

Physics Research in Affiliated Areas

Quantum Optics, Biological Physics, Biomedical Optics,
Ultramicroscopy, Device and Materials Physics

Bennett Goldberg, PHY
Shyam Erramilli PHY
Alexander Sergienko ECE
Ted Moustakas ECE
Selim Ünlü ECE
Luca Dal Negro ECE
Irving Bigio BME
Evan Evans BME
Amit Meller BME
Bahaa Saleh ECE
Mal Teich ECE





QUANTUM IMAGING LABORATORY at Boston University

CO-DIRECTORS:

B. E. A. Saleh, A. V. Sergienko, M. C. Teich

<http://www.bu.edu/qil>

Postdocs

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G. Jaeger

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Y. Liu
M. Nasr
M. Shaw
K. Toussaint
N. Vamivakas
Z. Walton
T. Yarnall

Undergrads

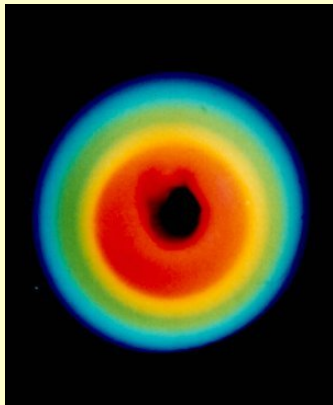
M. Corbo
E. Dauler
J. Hofman
V. Lai
B. O'Hare
A. Schwartz

Support

NSF CenSSIS
NSF (CCR, CISE, AMOP)
Packard
CIPA
MIT LL
DARPA Quist
NRO
NIH
BUPC

Parametric Down Conversion - source of entangled states

Phase Matching TYPE I



-Photons 1 and 2 have the same polarization and traverse the same direction

Phase Matching TYPE II



-Photons 1 and 2 have orthogonal polarizations and travel different directions



Applications

Quantum Information and Communication, Quantum Networking:

multiparty secure quantum key distribution (quantum cryptography).

(In cooperation with Tom Toffoli and Lev Levitin at BU).

Quantum Imaging (Spatial Entanglement at Work): designing imaging configurations for unconventional practical applications.

Quantum Ellipsometry: characterization of surface properties of semiconductors, and materials used in optoelectronics.

Quantum Optical Tomography: (of real objects) do not confuse with tomography of quantum states.

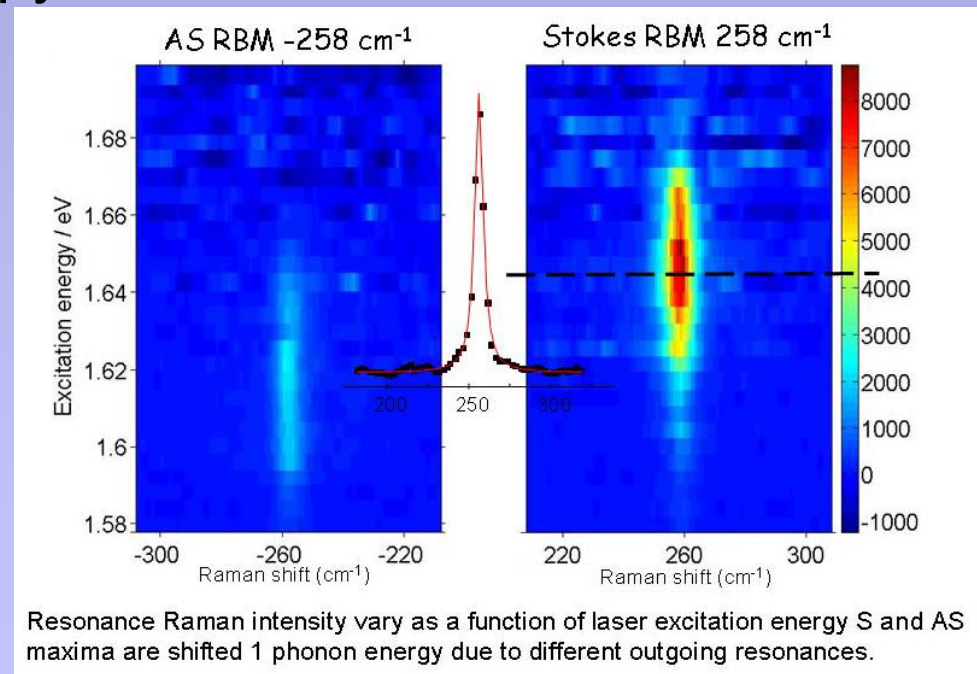
The feasibility of cryptography, metrology, and imaging has been demonstrated experimentally in our laboratory and experiments demonstrating ellipsometry, microscopy, tomography, and holography are underway.

