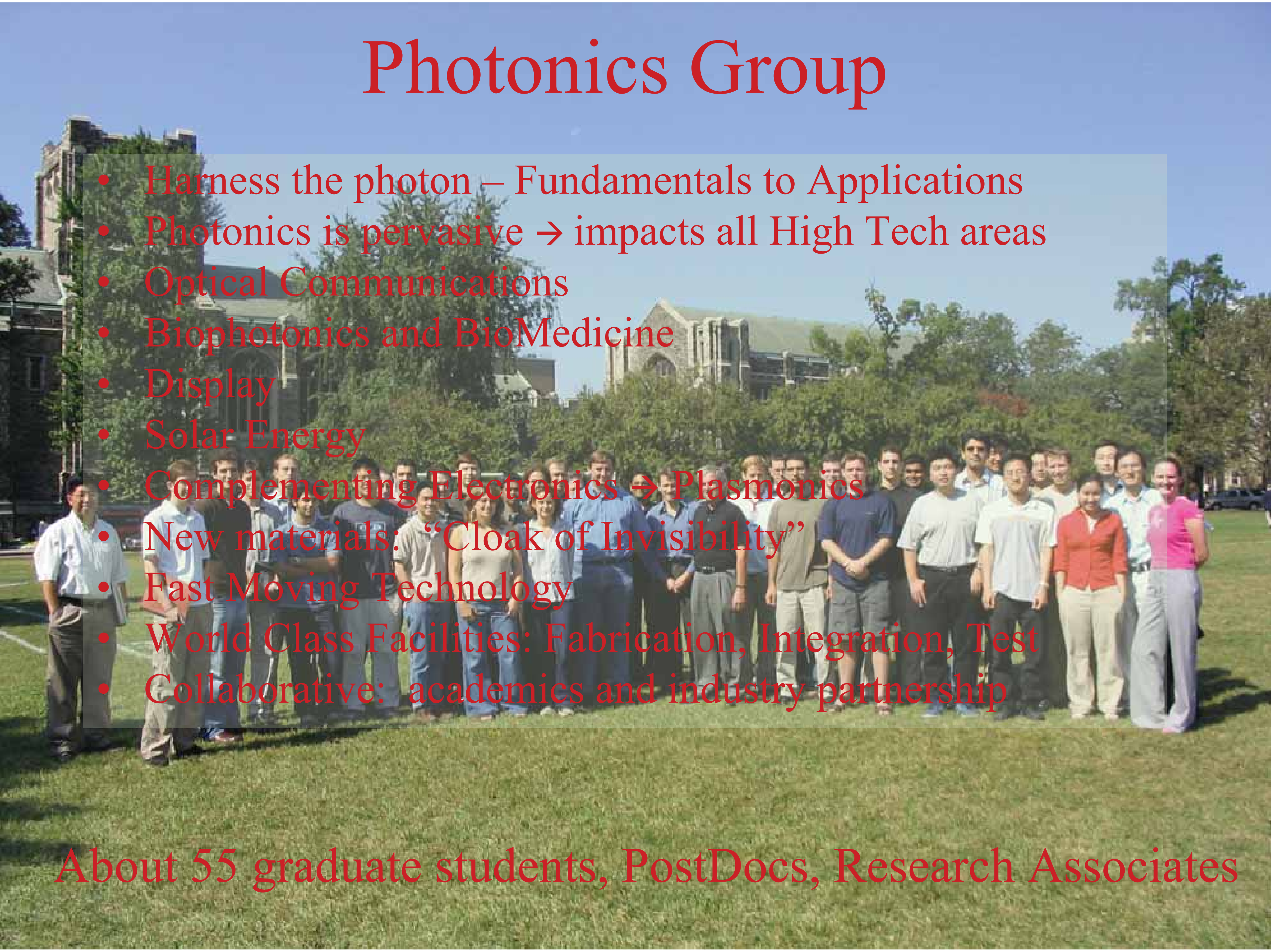
Photonics Group



- Harness the photon – Fundamentals to Applications
- Photonics is pervasive → impacts all High Tech areas
- Optical Communications
- Biophotonics and BioMedicine
- Display
- Solar Energy
- Complementing Electronics → Plasmonics
- New materials: "Cloak of Invisibility"
- Fast Moving Technology
- World Class Facilities: Fabrication, Integration, Test
- Collaborative: academics and industry partnership

About 55 graduate students, PostDocs, Research Associates

Photonics vs. Electronics

Miniaturization!

Fast Speed!

Integration!

PLC (few hundred elements)

U. Eindhoven

Pentium 4 (42 mill. transistors)

Intel Corp.

Photonics: Graduate Courses

Fall Term		
ECE1448F	Quantum Mechanics for Engineers	S. Dmitrevsky
ECE1467F	Integrated Optical Circuit Design	J.S. Aitchison
ECE1473	Micro and Nano Fabrication Technologies for compound semiconductors.	A. Helmy
ECE1471F	Photonics Fabrication and Packaging	P. Herman
Spring Term		
ECE527S	Photonics I	L. Qian
ECE 1468	Electronic and Optical Properties of Quantum Dots	E. H. Sargent
ECE1450S	Photonics II	P.W.E. Smith

More Information On-Line

http://photonics.light.utoronto.ca/

Photonics Research Group

- Prof. J. Stewart Aitchison
- Prof. Amr Saher-Helmy
- Prof. P. R. Herman
- Prof. N. Kherani
- Prof. M. Mojahedi
- Prof. L. Pavel
- Prof. L. Qian
- Prof. H. Ruda
- Prof. E. H. Sargent
- Prof. S. Dmitrevsky
- Prof. K. Izuka
- Prof. P. W. E. Smith
- Prof. S. Zukotynski

Prof. J.S. Aitchison
B.Sc. (Heriot-Watt), Ph.D. (Heriot-Watt)
Professor; Nortel Institute Chair in Emerging Technology; Chair, Photonics Group

Office: GB444
Tel: 416-946-7349
Fax: 416-971-3020
E-Mail: stewart.aitchison *(@utoronto.ca)*
Website: http://www.photonics.light.utoronto.ca/aitchison

Brief Research Description

Nonlinear Guided waves: Spatial and temporal solitons, All-optical switching and signal processing, Optical frequency conversion and parametric interactions. Novel optoelectronic materials and photonic microstructures for linear and nonlinear applications. Optoelectronic Integration: Hybrid Integration, monolithic Integration and integrated bio-sensors for lab-on-a-chip applications.

Prof. A. Helmy
B.Sc. (Cairo), M.Sc. (Glasgow), Ph.D. (Glasgow)
Assistant Professor

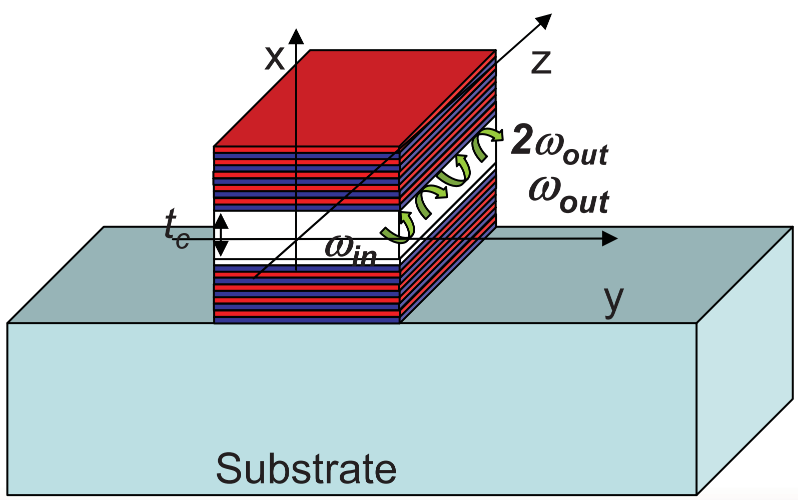
Office: GB446
Tel: 416-946-0199
Fax: 416-971-3020
E-Mail: a.helmy *(@utoronto.ca)*
Website:
http://www.photonics.light.utoronto.ca/helmy

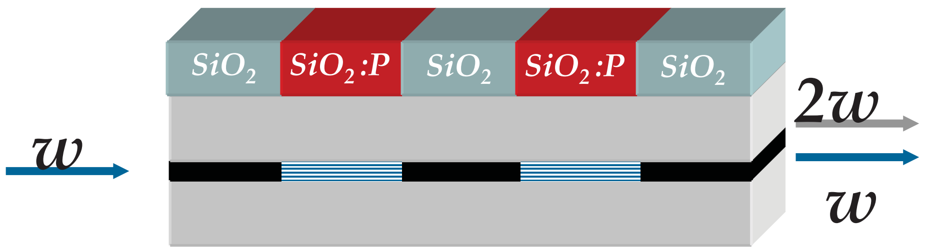
Brief Research Description

Photonic device physics and characterization techniques (lasers, modulators, amplifiers, switches), non-linear optics in III-V semiconductors (second and third order ultrafast non-linearities), applied optical spectroscopy for III-V optoelectronic devices and materials (spatially and temporally resolved photoluminescence and Raman), III-V fabrication and monolithic integration techniques (dry etching, quantum well intermixing, oxidation).

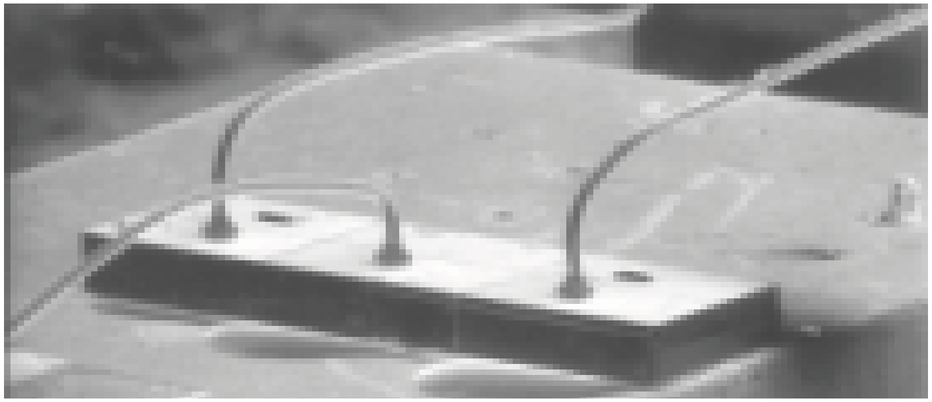
Example 1: NLO

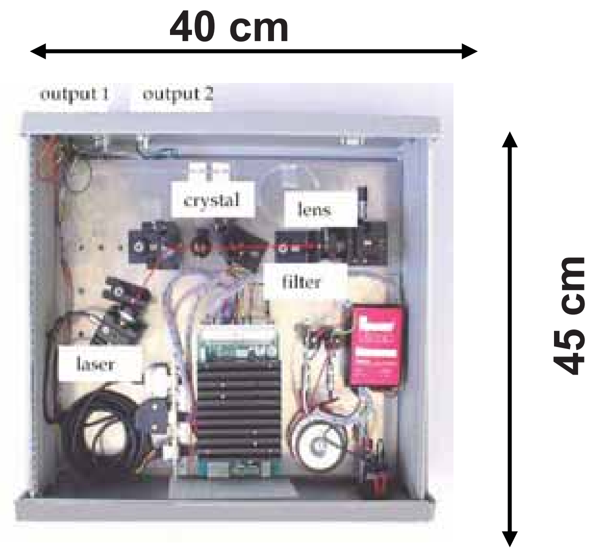
- Semiconductors do not allow the use of some non-linear coefficients due to symmetry
  - One example is the $\chi^{(2)}$ coefficient which is responsible for mixing frequencies
    - Materials could however be engineered to have a finite $\chi^{(2)}$ coefficient through nano-structuring





