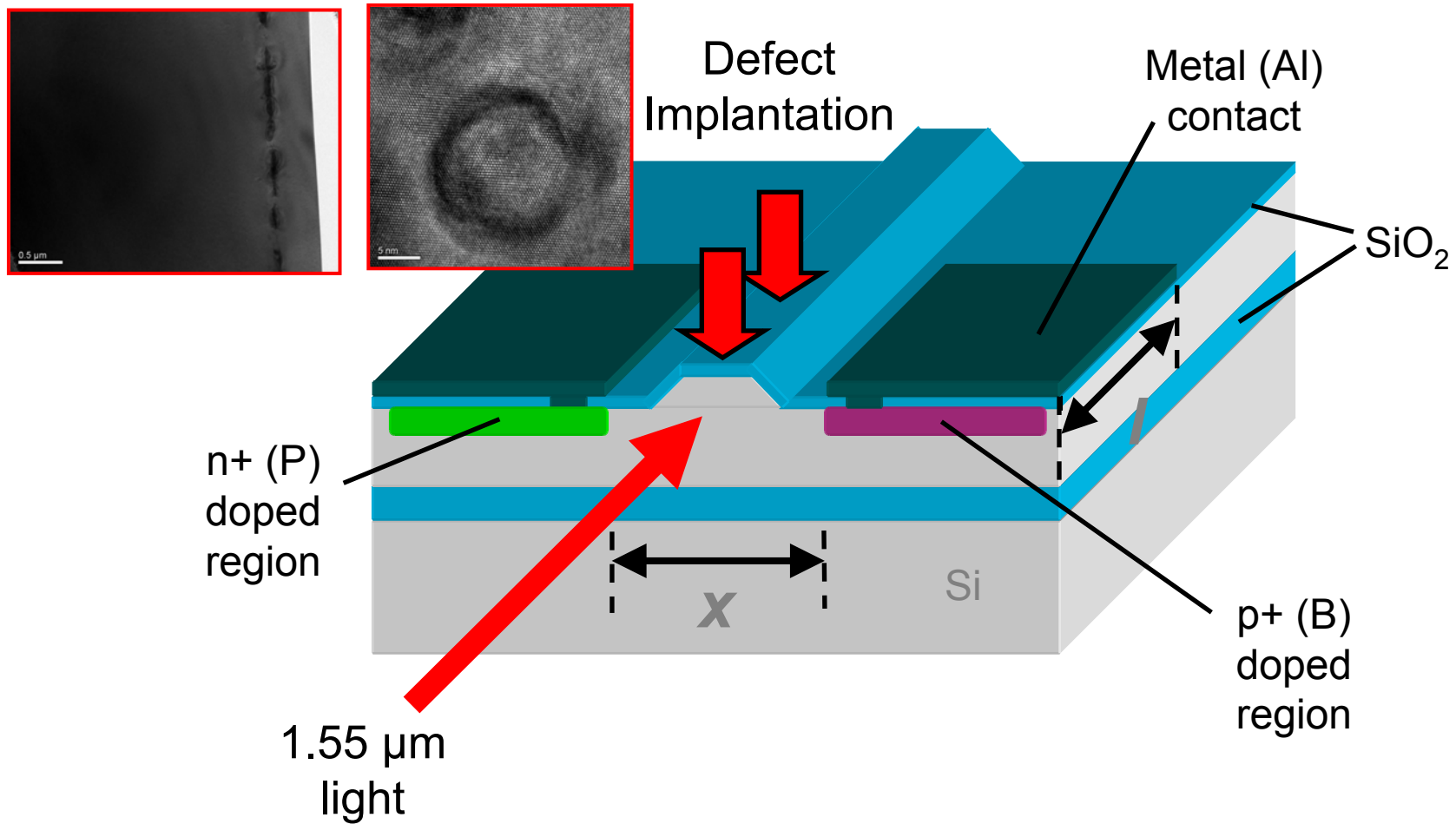


Silicon-based Photonic Systems





Device Design & Fabrication

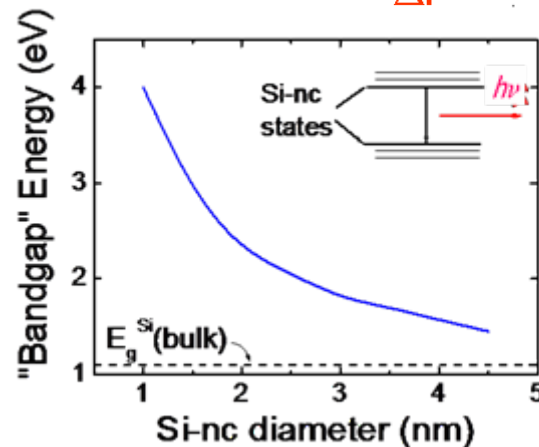
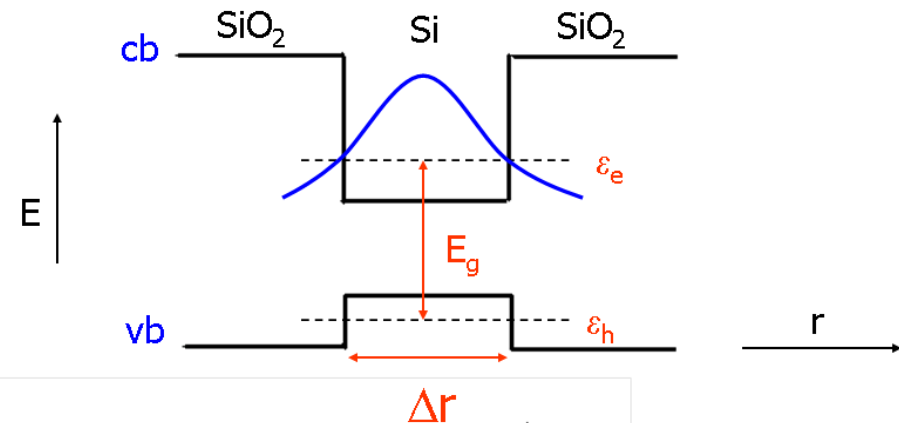
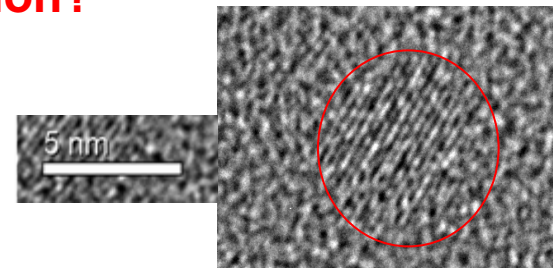


Bradley, Jessop, and Knights, APL 86, 241103 (2005).



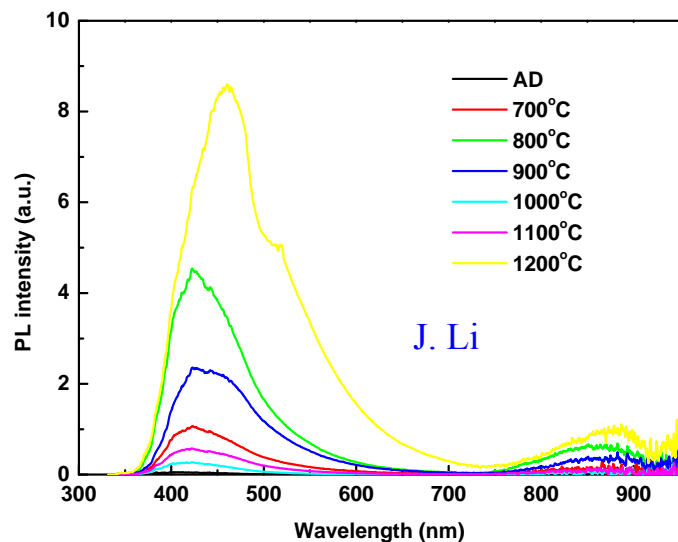
Silicon Photonics – A Nano Solution?