Nanophotonics and Optical Characterization

M. Selim Ünlü, B. B. Goldberg
Anna Swan

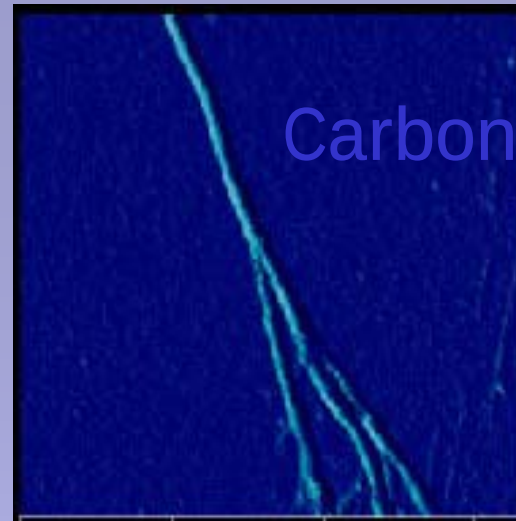
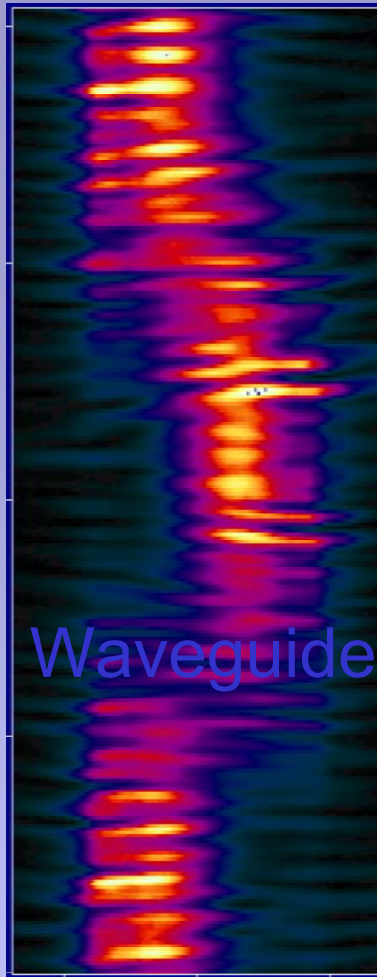
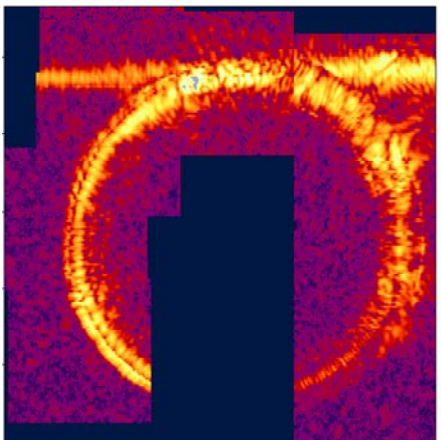
DARPA, NSF, ONR, ARO

- Ultramicroscopy
- Material Characterization
- Time-resolved spectroscopy
- Scanning probe microscopy
NSOM, tip-enhanced
- Biological detection and sensing
- Thermal Imaging
- Photodetectors
- Resonant Raman from single Nanotubes