Outcome: OPO Chip

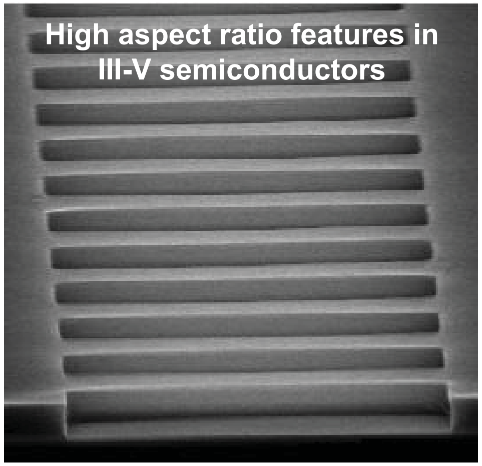


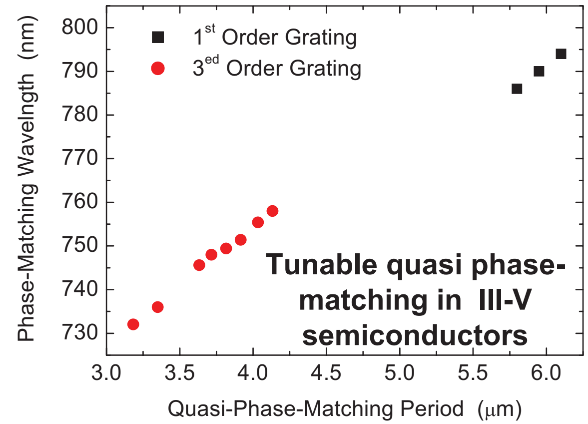


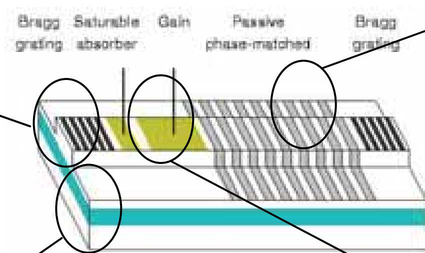
GAP Optique Geneva

Coherent Sources

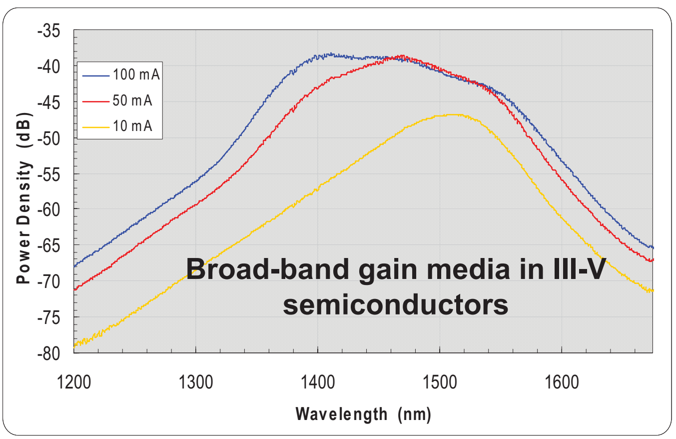
Rugged, efficient coherent sources for **1-17 μm** radiation based on GaAs linear + non-linear integrated devices



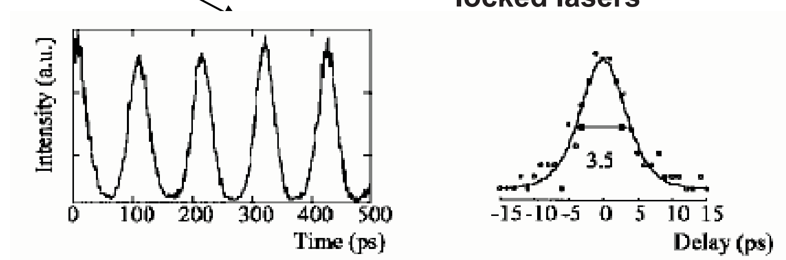




Integrated Optical Parametric Oscillator



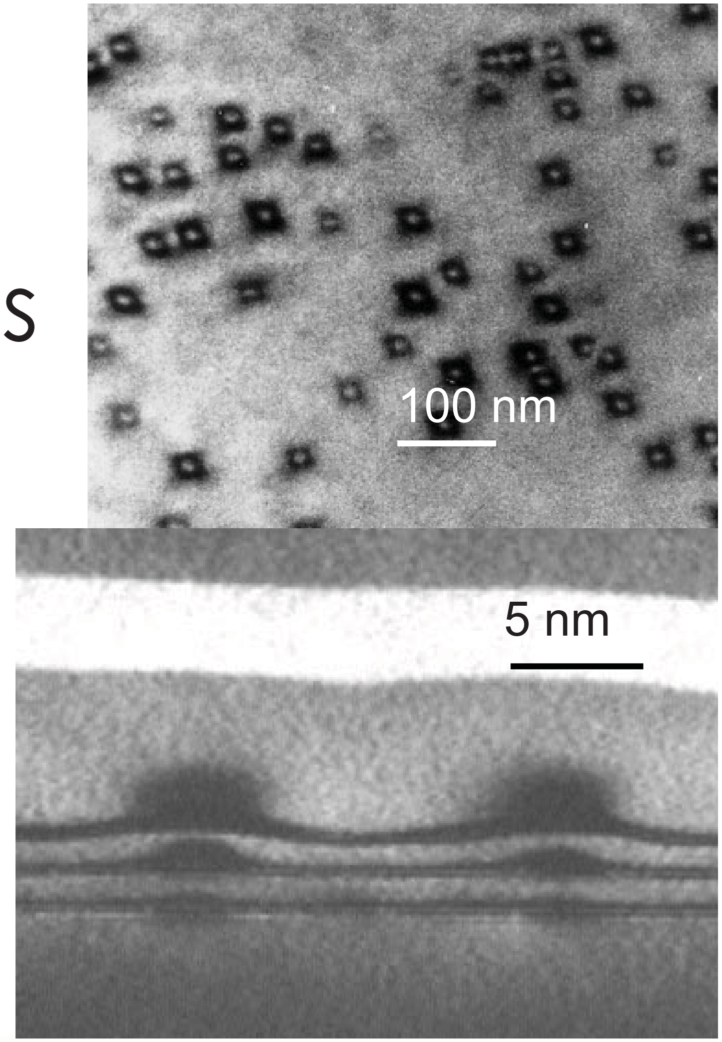
Integrated short-pulse mode-locked lasers



a.helmy@utoronto.ca

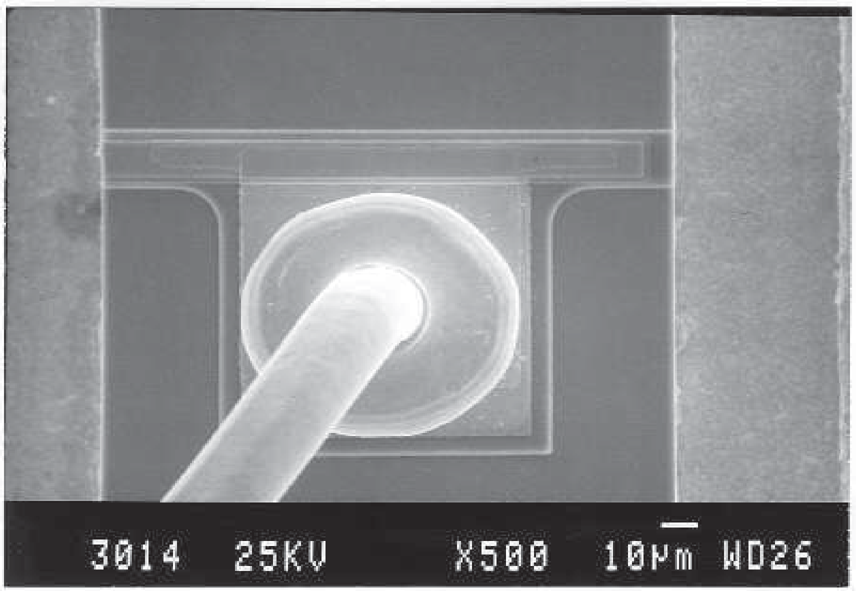
Example 1: QDs

- Quantum dots in semiconductors are grown via strain effects
  - They have radii of a few nm
  - Their modified density of states offers benefits to
    - light emitters,
    - detectors,
    - biological sensors,
    - environmental monitors,
    - ....



Quantum Dot Lasers

- Due to the 0-D like density of states offered by QDs
  - Can provide high power
  - High temperature of operation
  - Large modulation bandwidths
  - Emission wavelengths beyond what we have



Prof. P.R. Herman
B.Eng. (McMaster), M.Sc.(Toronto), Ph.D. (Toronto)
Professor; Graduate Group Secretary

Office: GB442
Tel: 416-978-7722
Fax: 416-971-3020
E-Mail: hermanp *(@ecf.utoronto.ca)*
Website:
http://photonics.light.utoronto.ca/laserphotonics

Brief Research Description

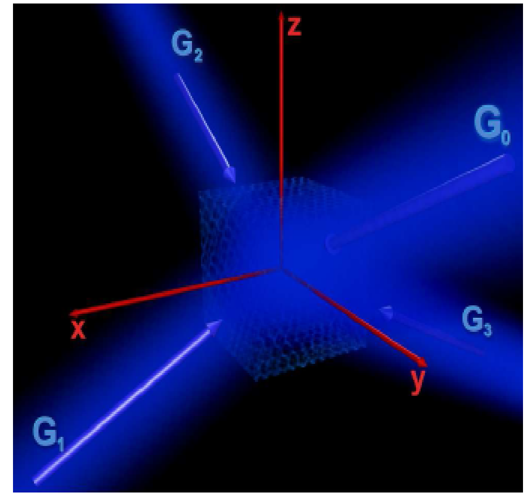
Novel laser processing technology for photonic devices and optical circuits.

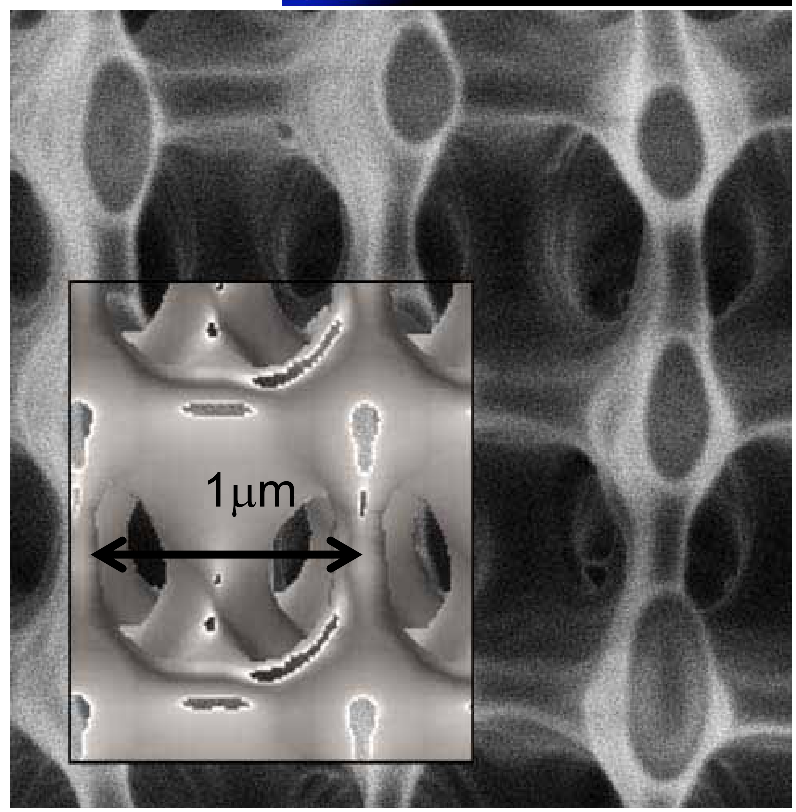
- 2-D and 3-D nanofabricated optical materials
- optical communication networks
- biophotonic lab-on-a-chip
- sensors

Three forefronts of laser technology

- shorter wavelength lasers in micro-structuring miniature optical devices directly inside optical fibers, optical circuits, and bulk 3-D glasses.
- ultra short-light pulses for *cutting and etching* or *trimming refractive index* in optically transparent materials → direct-write waveguides.
- 3-D laser holographic nanolithography: 3-D nanomolding of new optical materials/devices