- Silicon on the nanoscale (Si-ncs)
 - Nanocrystals
 - Amorphous nanoclusters
- Quantum confinement
 - Localization of electrons and holes
 - Bandgap widening
 - Relaxation of k-selection rules
 - Uncertainty principle
 - 'quasi-direct' recombination
- Inter-bandgap electronic states
 - Limit observed emission range
 - Si=O double bond
 - Wolkin *et al.* PRL **82**, 197 (1999)

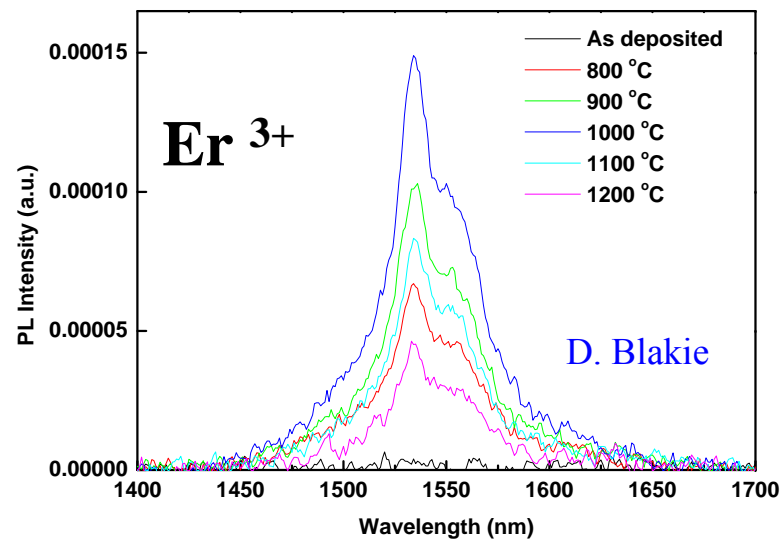
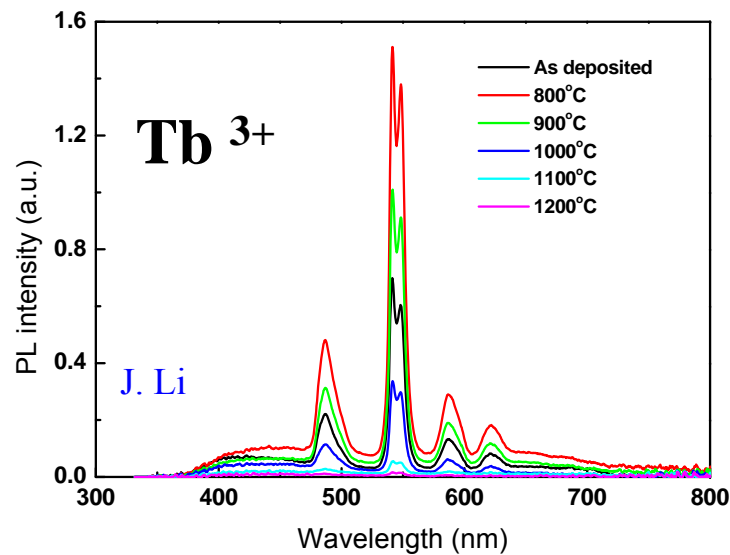
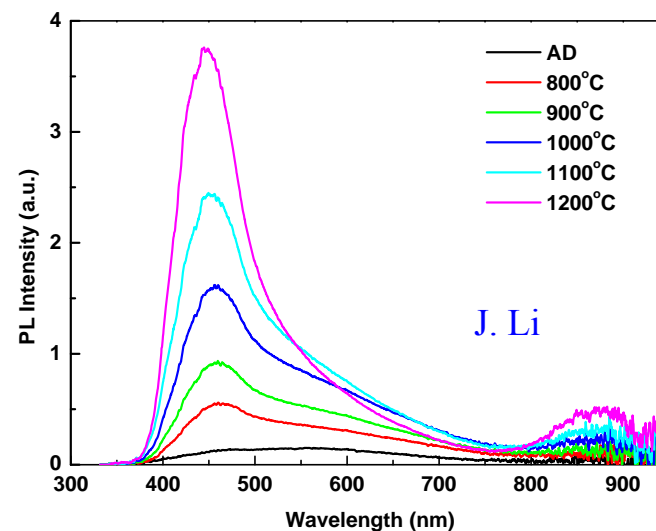




Ce³⁺ (and Si-ncs)