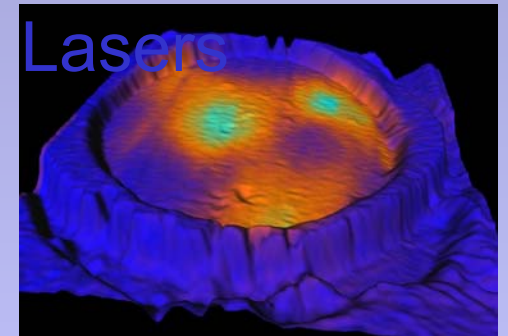


NANO OPTICS

Imaging of PBG, Waveguide Devices and Lasers



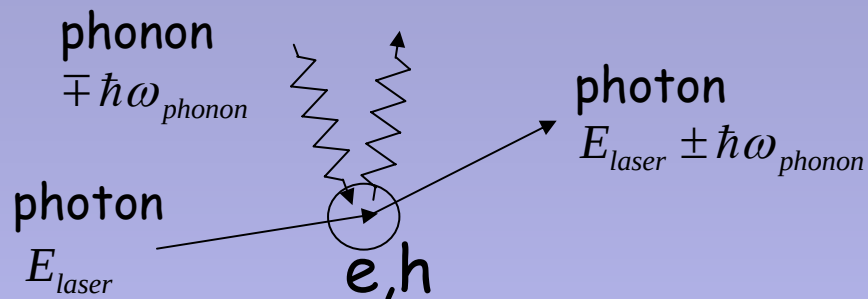
Carbon Nano-tubes



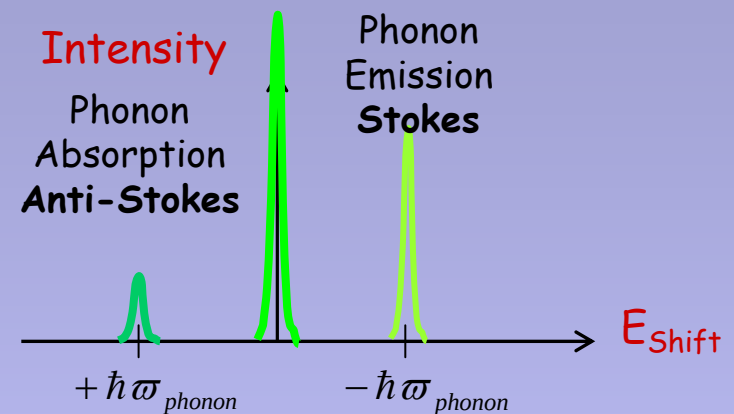
- High spatial resolution subsurface microscopy
- Quantum Dot Spectroscopy