Laser Holographic 3-D Lithography





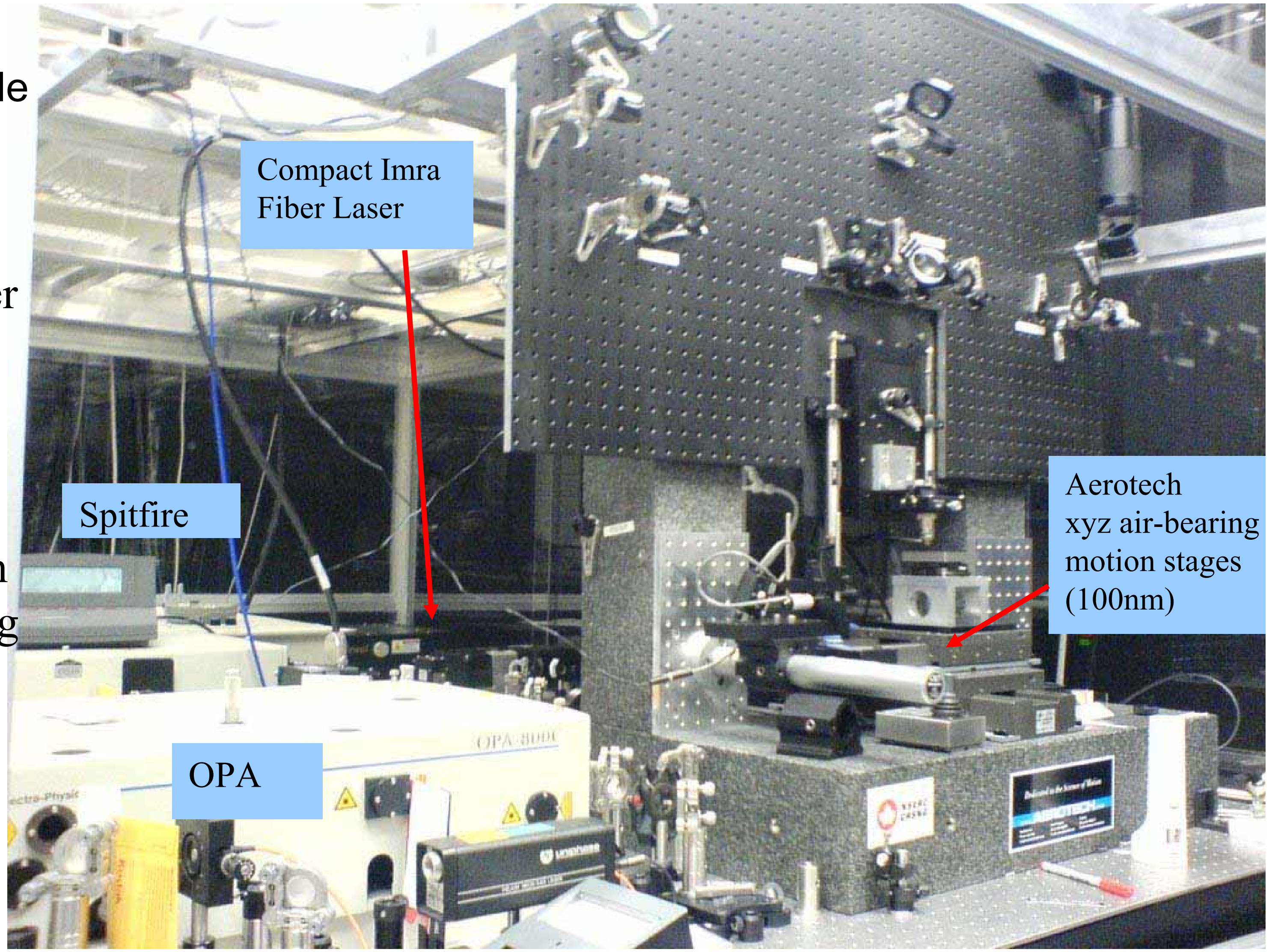
3-D Photonic Crystals

Burst Ultrafast Laser 3-D Nanofabrication

-Modified burst-mode kHz laser (Spitfire)

-Compact fiber-amplified MHz laser (Imra America)

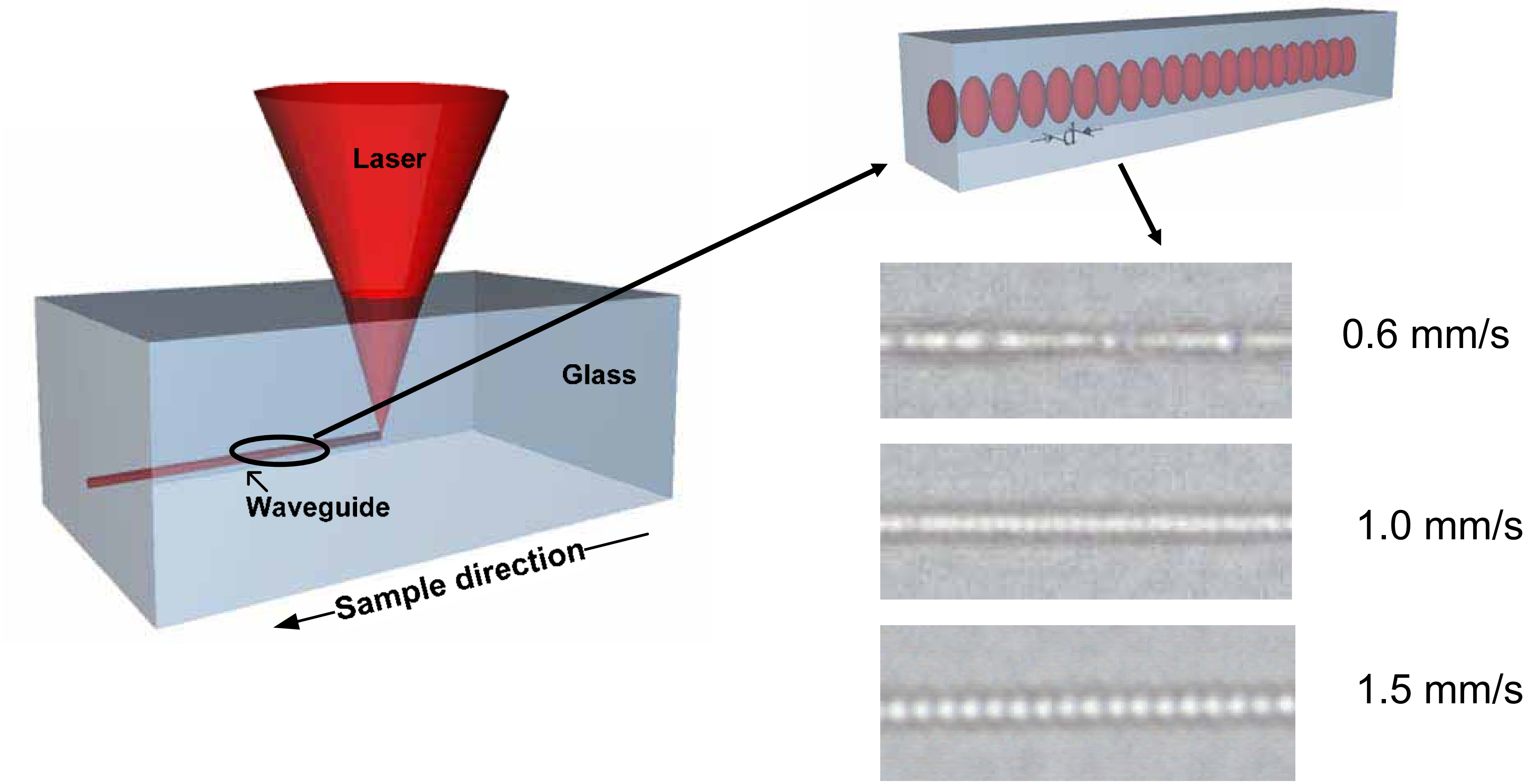
-High resolution optical processing station with 100-nm precision air-bearing xyz positioning stages