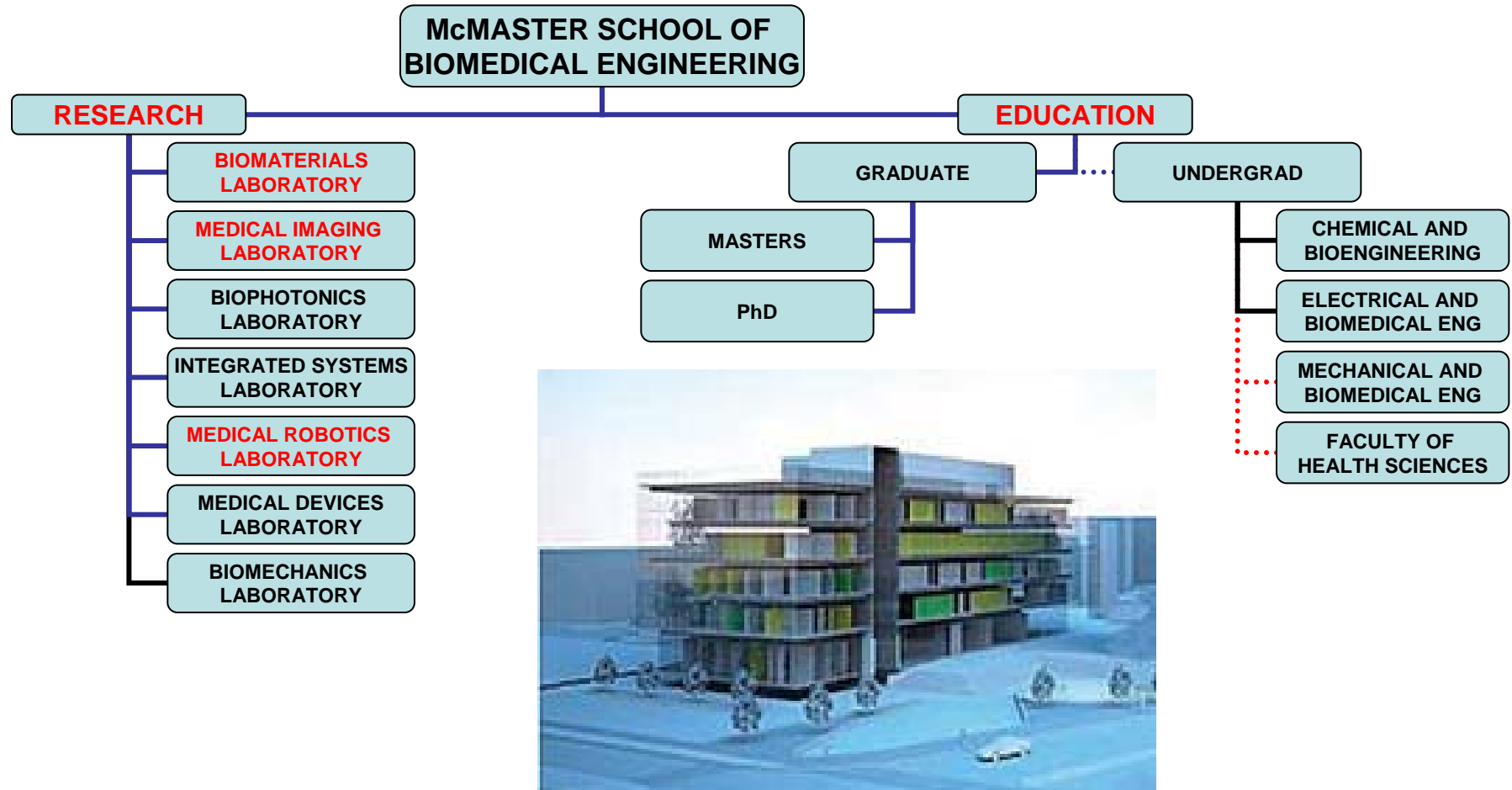


Eu²⁺ (and Si-ncs)





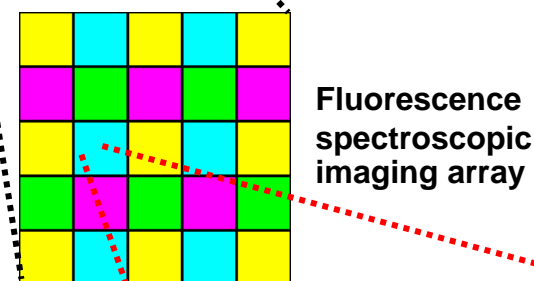
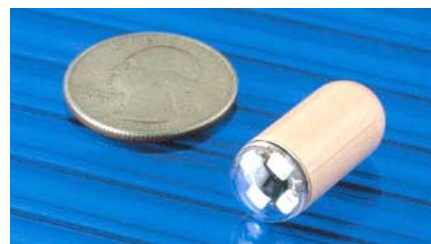
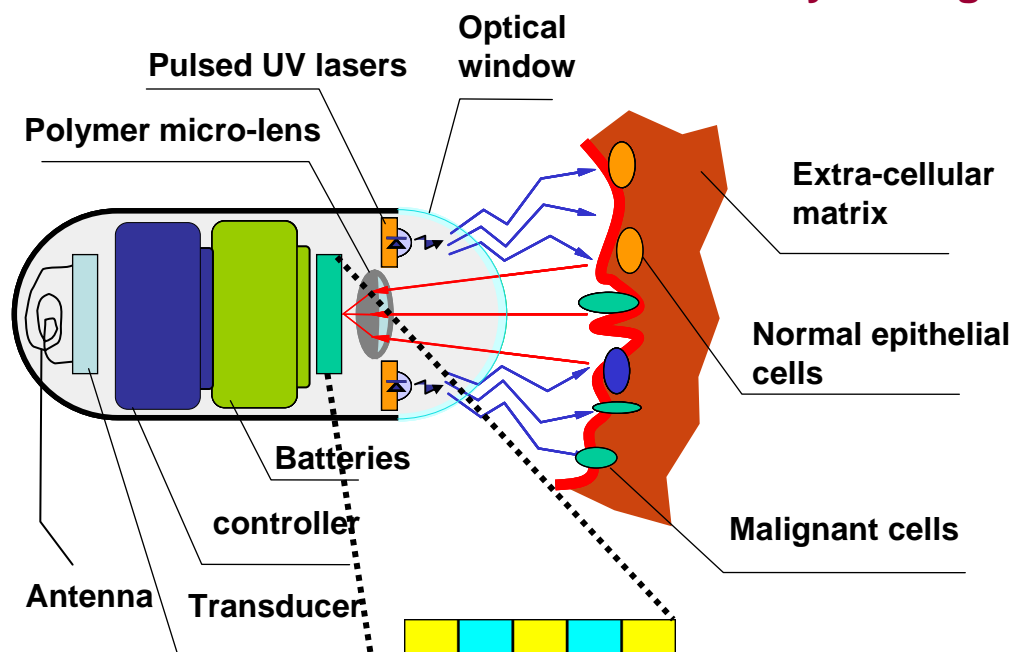
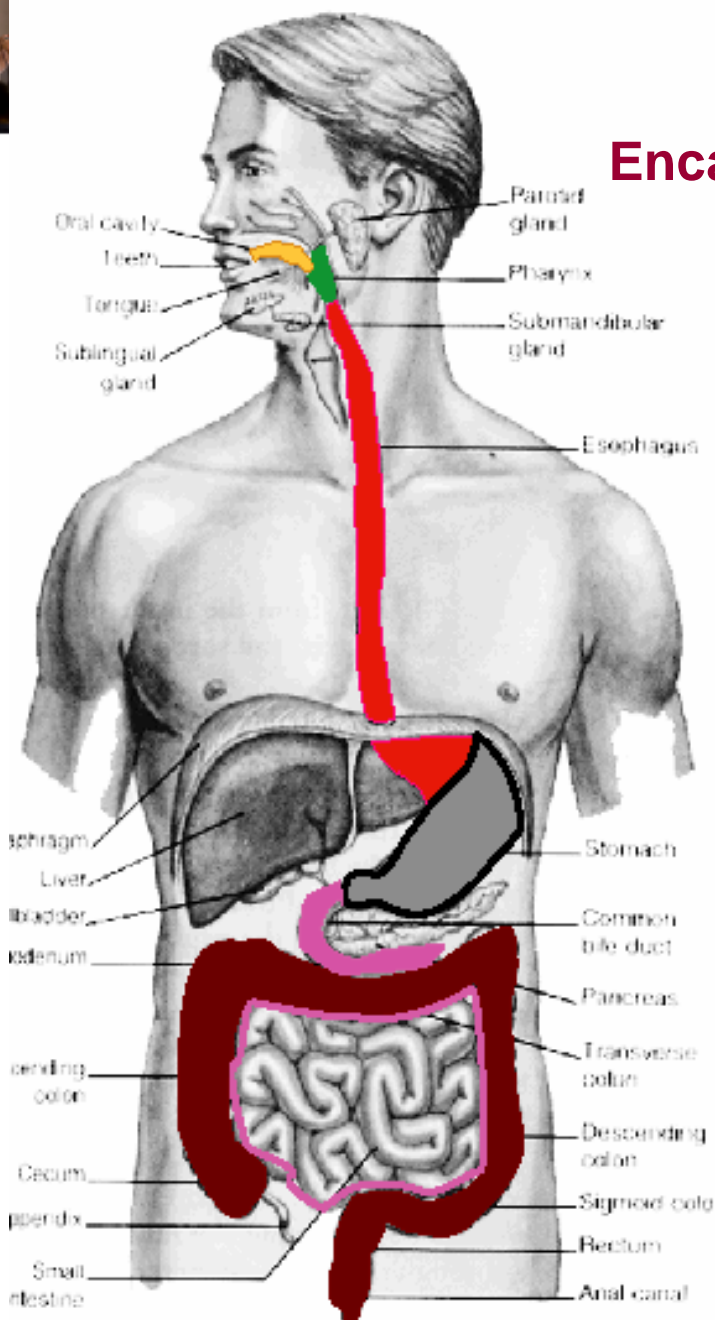
McMaster School of Biomedical Engineering – An Equal Partnership of Engineering and Health Sciences