Resonant Raman scattering from Nanotube

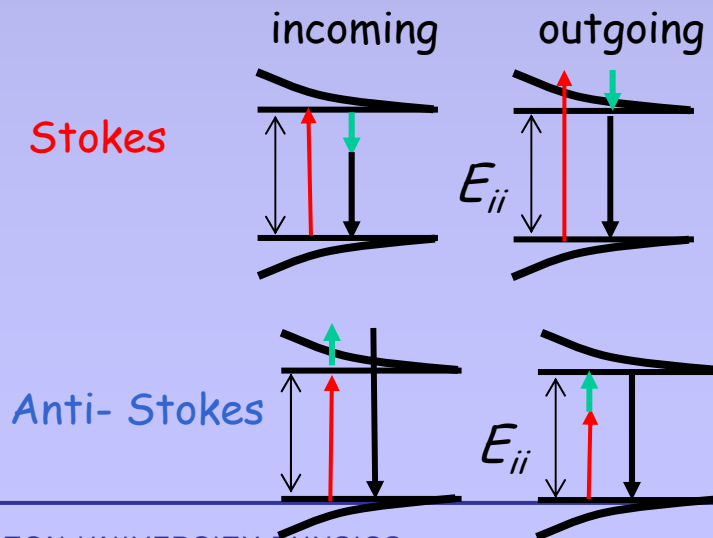
Raman scattering



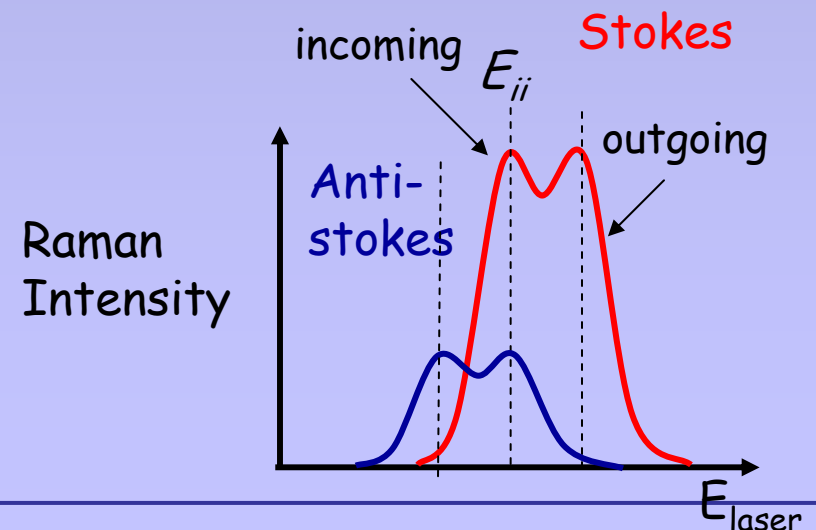
Raman spectrum



Resonant Raman scattering

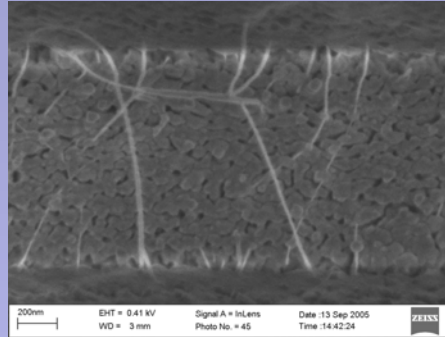


Resonant Raman excitation profile



Resonant Raman Scattering Excitation (RRSE) of CNT (11,0)

CVD growth Carbon
nanotube suspended
in trenches

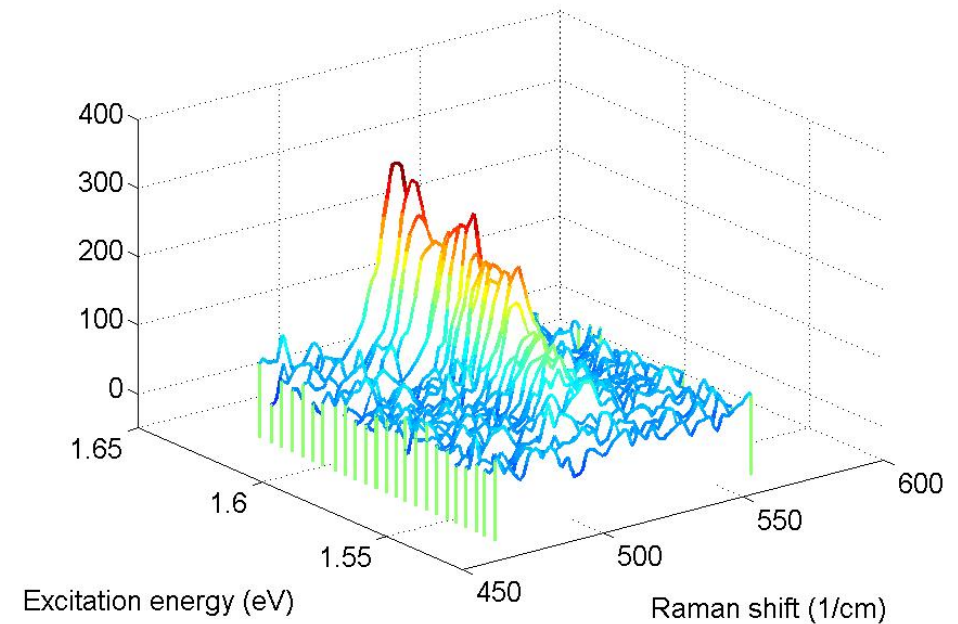
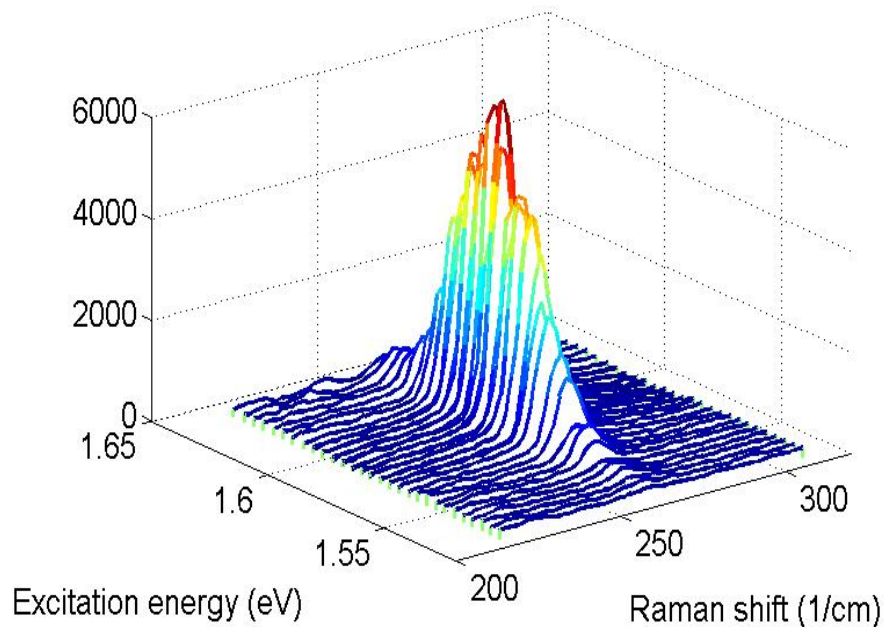