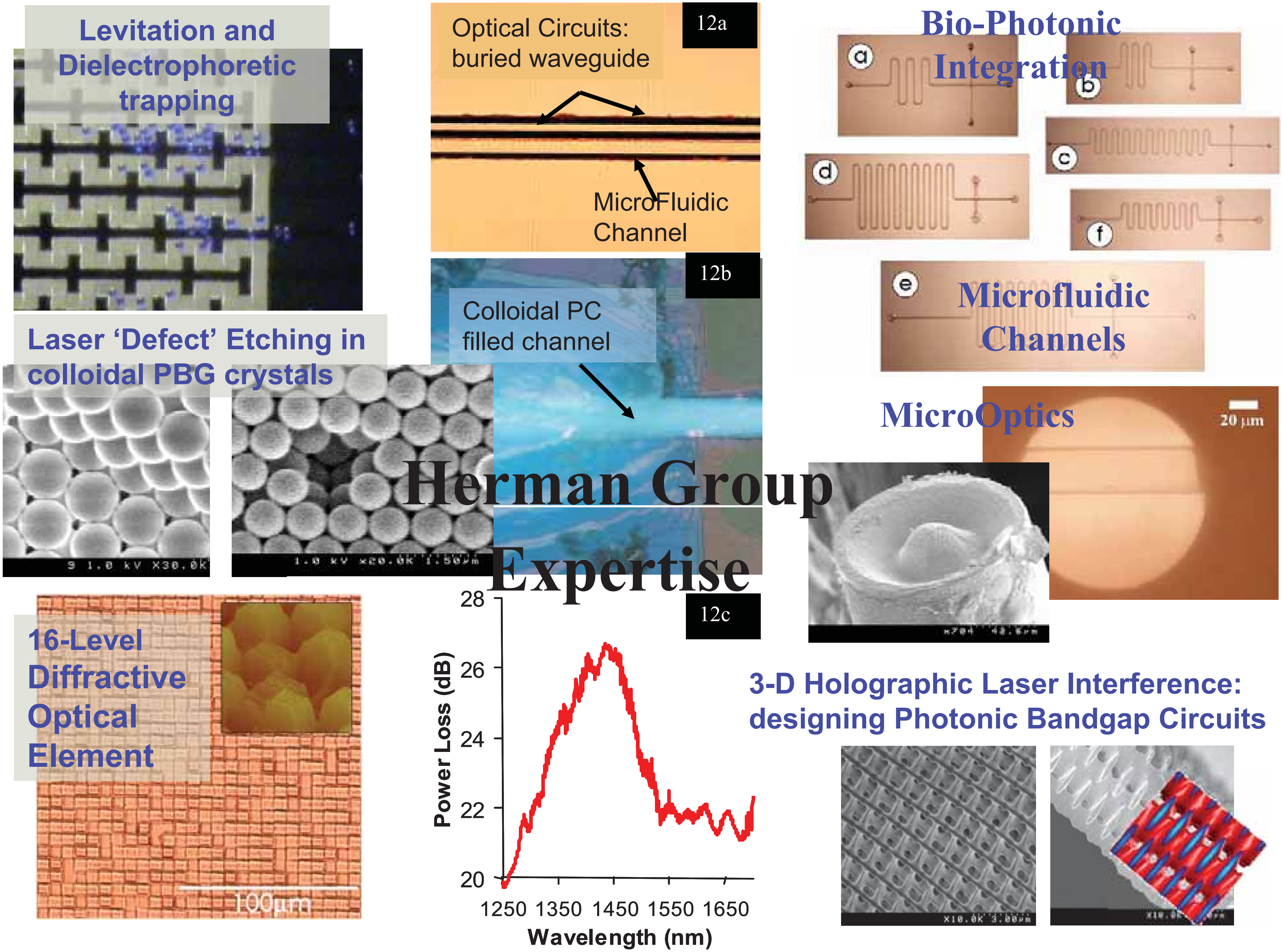


Bragg Grating Filter- Light Circuits

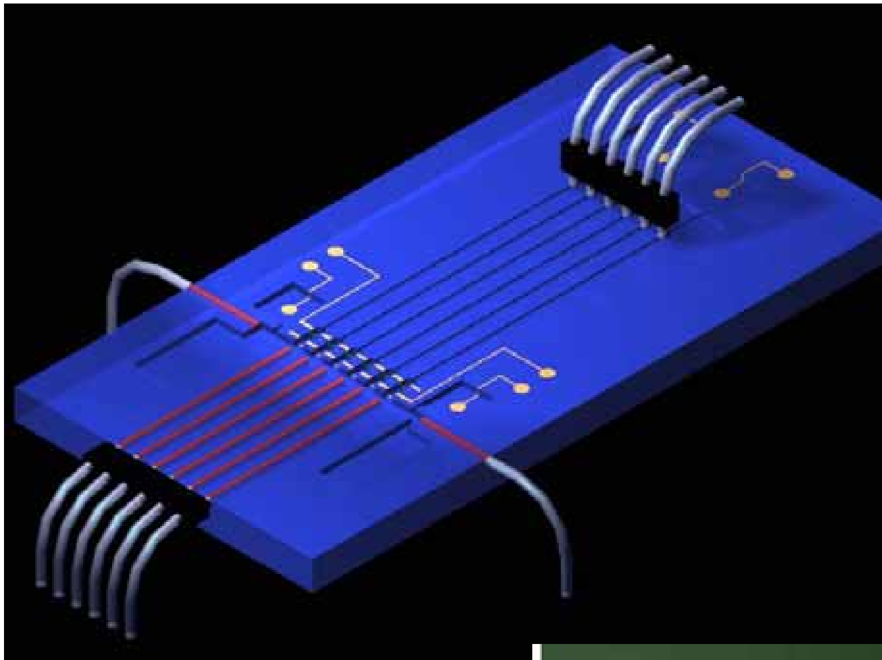
Type II waveguide writing scheme

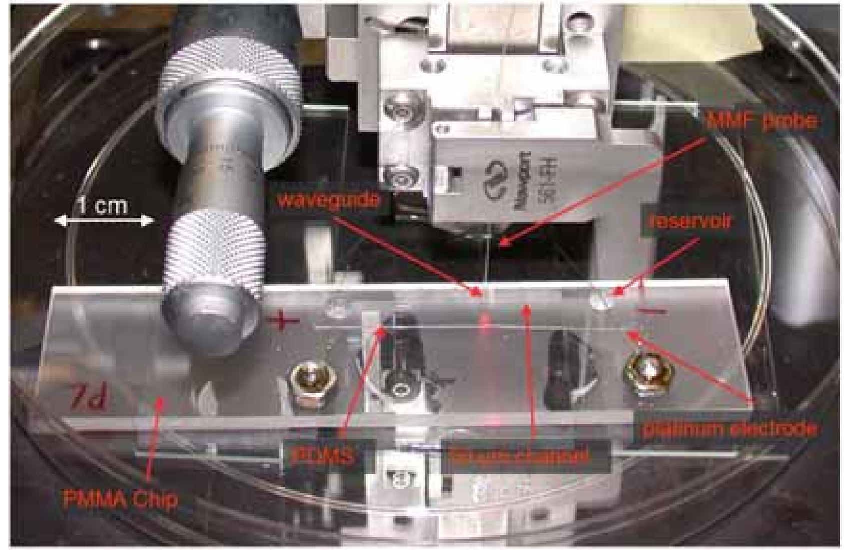
At high scan speed of ~1mm/s

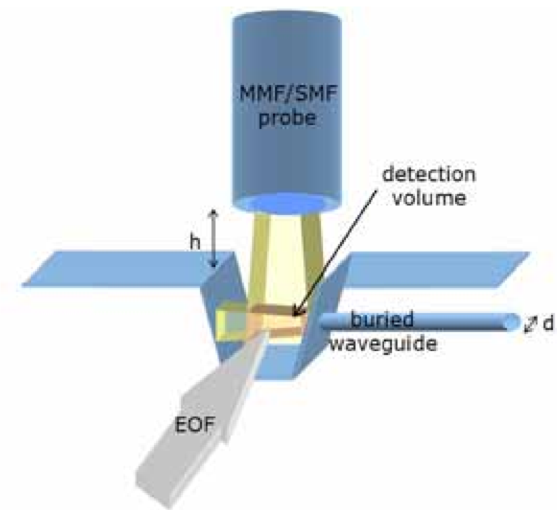


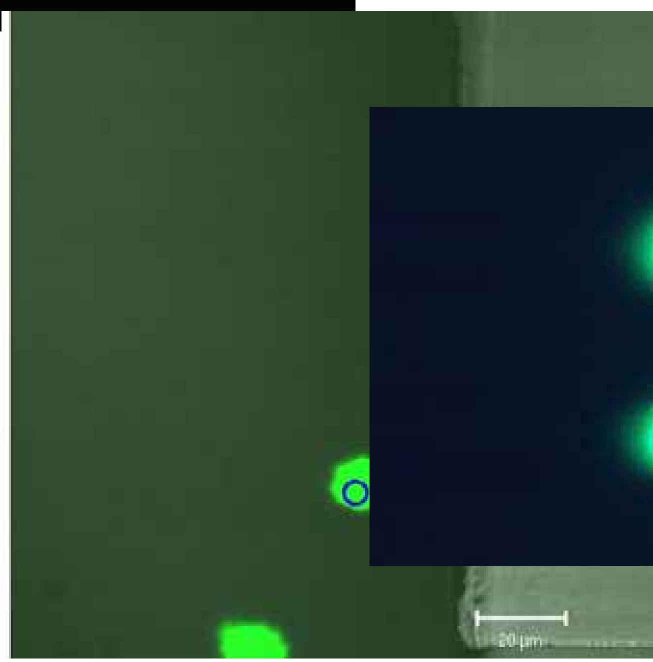

Herman Group Expertise
Levitation and Dielectrophoretic trapping
Optical Circuits: buried waveguide
12a
MicroFluidic Channel
12b
Colloidal PC filled channel
Bio-Photonic Integration
a
b
c
d
e
f
Microfluidic Channels
MicroOptics
20 µm
Laser 'Defect' Etching in colloidal PBG crystals
16-Level Diffractive Optical Element
100µm
12c
Power Loss (dB)
28
26
24
22
20
1250 1350 1450 1550 1650
Wavelength (nm)
3-D Holographic Laser Interference: designing Photonic Bandgap Circuits

Biophotonic lab-on-a-chip: with BioMed Physics, UofT









Prof. N. Kherani
B.A.Sc. (Toronto), M.A.Sc. (Toronto), Ph.D. (Toronto)
Associate Professor

Office: GB254C
Tel: 416-946-7372
Fax: 416-971-2326
E-Mail: mailto:kherani *(@ecf.utoronto.ca)*
Website:
http://www.ecf.utoronto.ca/~kherani/

Brief Research Description

Materials and devices research and development program in the areas of thin film amorphous silicon and carbon and emerging nanocrystalline materials for application in the fields of renewable-sustainable energy (photovoltaics and hydrogen as an energy vector) and micro-opto-electronics (rigid and flexible substrates).

Prof. M. Mojahedi
B.S. (New Mexico), M.S. (New Mexico), Ph.D. (New Mexico)
Assistant Professor

Office: BA5124
Tel: 416-978-0562
Fax: 416-978-0804
E-Mail: mojahedi *(@waves.utoronto.ca)*
Website:
http://www.waves.utoronto.ca/prof/mojahedi/mo.html

Brief Research Description

Matter wave interactions, meta-materials, photonic crystals, dispersion engineering, abnormal velocities, quantum dots and wells, band engineering, fundamental electromagnetic theory, efficient antennas with periodic substrates, macro and nano-scale microwave and photonic systems.

Prof. L. Pavel
B.Sc. (Iasi), Ph.D. (Queen's)
Assistant Professor

Office: GB343A
Tel: 416-946-8662
Fax: 416-978-0804
E-Mail: pavel *(@control.utoronto.ca)*
Website: http://www.control.toronto.edu/~pavel

Brief Research Description

Application of system theory and control to optical communication networks. Novel techniques and methods for dynamical compensation of optical transmission impairments. Dynamics and transient control for optical amplifiers, dynamic filters, interconnected optical network. Advanced control methods (robust and adaptive control, real-time optimization) applied to agile optical networks.

Prof. L. Qian Waleed Mohammed, Bing Qi

B.A.Sc. (Toronto), M.A.Sc. (Toronto), Ph.D. (Toronto)
Assistant Professor

Office: GB443
Tel: 416-946-5517
Fax: 416-971-3020
E-Mail: l.qian *(@utoronto.ca)*
Website: http://www.ecf.utoronto.ca/~qianli

Brief Research Description

Photonic material, devices, and components - Novel semiconductor materials, ultrafast optical phenomena in semiconductors, ultrafast optical switching devices, micro-optical packaging; Advanced optical amplifier technology - extended bandwidth amplification, transient gain control, module integration and miniaturization, high concentration erbium-doped fibre amplifier modeling.

Fiber Optics – Trillion-Dollar Industry

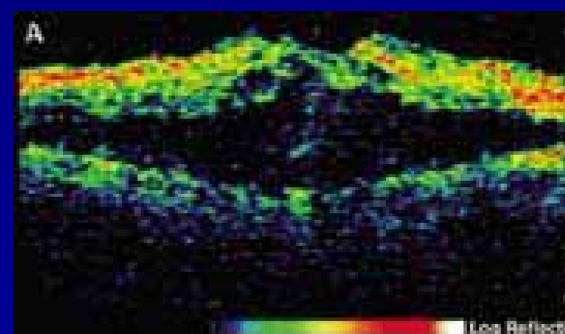
Most wide-spread commercial applications in Photonics

Communications

Sensing

Largest Employment in Photonics is in Fiber Optics !

High-power cutting/welding



Medical Imaging

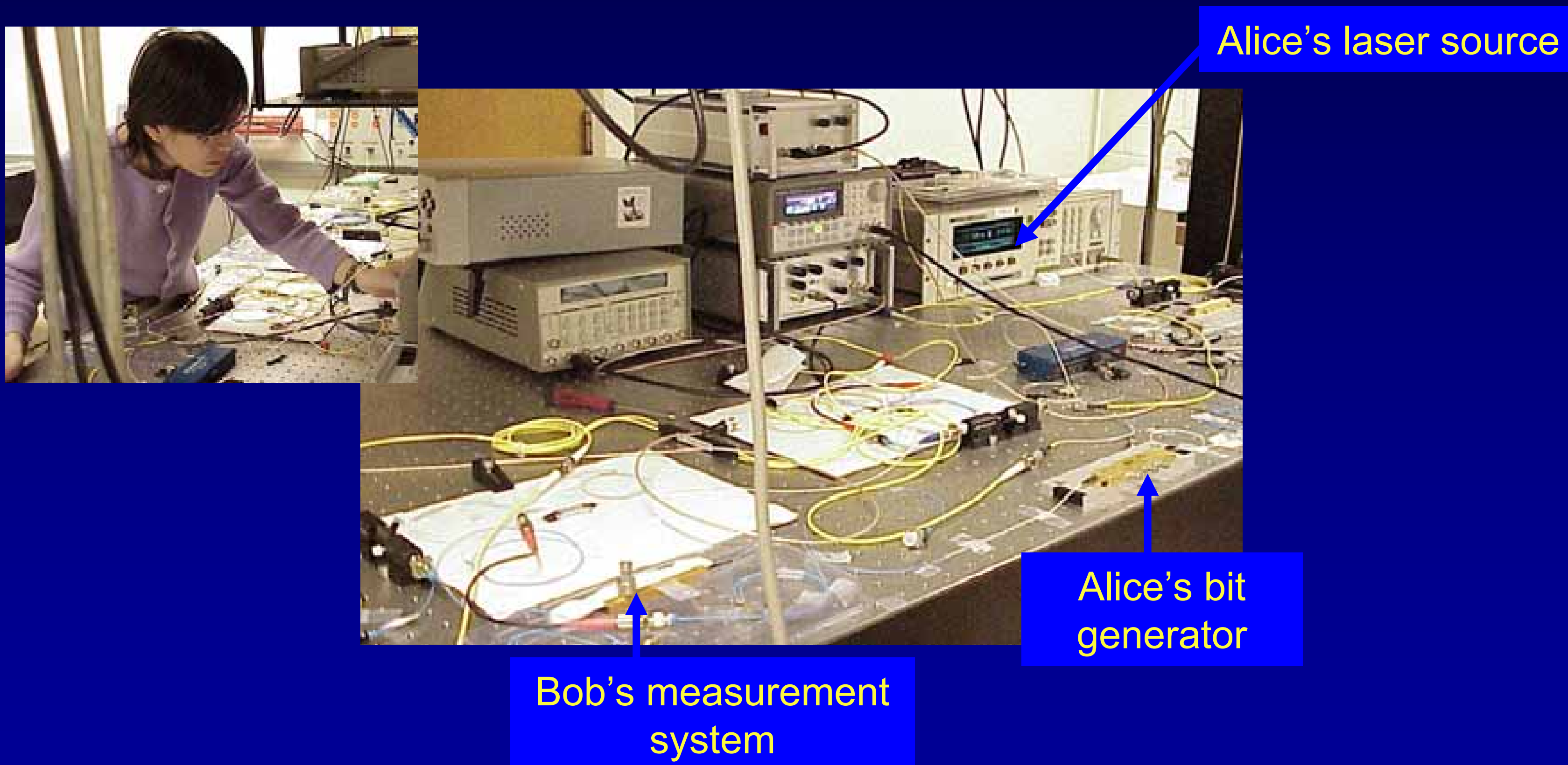
Join Qian's Fiber Optics Group

Experimental Quantum Communication
Ultrafast Photonics / Nonlinear Photonics
Measurements & Instrumentation