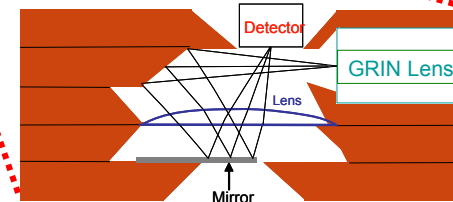


Encapsulated fluorescence imaging - clinical diagnosis

Jamal Deen and Qiying Fang



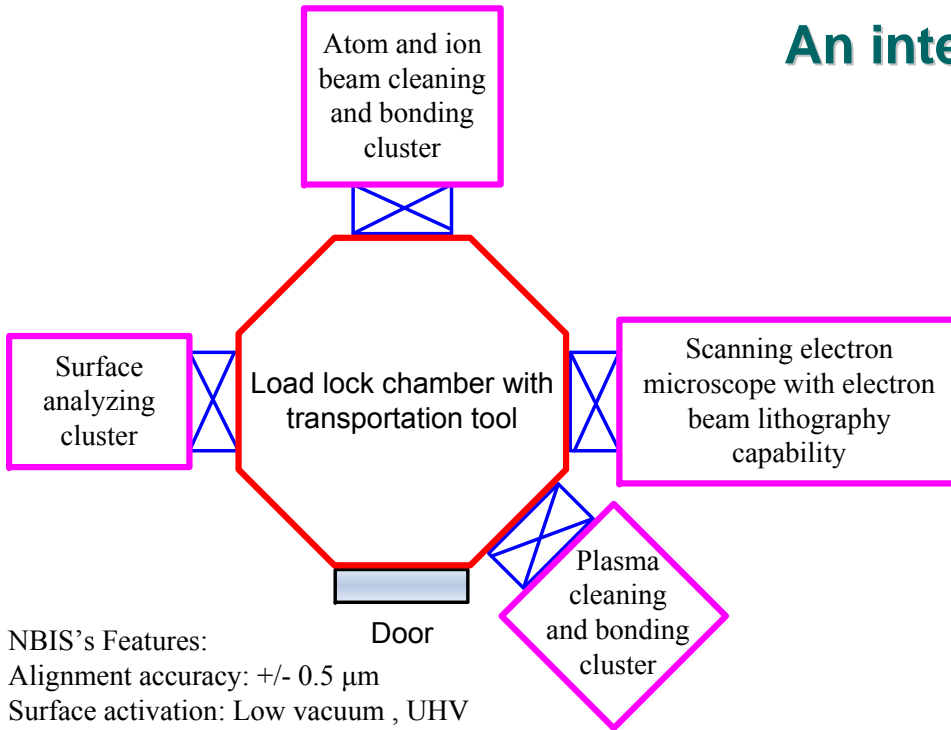
Fluorescence lifetime spectroscopic detection single detector





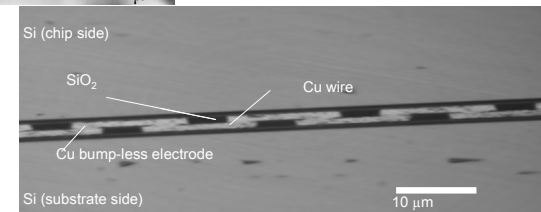
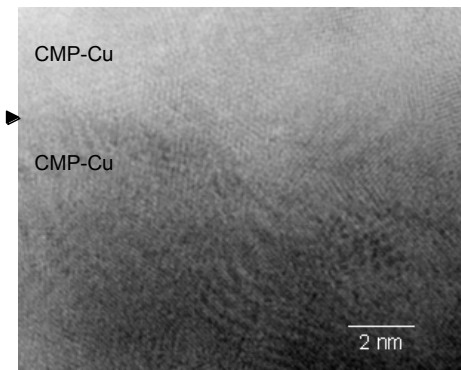
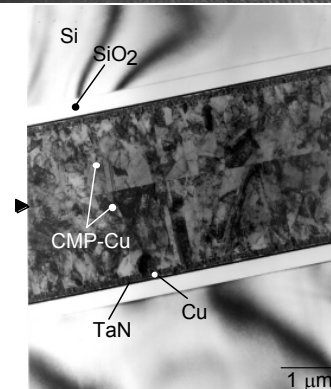
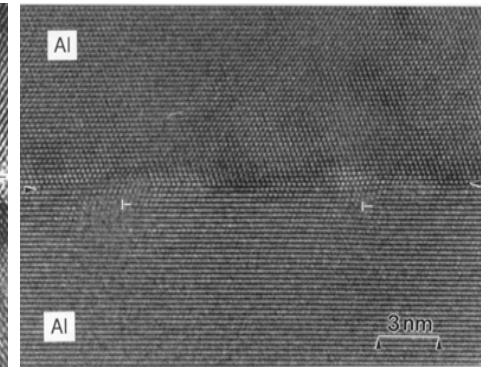
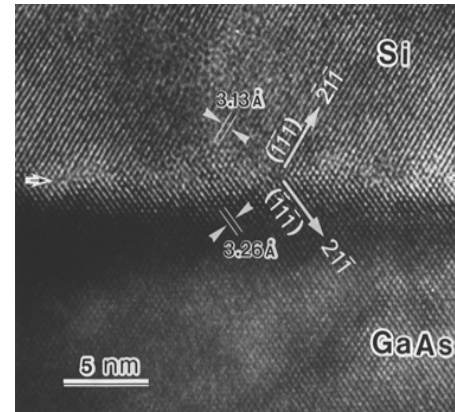
Bonding and Interconnect System

An integration facility that will be second to none in its capabilities



NBIS's Features:

Alignment accuracy: $\pm 0.5 \mu\text{m}$
 Surface activation: Low vacuum, UHV
 Sample accommodation: as small as 1 sq. mm.
 Bonding environments: Low vacuum, UHV N_2 gas, Air
 Bonding materials: Ultra-thin metal, semiconductor, ceramic and piezoelectric material



Key advantages of surface activated bonding

- No requirement of external pressure, adhesive or heating
- Sub- μm alignment and placement of components
- Two- and three-dimensional integration of dissimilar materials



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PHOTONICS
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for Materials Research**

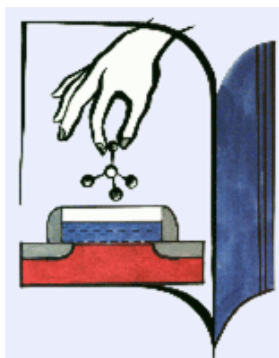
John S. Preston, Director

prestonj@mcmaster.ca

M. I. N. I.

MCMaster INITIATIVE in NANO INNOVATION

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Nano and Giga Challenges in Electronics, Photonics and Renewable Energy