SEM

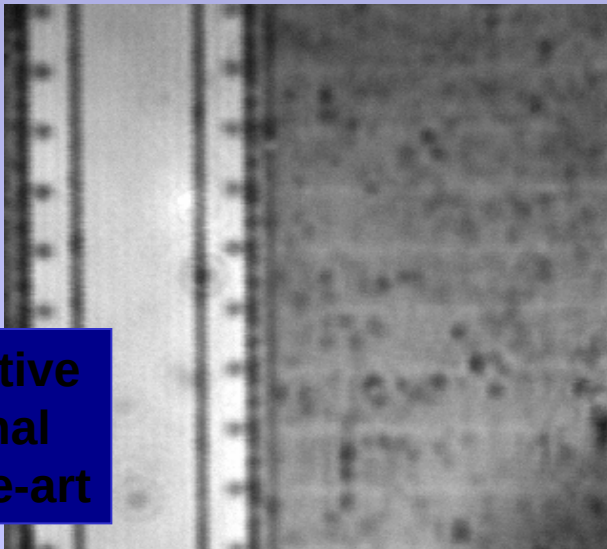
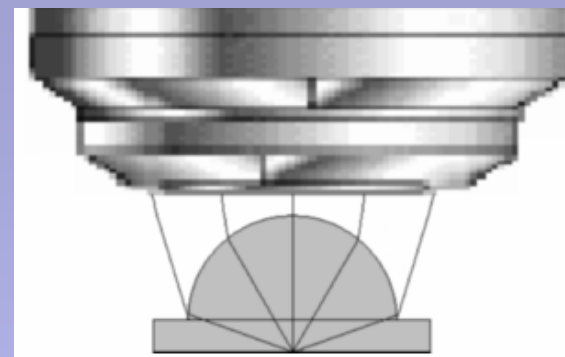
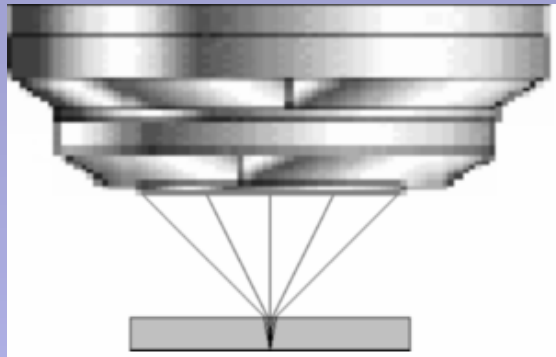
1-phonon: RBM