Prof. Li Qian
Canada Research Chair in
Photonic Technologies and Applications

Research Area I – Experimental Quantum Key Distribution (QKD)

Quantum communication = The most secure way to communicate

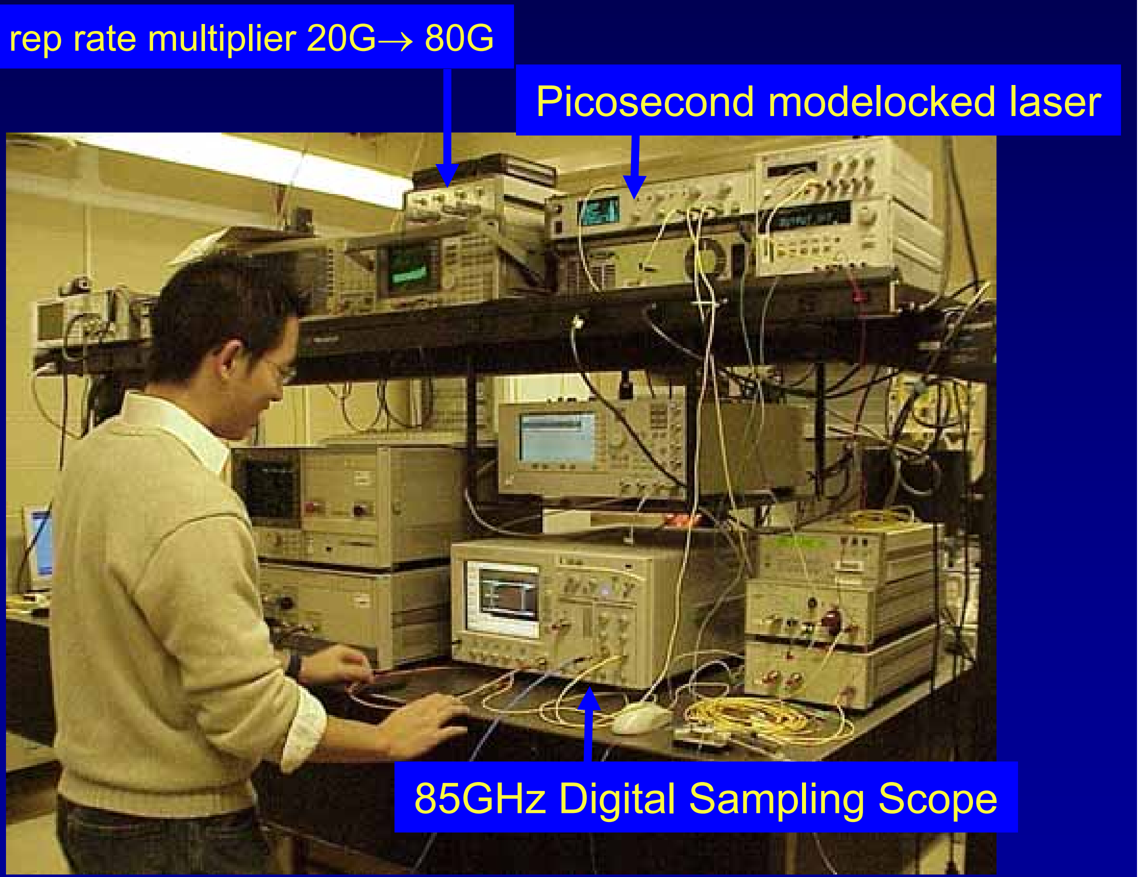


Our Goal: Making Quantum communication practical = implementing in fiber

Research Area II – Ultrafast/Nonlinear Photonics

Optical signal processing = The fastest way to process signals

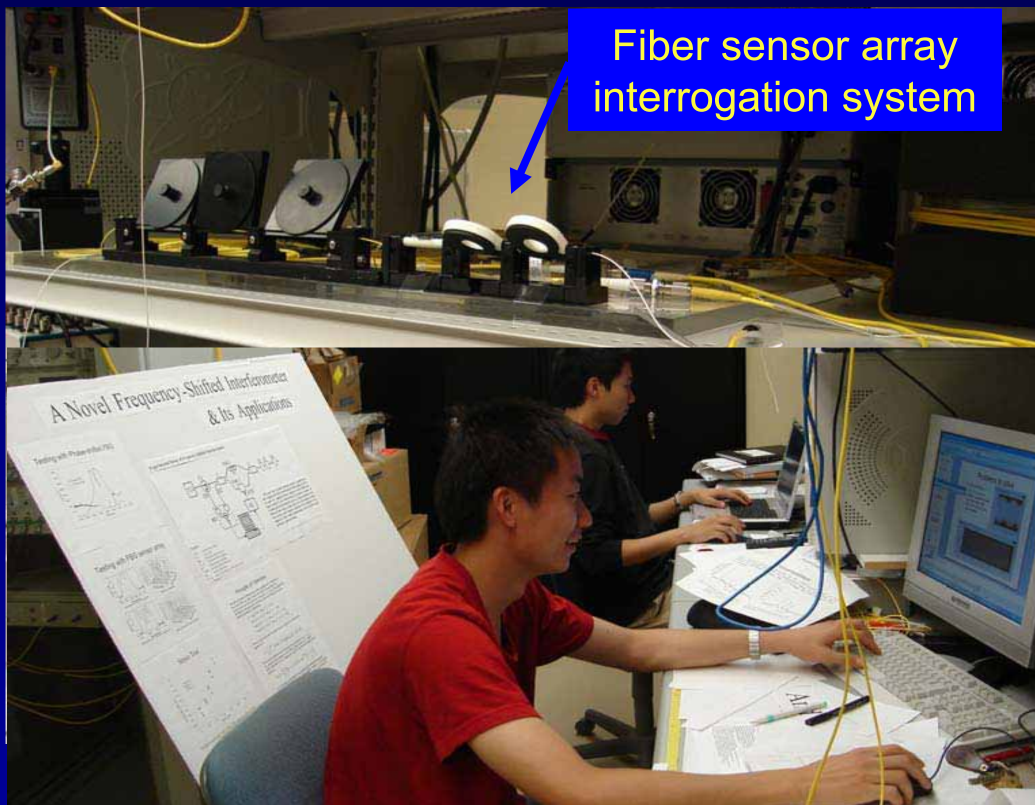
- Pulse shaping
- High-speed (80Gb/s) optical time domain demultiplexing
- Nonlinear optics – Mid-IR generation in fiber



Our Goal: Making optical signal processing competitive = implementing in fiber

Research Area III – Optical Measurements & Instrumentation

Optical measurement = The most accurate way to measure



- Low-cost dispersion measurement
- Fiber sensor array interrogation

Our Goal: Making precision optical measurement cheap = implementing in fiber

Prof. H.E. Ruda
B.Sc. (London), Ph.D. (MIT)
Energenius Professor of Advanced Nanotechnology;
Centre for Advanced Nanotechnology

Office: MB202B
Tel: 416-978-4556
Fax: 416-978-3801
E-Mail: ruda *(@ecf.utoronto.ca)*
Website: **http://www.utoronto.ca/~emg**

Brief Research Description

Molecular beam epitaxy of optoelectronic materials and devices; scanning probe based nanolithography; optical and electronic properties of quantum heterostructure including quantum boxes, wires and wells; influence of surfaces and interfaces on performance of photonic/electronic devices; virtual reality artificial intelligence system for atomic level manufacturing of nano-devices; microelectromechanical systems for photonics.

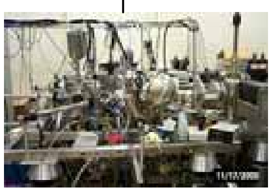
GROUP PROFILE

FACILITIES: Fabricn., Process. & Characterisn.

EPITAXY ANDROCESSING

CHARACTERIZATION

MBE
- ATC-EP3 MBE System
- UHV SPM-Based Nanolithography System



Class 100/1000 PROCESSING

LITHOGRAPHY
- Karl Suss Double Sided Mask Aligner
- Raith e-Beam Lithography

DEPOSITION
- Solution Synthesis of Quantum Dots
- SolGel Processing
- RF Plasma Ferroelectric Deposition
- Thermal Evaporator for Metallization
- Electron- Beam Metallization

ETCHING, RTA, AND BODING
- RTA
- K&S Wire Bonder and Wafer Scriber
- Samco Load-Locked Plasma Etcher

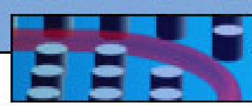
OPTICAL CHARACTERIZATION
- Polarization-Resolved LT μ-PL Imaging
- SPV
- PR and ER
- Ultrafasr system : Mira 900 Ti:Sapphire & OPO

ELECTRICAL CHARACTERIZATION
- Hall Effect System
- IV & Variable Frequency CV
- DLTS
- Radiant Ferroelectric Test System
- Omicron VT Deflection AFM
- Oxford Kelvinox Dilution Fridge Magneto-Transport System