14th Canadian Semiconductor Technology Conference

Symposium and Summer School (Tutorial Lectures)
Hamilton, Ontario, Canada, August 10 - 14, 2009

For further information and registration visit our web site at:

<http://asdn.net/ngc2009/> or <http://cstc2009.mcmaster.ca>

or contact

organizers@asdn.net



Inspiring Innovation and Discovery



McMaster University – Research Accolades

- Ranked Canada's most innovative "medical doctoral" university eight times in the last 11 years in *Macleans*'s annual ranking of universities
- Ranked #1 in Canada for Research Intensity (\$ per full-time faculty) Canada's Research University of the Year 2004 (*ResearchInfosource*)
- Ranked 6th in Canada's Top 50 Research Universities with \$308.3 million in sponsored research income
- Ranked among the top 100 universities in the world (*China's Shanghai Jiao Tong University* annual ranking)
- 1 of only 7 Canadian universities ranked in the top 200 universities in the world by *The Times Higher Education Supplement* (2006)



Inspiring Innovation and Discovery

McMaster University

Strategic Research Areas

- Molecular Biology
- Information Technology
- Globalization and the Human Condition
- Science-based Innovation in Manufacturing and Materials
- Work and Society
- Integrated Health Research

Faculty of Engineering

Research Priority Areas

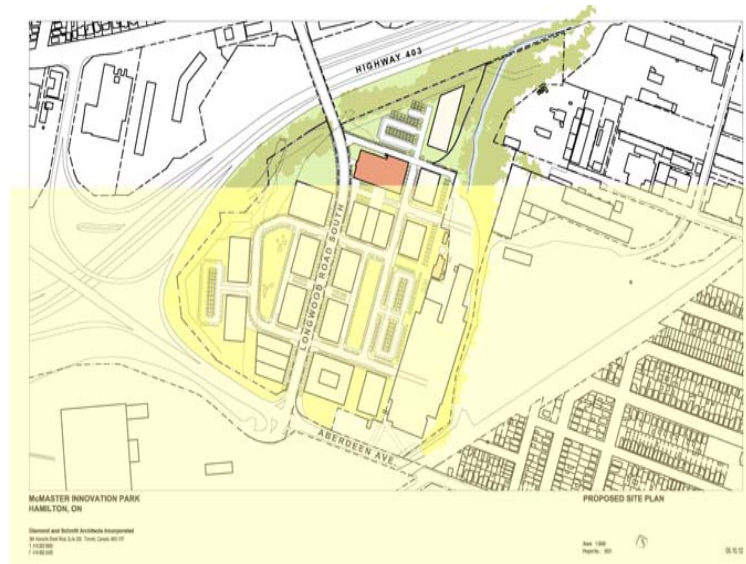
- Information Technology
- Biomedical Engineering
- Materials and Manufacturing
- Sustainable Energy Systems
- Micro- and Nano-systems





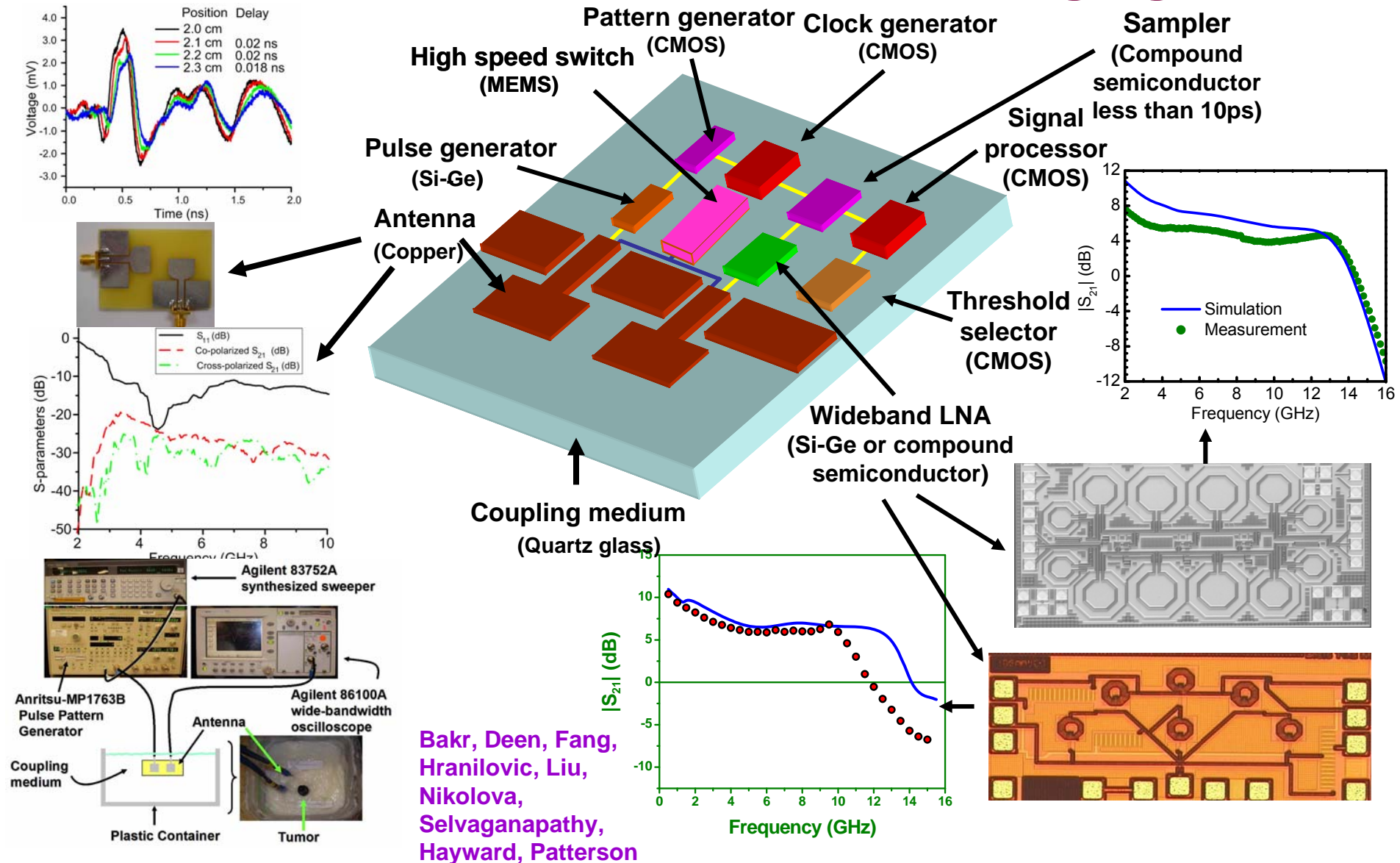
McMaster Innovation Park

- 37-acres of brownfields and warehouses being developed into a premiere research park
- Future home of **CANMET Materials Technology Laboratory** and **General Motors of Canada's Centre for Corrosion Engineering Research**