2-phonon: RBM^2

+

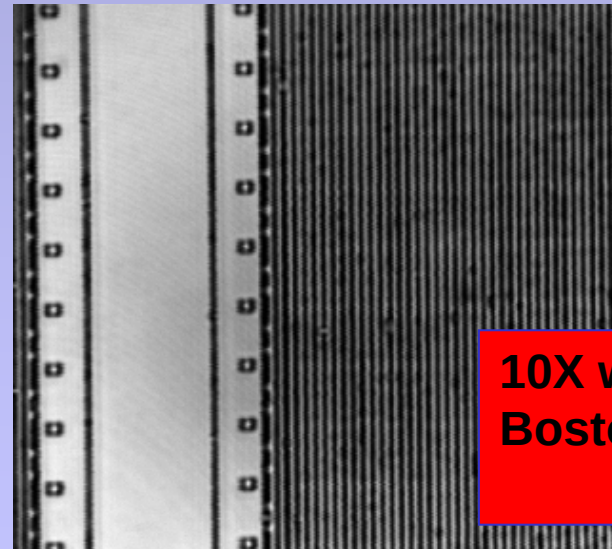


NAIL: Numerical Aperture Increasing Lens



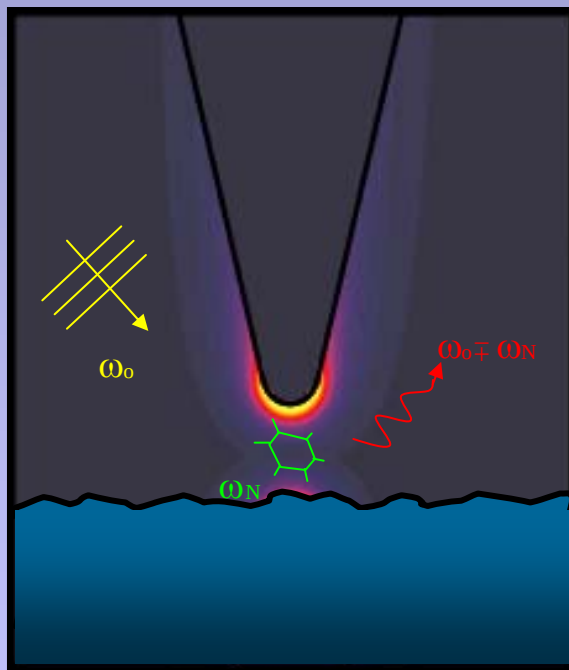
**100X objective
Conventional
State-of-the-art**