EPMG

University of Toronto

electronic-photonic materials group

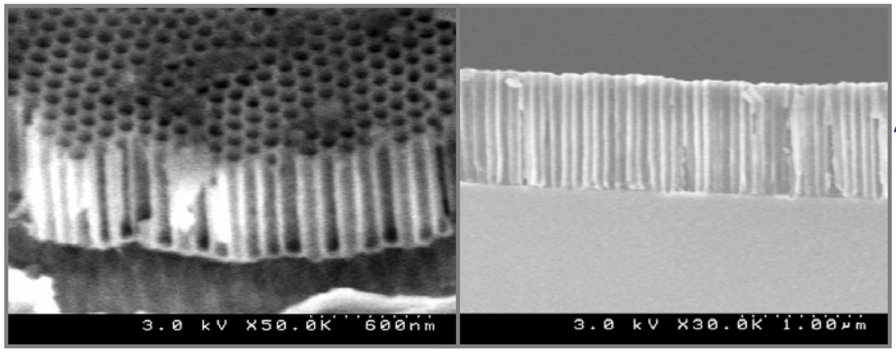


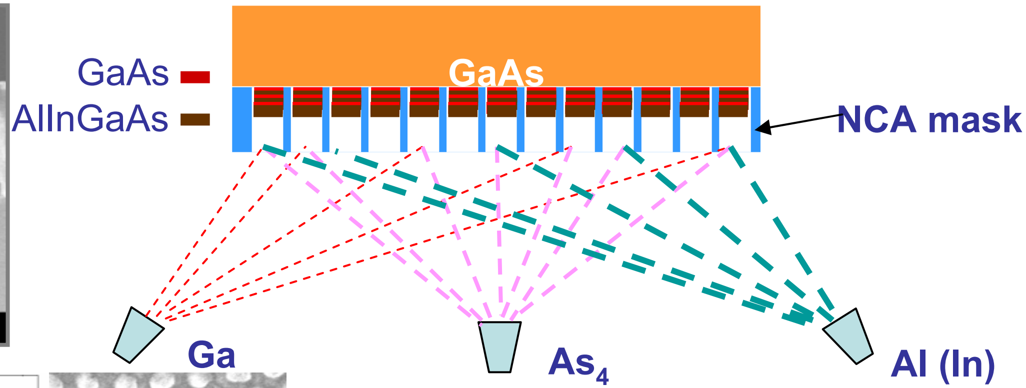
harry.ruda@utoronto.ca

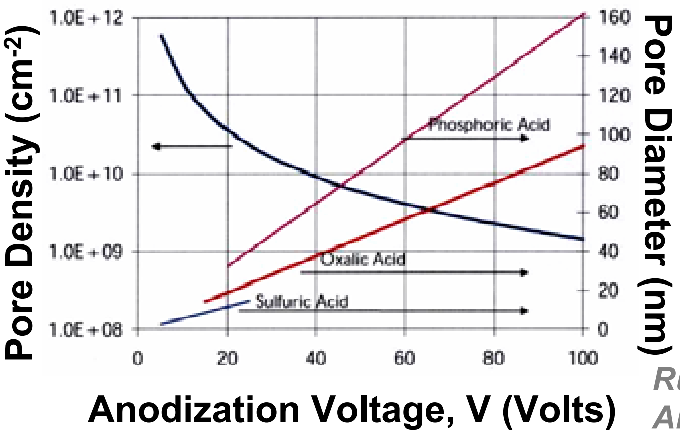
http://www.utoronto.ca/~emg

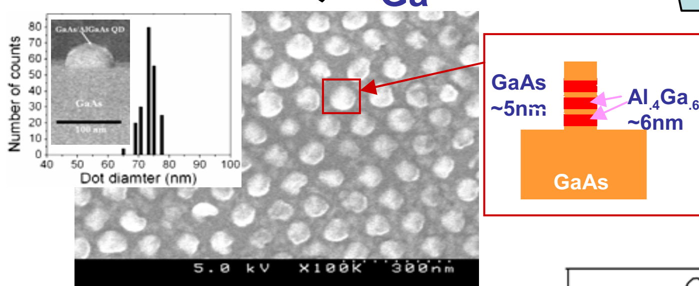
GROUP PROFILE

PROJECT AREAS: 1. QD Heterostructure Arrays

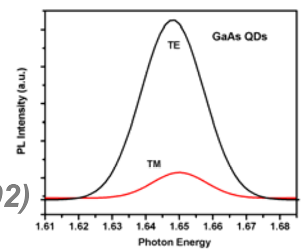


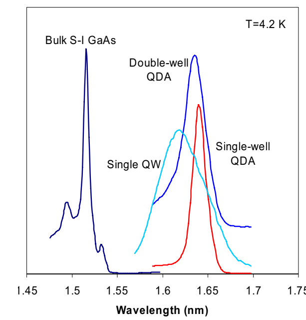






Ruda et al.,
APL: 82(7),967(2003);81(2),361(2002)
JJAP: 42,L508(2003); 41(12),7297(2002)
JCG: 251(1-4),253(2003)



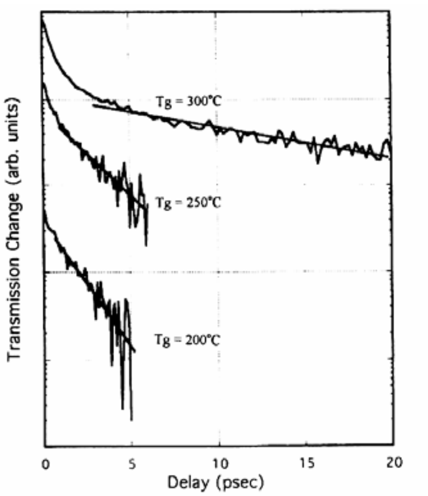


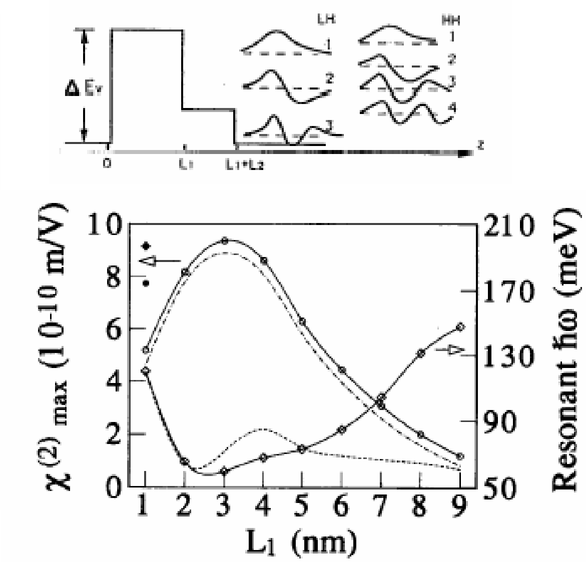
harry.ruda@utoronto.ca

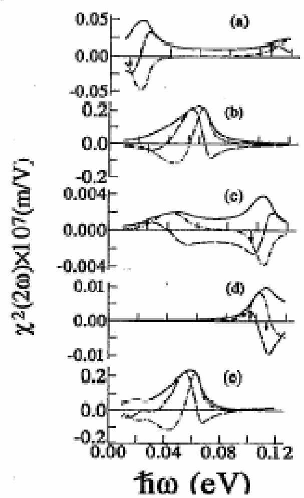
http://www.utoronto.ca/~emg

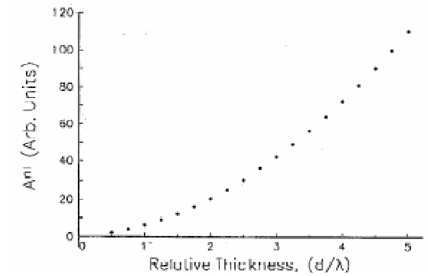
GROUP PROFILE

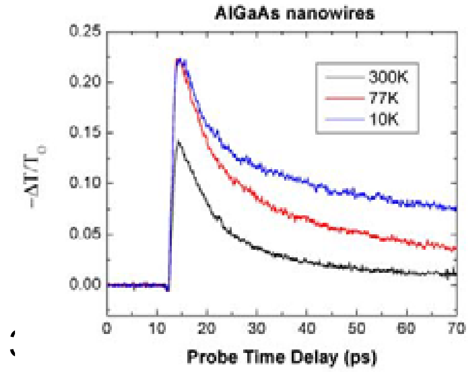
PROJECT AREAS: 4. Ultrafast/Nonlinear Nanostr











Differential transmission for LT-GaAs: T_g = 200, 250 and 300°C (anneal:700°C for 3
Corresponding carrier lifetimes: 1.5, 2.2 and 12 ps.

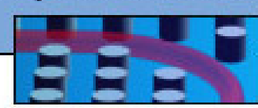
AQWs: SHG (interband, intraband), FDM in 2d and 1d

Ruda et al. in:

- *Phys. Rev. B6308(8), pp.5203-5207(2001); B50(8), pp.5703-5706(1994)*
- *APL: 62, (16), pp.1946-1998(1993); 65(25), pp.3176-3178(1994)*
- *JAP, 75, (1), pp.54-57(1994)*
- *IEEE J. Quant. Electron., 31(2), pp.228-231(1995)*
- *Bull. Amer. Phys. Soc., 44, pp.195-199(1999)*
- *Nanotechnology 12, pp.523-528(2001)*

EPMG
University of Toronto

electronic-photonic materials group



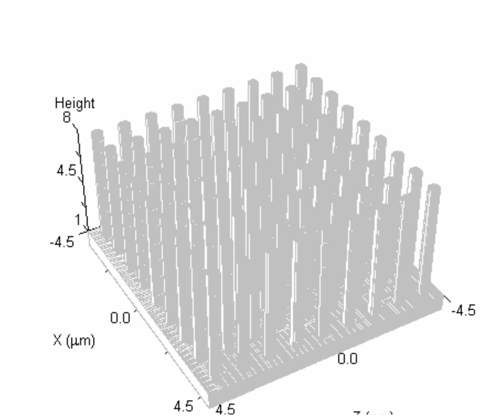
harry.ruda@utoronto.ca

http://www.utoronto.ca/~emg

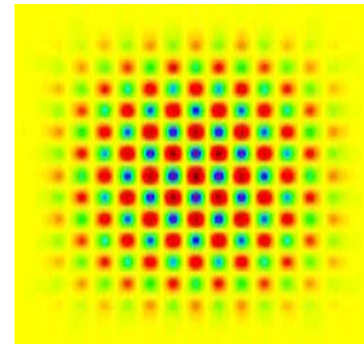
GROUP PROFILE

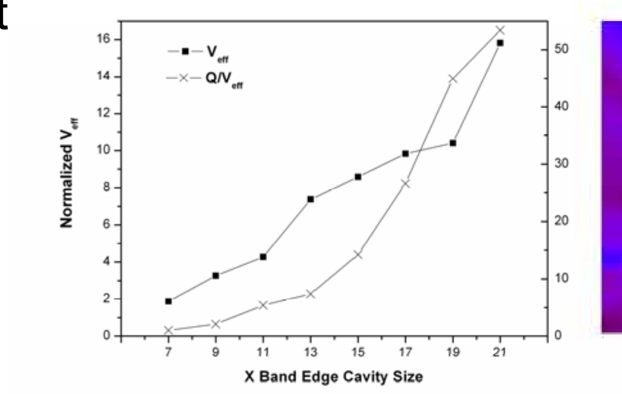
PROJECT AREAS: 4. Cavities & Laser Arrays

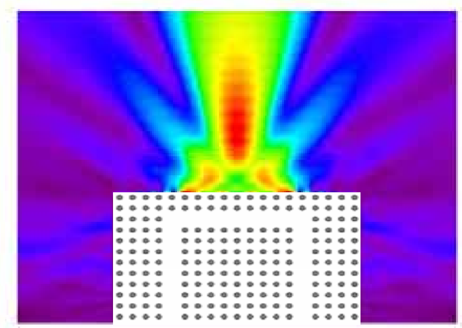
- **Interaction of light & matter dramatically altered by presence of microcavity** – depends on photon lifetime in cavity (Q) and spatial localization (V_{eff}) [i.e., energy density of field]: Great importance for μlasers ⇔ enhanced spontaneous emission: Purcell factor ~ Q/ V_{eff}.
- **Nanowire μcavities** based on a defect mode in a photonic crystal band gap, or operating around the band edge, **can have high Q values and extremely small V_{eff}.**
- **Currently working on fabricating nanowire array μcavities** – calculated Purcell factors >50



(1,1) Mode







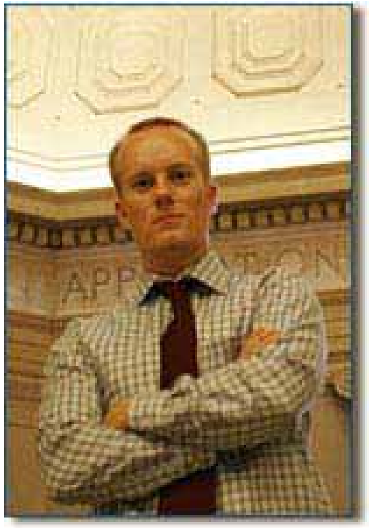
EPMG
University of Toronto
electronic-photonic materials group

harry.ruda@utoronto.ca
http://www.utoronto.ca/~emg

OPPORTUNITIES FOR NEW STUDENTS

SOME AVAILABLE TOPICS

- Using selected area MBE growth for nanoscale laser/photodetectors
- Developing a nanoscale single photon source
- Spin-based optical devices using nanowires
- Using 3d nanoscale heterostructures for non-linear and ultra-fast switching devices
- Studying excitons in arrays of coupled nanosystems
- Integration of nanoscale emitters/detectors with Photonic Crystals
- Nanoscale optical imaging and processing with UHV VT-AFM



Prof. E.H. Sargent Sjoerd Hoogland

B.Sc. (Queen's), Ph.D. (Toronto)

Nortel Junior Professor of Emerging Technologies

Office: GB447

Tel: 416-946-5051

Fax: 416-971-3020

E-Mail: ted.sargent *(@utoronto.ca)*

Website: http://light.utoronto.ca/tsargent

Brief Research Description

Nanotechnology applied in energy, health, and information technology. Solution-processed semiconductor quantum dots emitting, sensing, and modulating light in the infrared spectral region. Monolithic integration of quantum dot detectors with silicon to produce infrared-sensitive focal plane arrays. Solution-processed photovoltaics sensitive in the infrared for efficient solar cells and for thermophotovoltaics. Light-emitting nanoparticles for biomedical imaging and early disease detection.