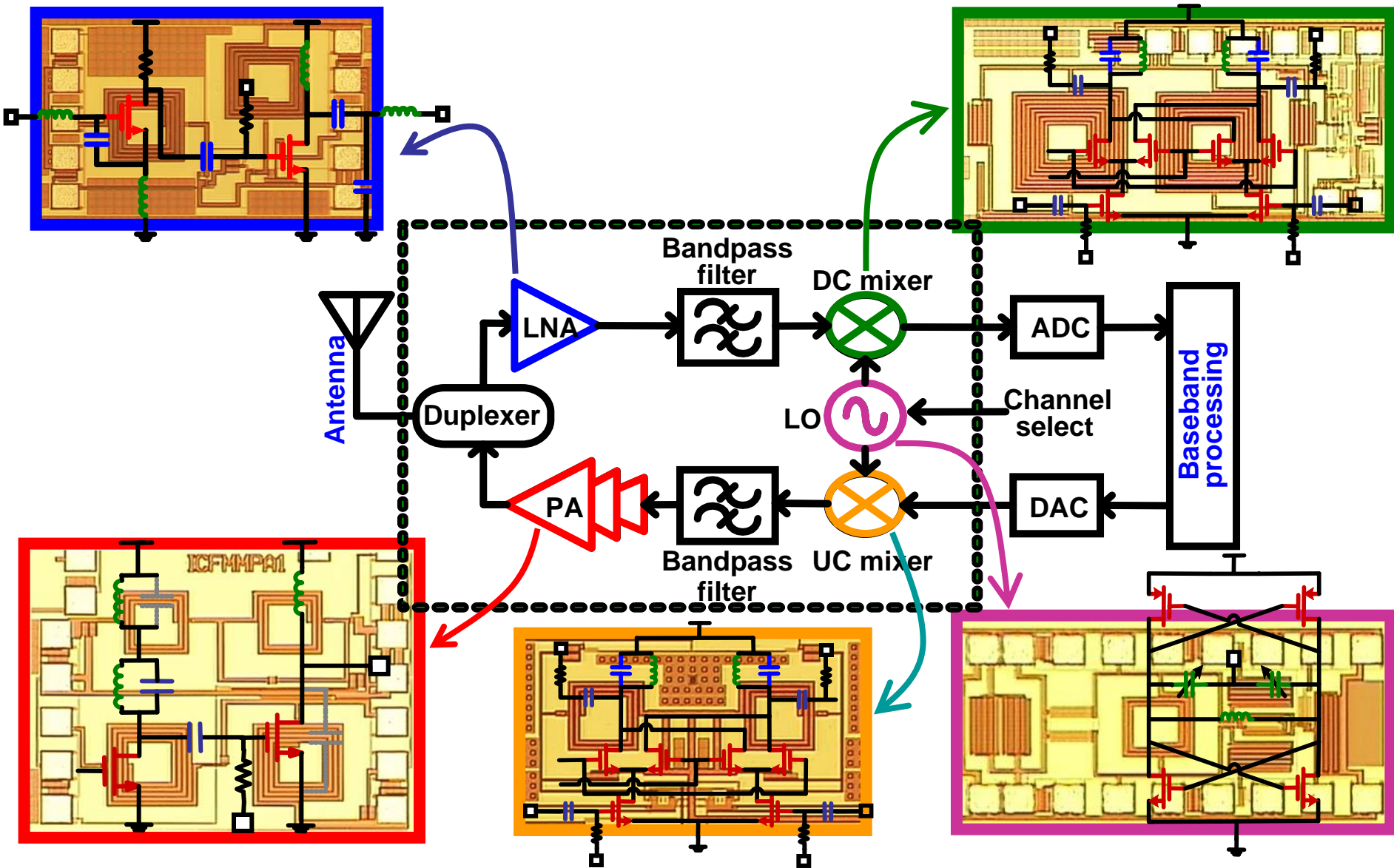


Nanoelectronics-based Bio-imaging



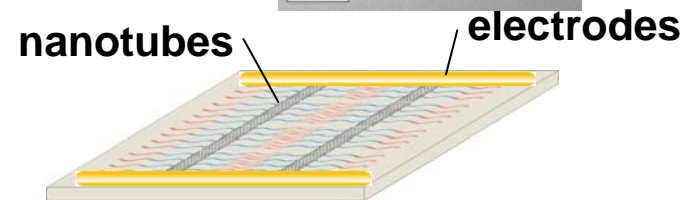
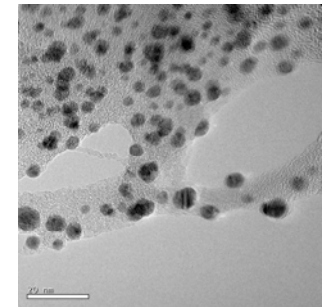
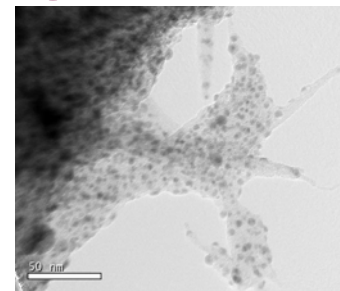
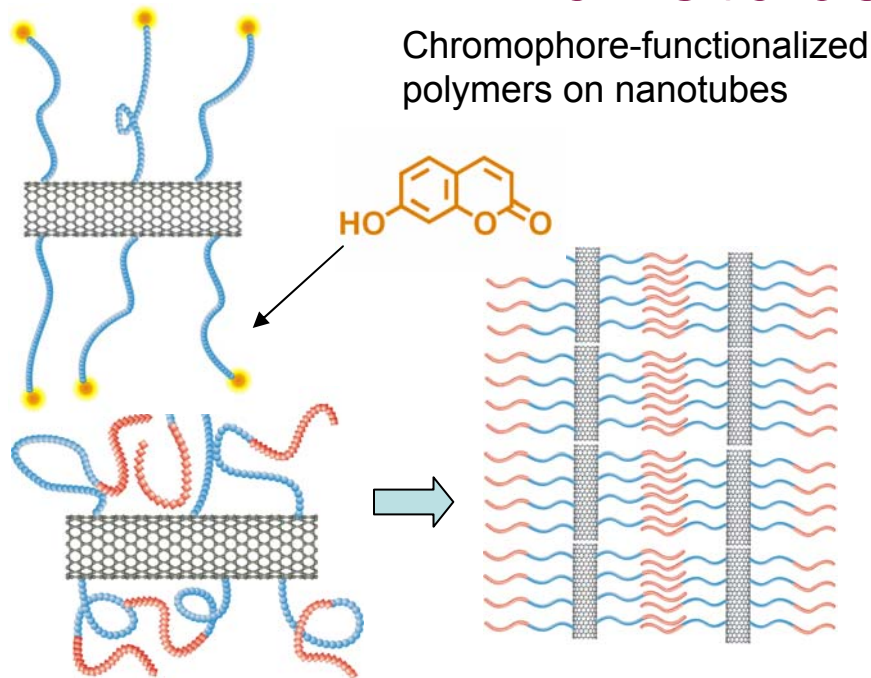


Nanoelectronics – Wireless Sensor

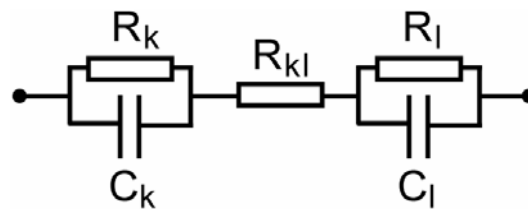
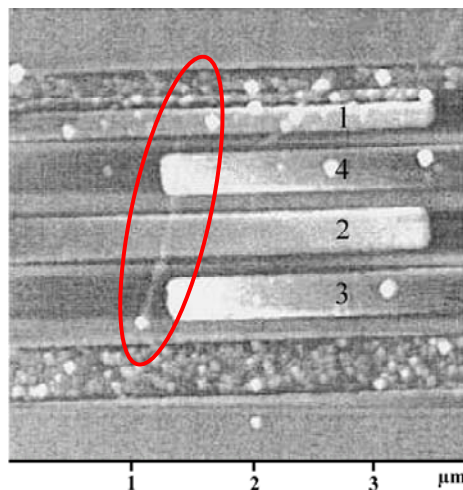