10 μm

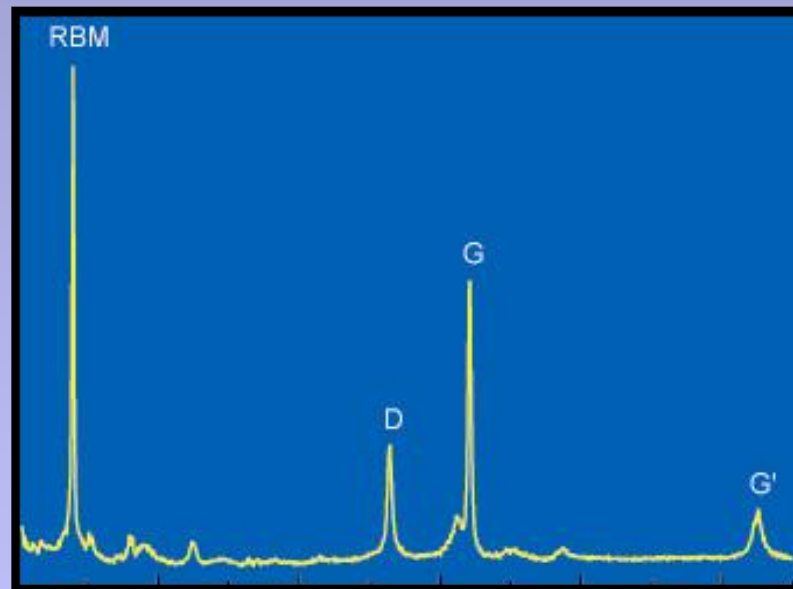


**10X w/ NAIL
Boston Univ.**

SURFACE ENHANCED VIBRATIONAL SPECTROSCOPY AND MICROSCOPY

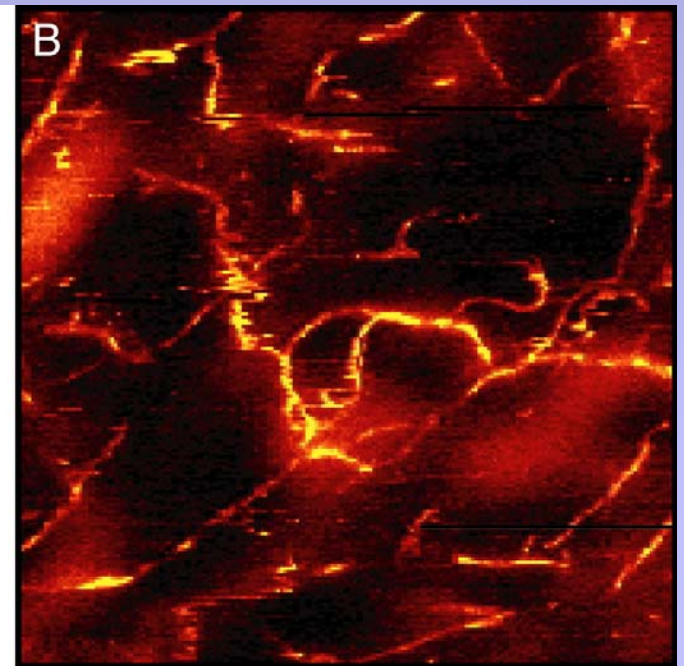
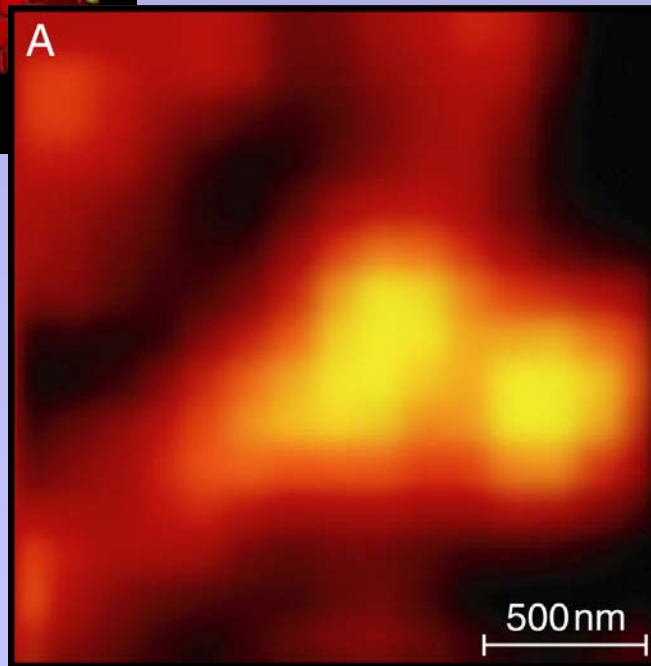
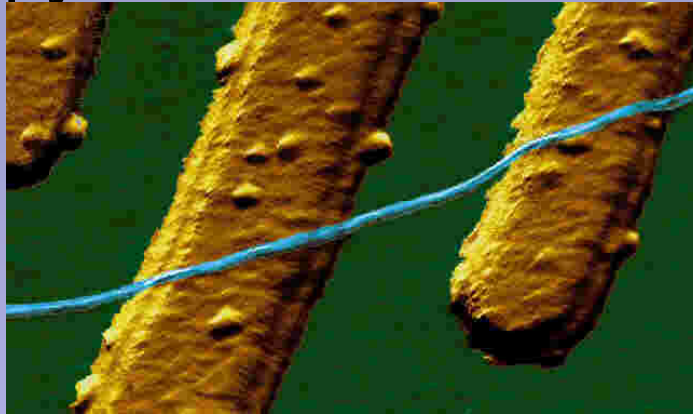
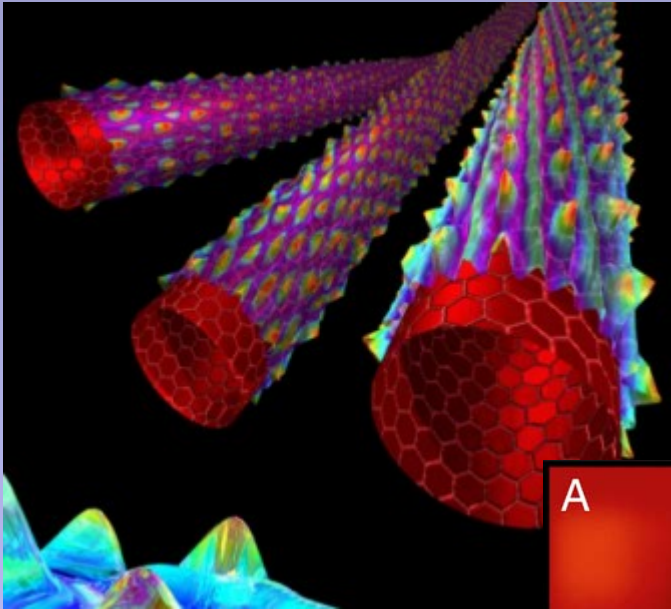