Professor Ted Sargent's group

Department of Electrical and Computer Engineering
University of Toronto

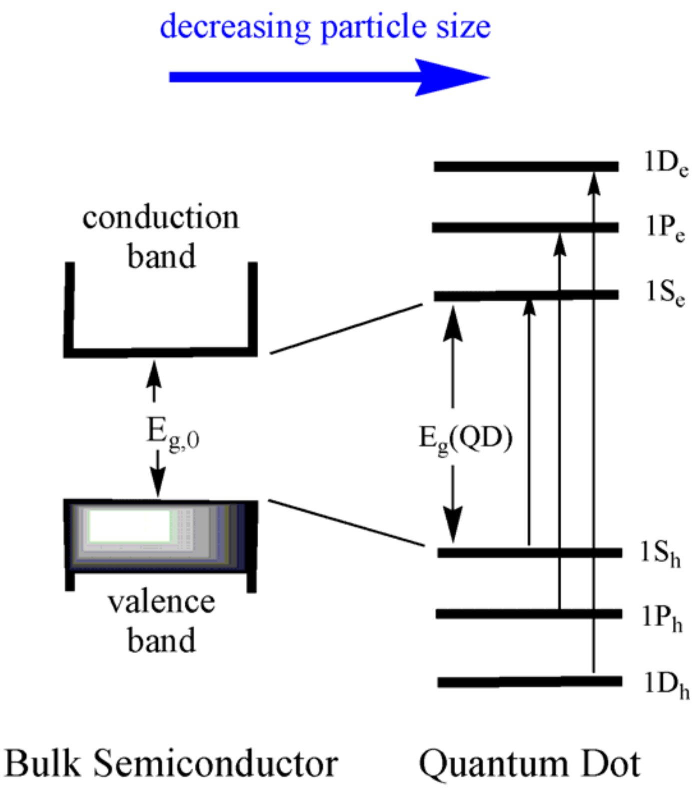
Office: GB447
Student office: GB402
Email: Ted.Sargent@utoronto.ca
Web: www.light.utoronto.ca

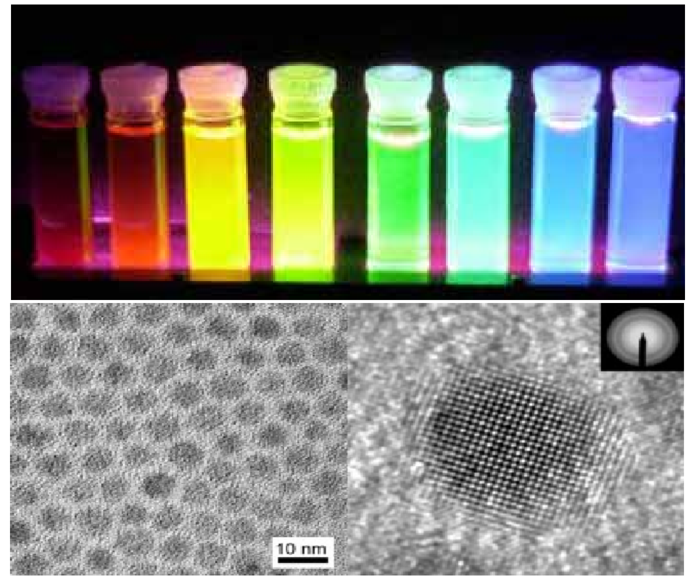
Nanotechnology:

"changing the world of optoelectronics from the bottom up"

Nanocrystals

'artificially changing material properties'





- 3 dimensional quantum confinement
- Discrete, atom-like energy levels
  => artificial building blocks of matter
- Optical/electrical properties size-tunable
- Cheap, easy synthesis
- Solution processible

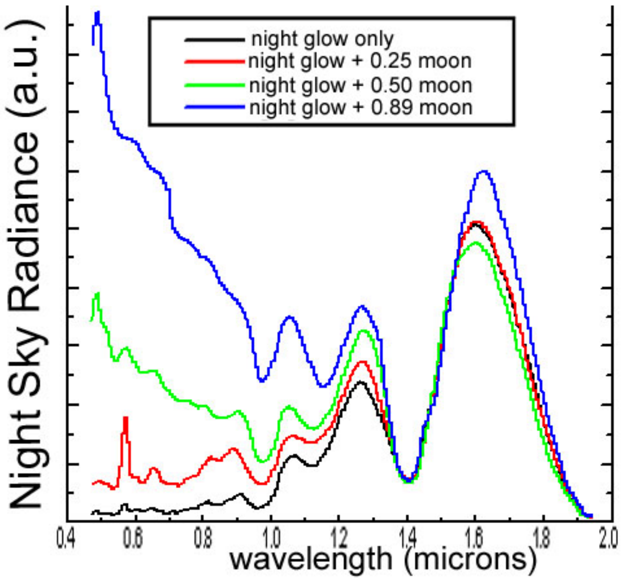
Material systems:

- Visible: CdS, CdSe
- Infrared: PbSe, **PbS**

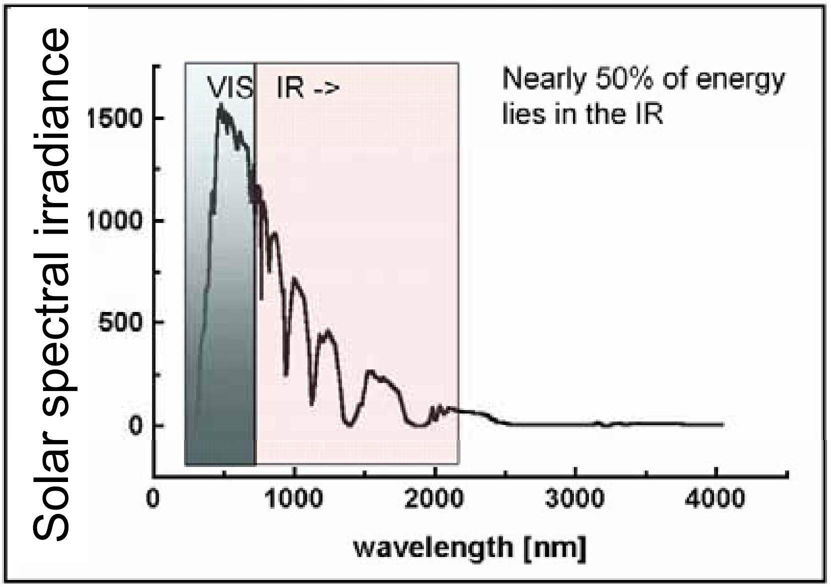
Ted Sargent group - ECE

Applications of near-infrared solution processable materials

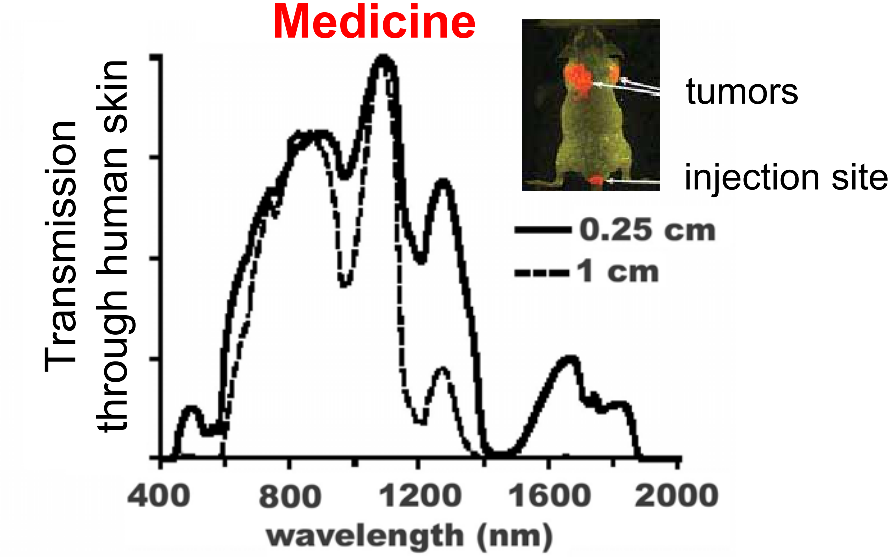
Night vision



Photovoltaics



Medicine



Optical interconnects

"Holy Grail in laser technology is a Silicon compatible coherent light source to save a multi-billion dollar industry"

Ted Sargent group - ECE

Daily tasks of a student in Ted Sargent's group

- Characterize nanocrystals received from group's chemists
  => electrical properties (conductivity, photo response, photovoltaic effect)
  => optical properties (absorption/emission spectrum, emission quantum efficiency)
- Make special electrodes in cleanroom
- Use optical setups to measure radiative lifetime (single photon counting system), excited carrier dynamics (ultrafast laser system), dynamical chemical properties of nanocrystals
- Perform chemical procedures to alter chemical surface of nanocrystal
- Make multilayer structures for electrical devices (spin coat nanocrystals, sputter/evaporate metal)

Prof. P.W.E. Smith [Stefan Myrskog]
B.Sc.(McGill), M.Sc. (McGill), Ph.D. (McGill), F.O.S.A., F.I.E.E.E.
Professor Emeritus

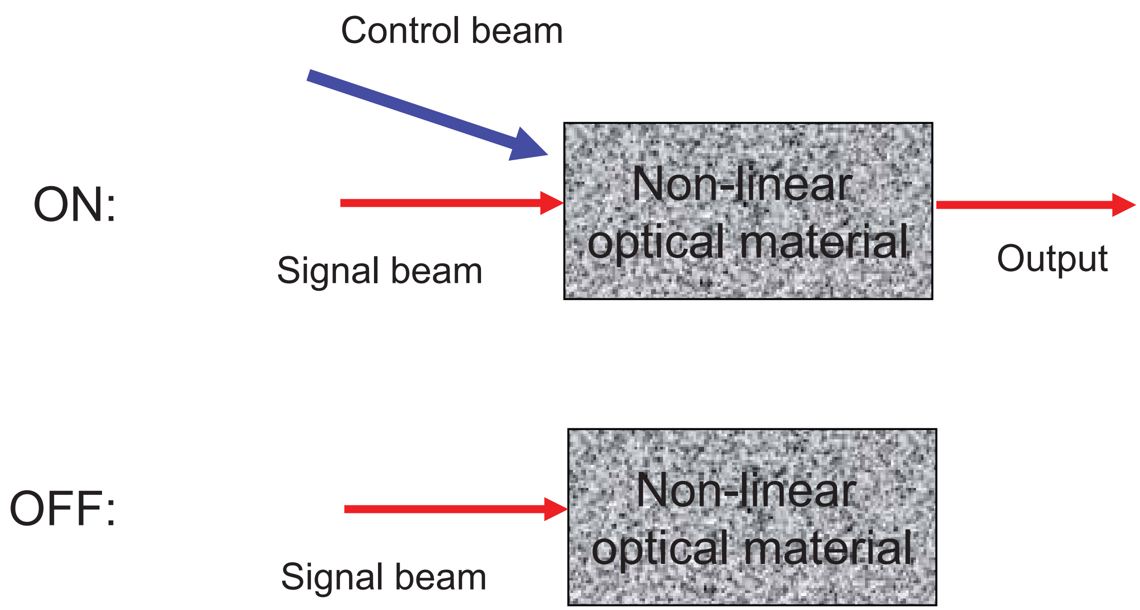
Office: GB444
Tel: 416-978-1646
Fax: 416-971-3020
E-Mail: pwes *(@ecf.utoronto.ca)*
Website: http://www.ecf.utoronto.ca/~upl/

Brief Research Description

Photonics; non-linear optical devices and phenomena; optical components for signal processing and communications systems.