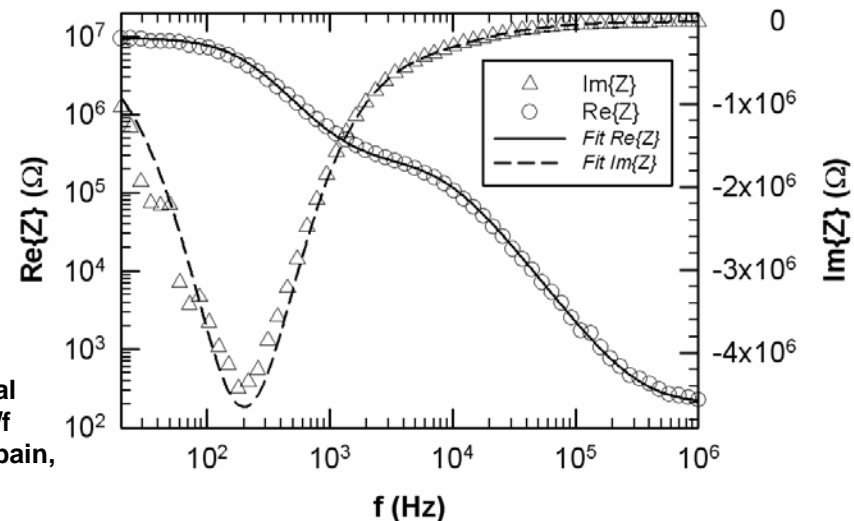
Nanotubes - Contacts



Block copolymer functionalized nanotubes might also SA into controllable patterns between deposited electrodes on surfaces



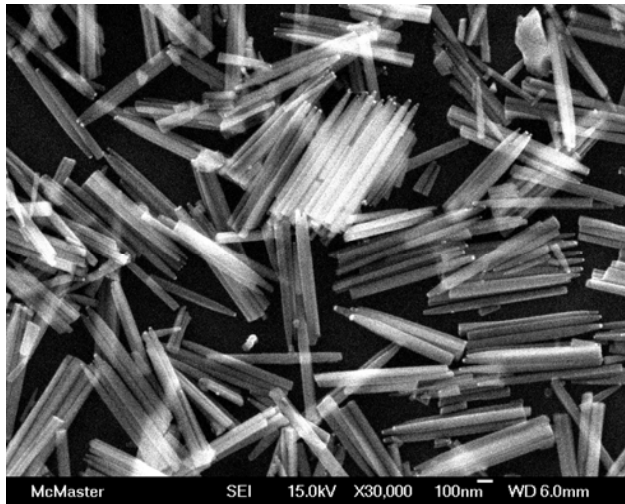
S. Soliveres, et al, Proc. 18th International Conf. on Noise in Physical Systems & 1/f Fluctuations (ICNF 2005), Salamanca, Spain, pp. 462-265 (19-23 September 2005).



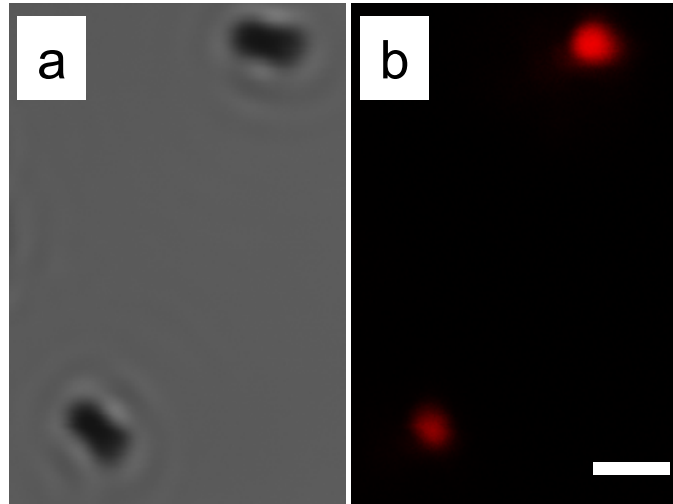


Collaboration between Ray LaPierre (Engineering Physics), Cecile Fradin (Physics), and Bhagwati Gupta (Department of Biology)

» LAPIERRE GROWS LIGHT EMITTING NANOWIRES. FRADIN AND GUPTA USE NANOWIRES FOR CELLULAR STUDIES.



SEM image showing ensemble of AlGaAs nanowires.



Microscopy (left) and PL image (right) of nanowires. Nanowires emit in the visible region (700 nm) at room temperature. Scale bar is 1 μm .

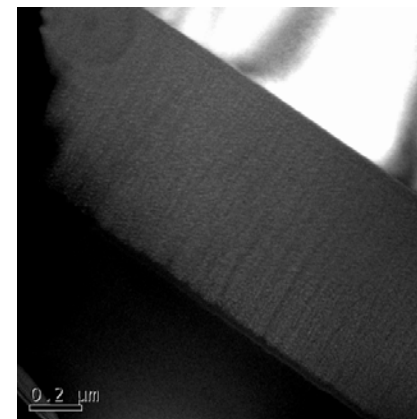
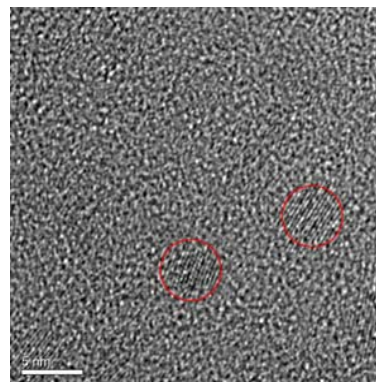
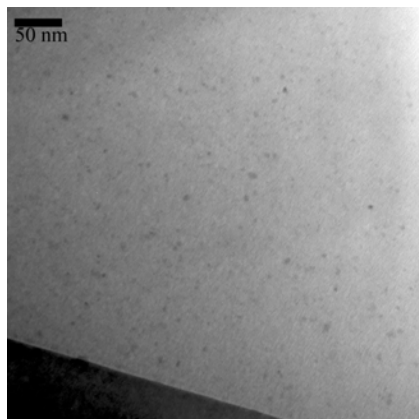


Nanowires are injected into nematode for cellular and toxicological studies.

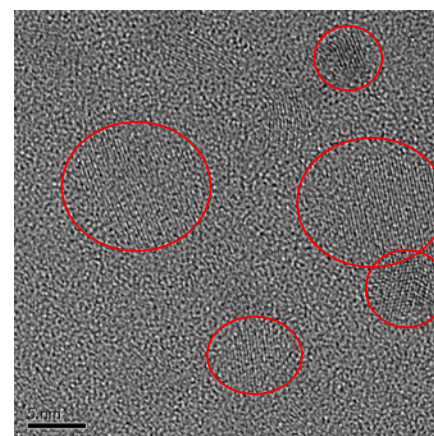
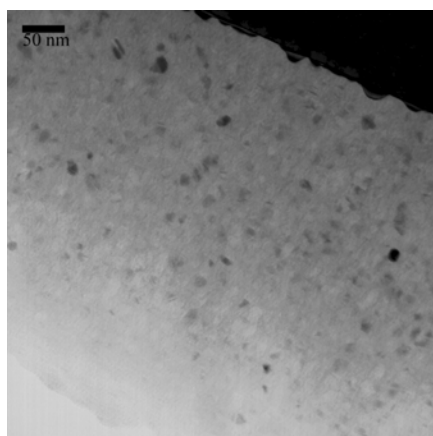


Si-ncs: Structure

- 39% Si, annealed at 1100 °C (BFTEM, HRTEM, EFTEM)



- 42 % Si, annealed at 1100 °C (BFTEM) and 1200 °C (HRTEM)



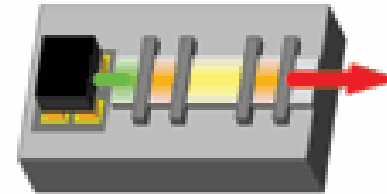


Silicon Photonics – The Giga Challenge

1) Light Source

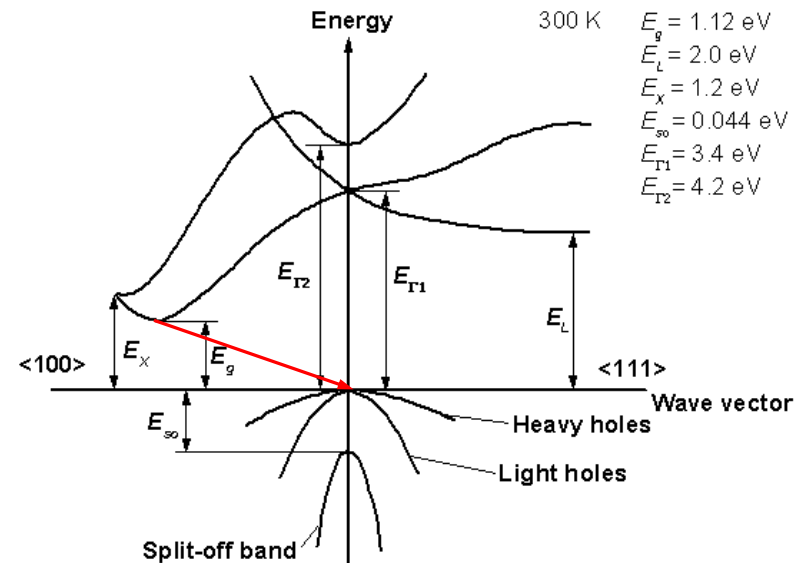
Si-based light sources

- ❑ Electrically pumped
 - Lasers, LEDs



Bulk Si - indirect bandgap

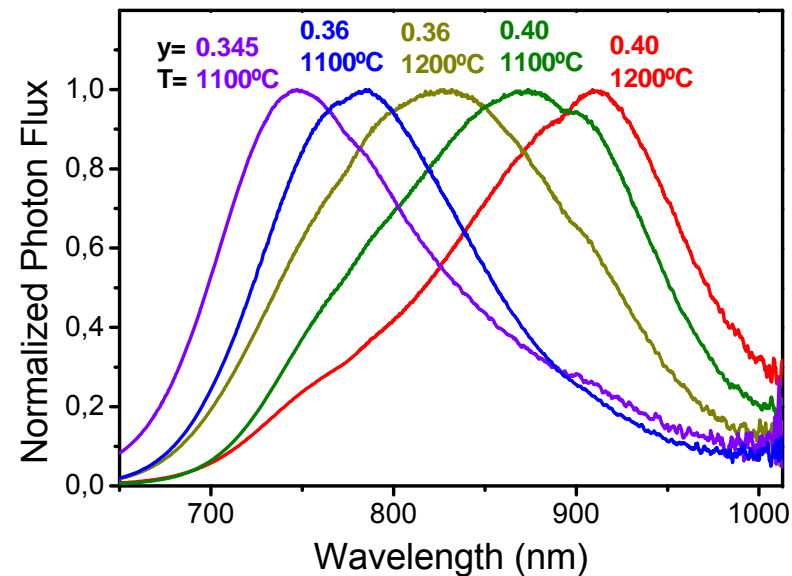
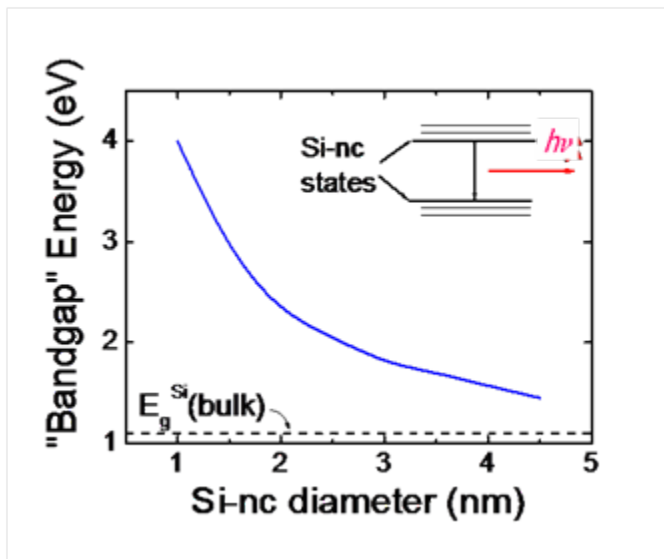
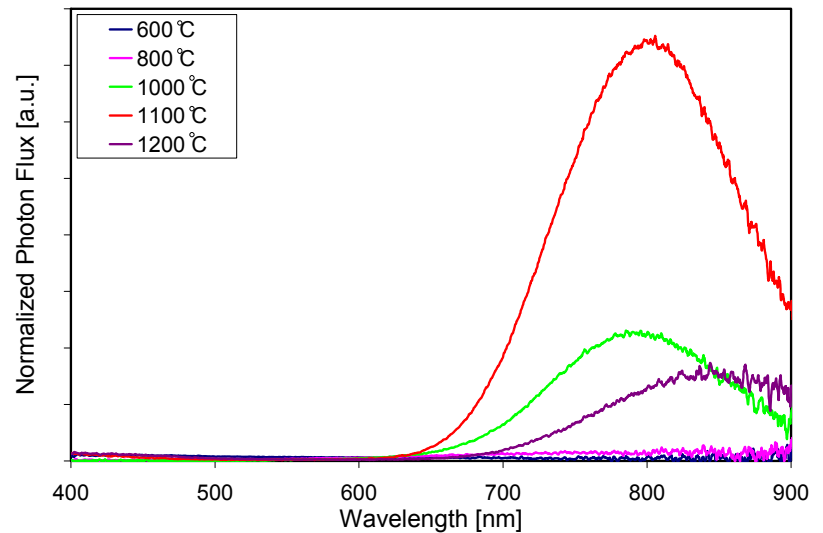
- ❑ e-h recombination
 - Phonon mediated
 - Slow
- ❑ Competing processes
 - Auger process
 - Free carrier absorption





Si-ncs: Photoluminescence

- UV excited PL
 - HeCd Laser
 - 325 nm excitation
 - SRSO Samples
 - PL in the NIR





Polymer-nanotubes composites