All Optical switching in nano-crystals

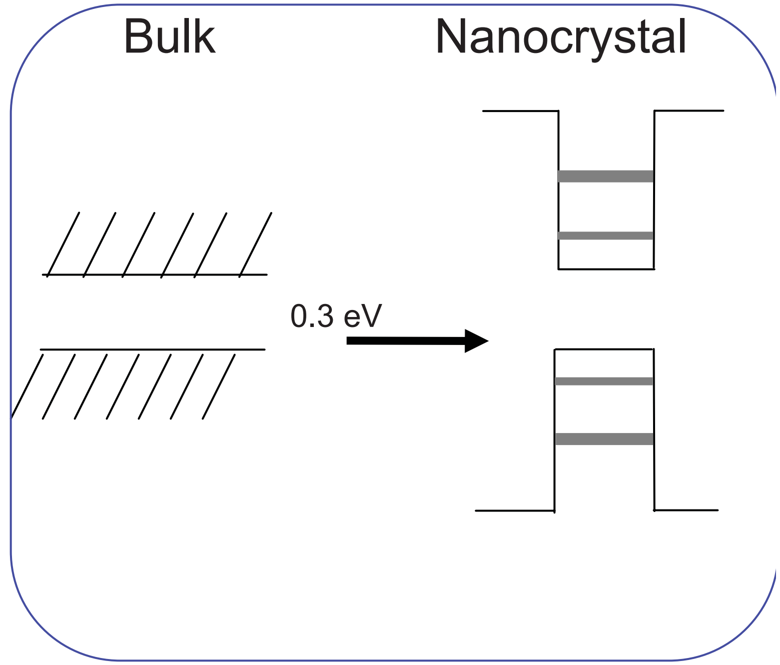
Stefan Myrskog

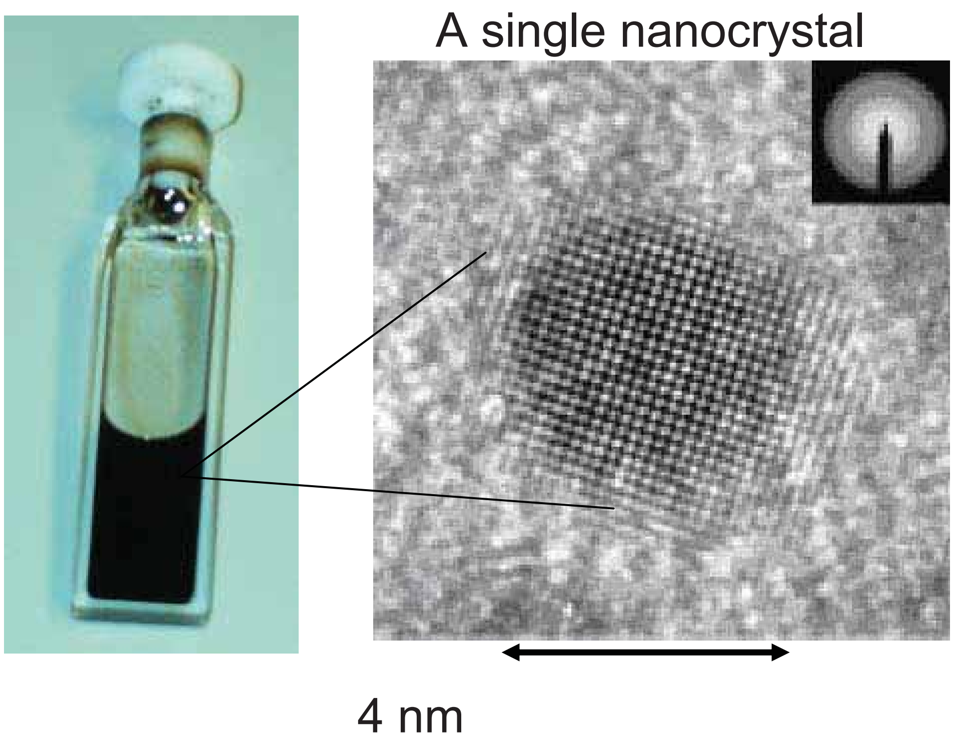


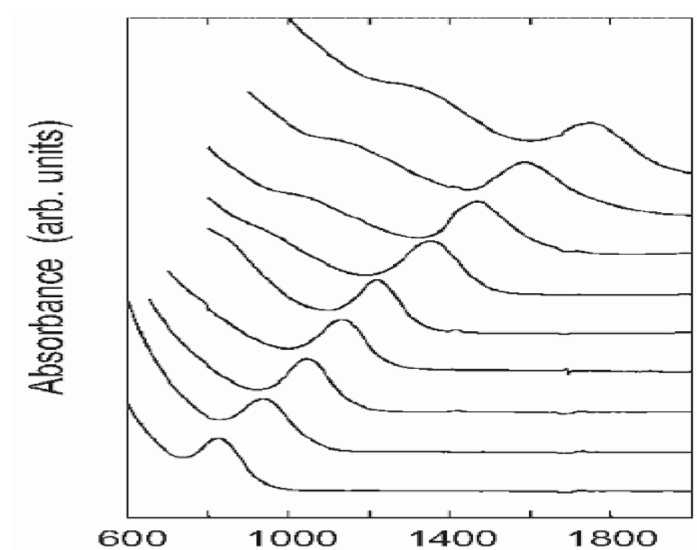
Supervisor: Prof. Peter Smith
in collaboration with
Prof. Ted Sargeant

Project

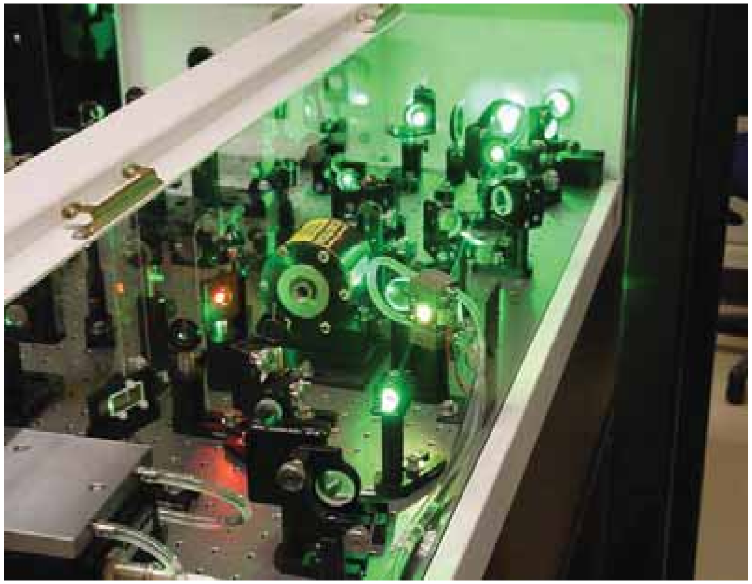
- All optical switching
  - all optical networks
  - optical computing
  - quantum computing/ quantum cryptography
- Why nanocrystal?
  - band gap/spectral response tuned by size
  - solution processable

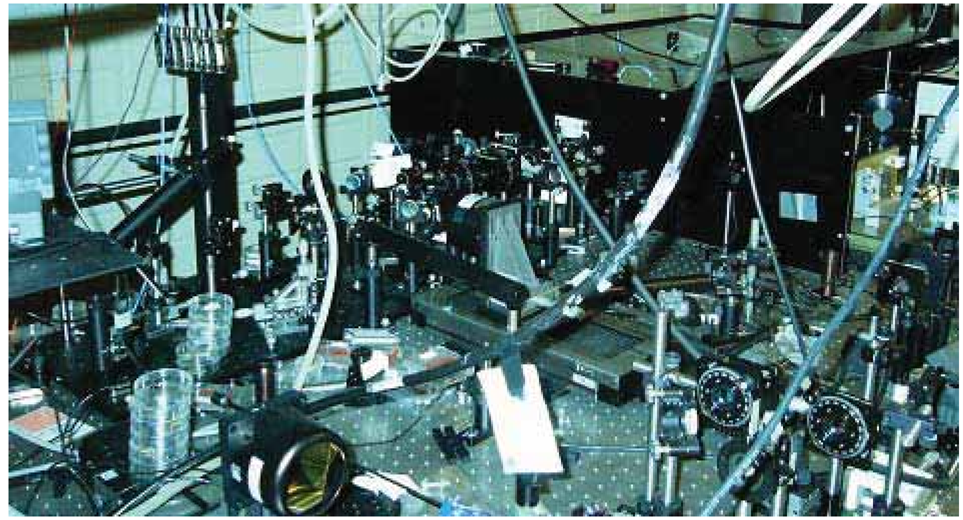






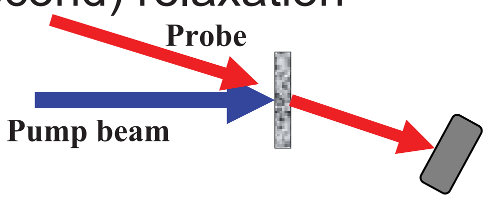
Organic and Polymer Optoelectronics Lab

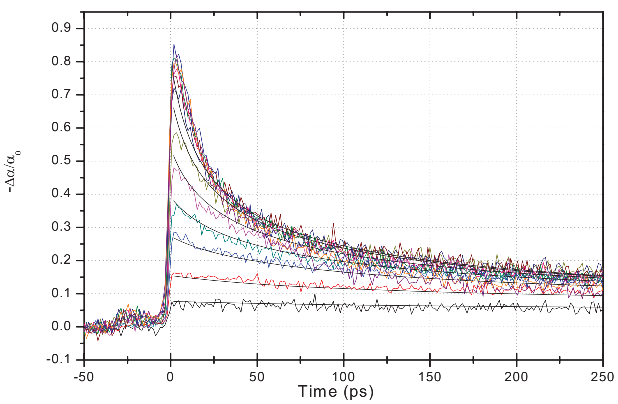




Transient absorption

- fast (picosecond) relaxation





Z-Scan:Nonlinear response

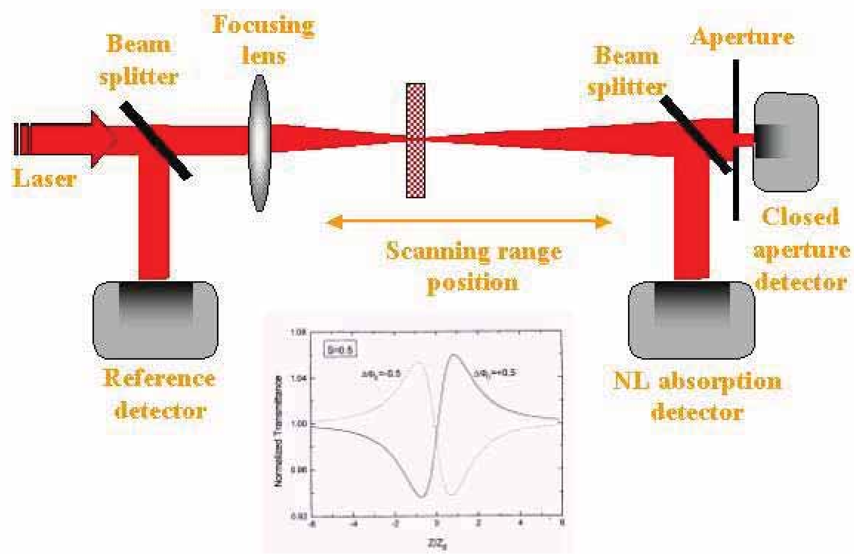
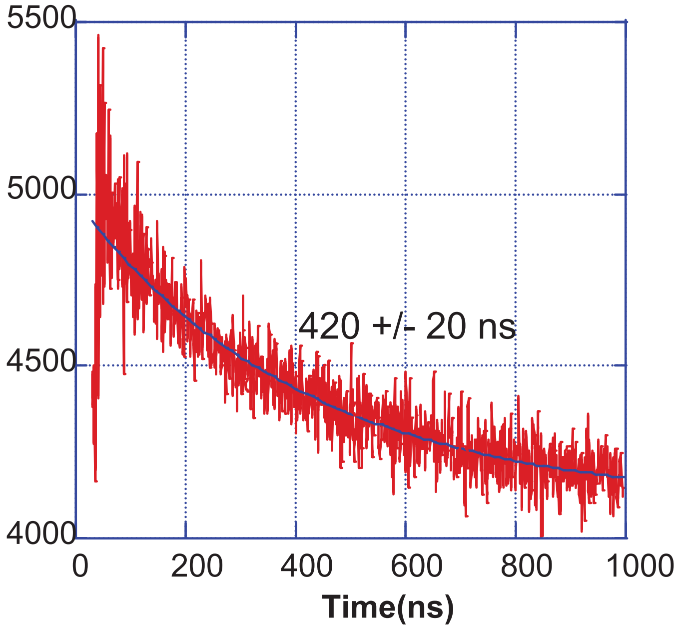


Photo-Luminescence

Time-correlated single photon counting

- Observe individual decay events on picosecond to second timescales

Time resolved Photo-luminescence



Current Work:

Identify trap states

Engineering nanocrystal surface

- photoconductively, charge separation, charge transport

Device design