Phys.Rev.Lett. **90**, 95503 (2003)

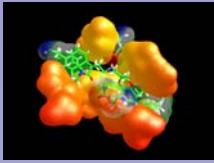


Carbon nanotubes: - well defined topography
- large σ_{Raman}
- resonance enhancement

Comparison of Confocal to Tip-Enhanced in Raman Microscopy of Carbon nanotubes



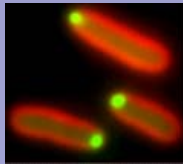
Molecules



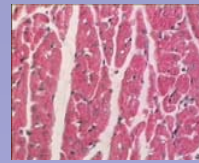
Organelles



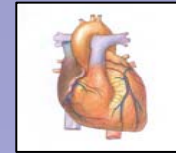
Cells



Tissue



Organs

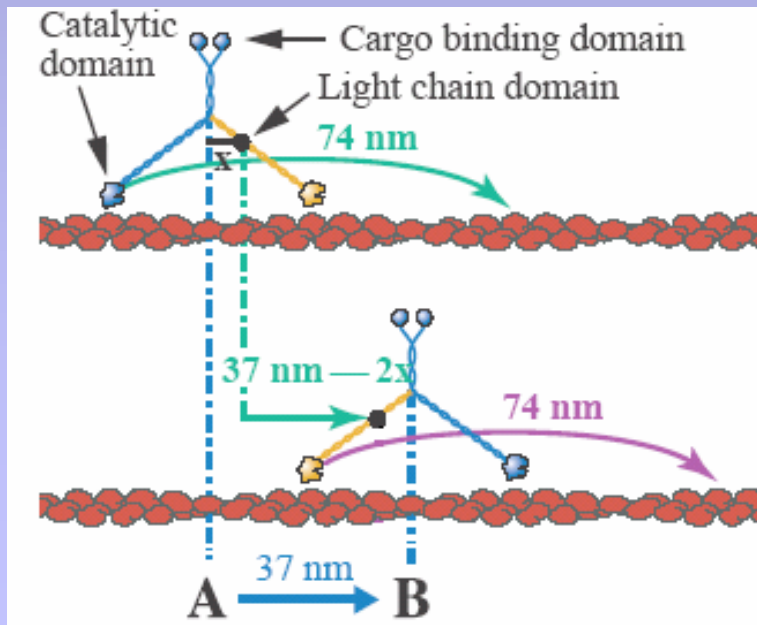


Organisms



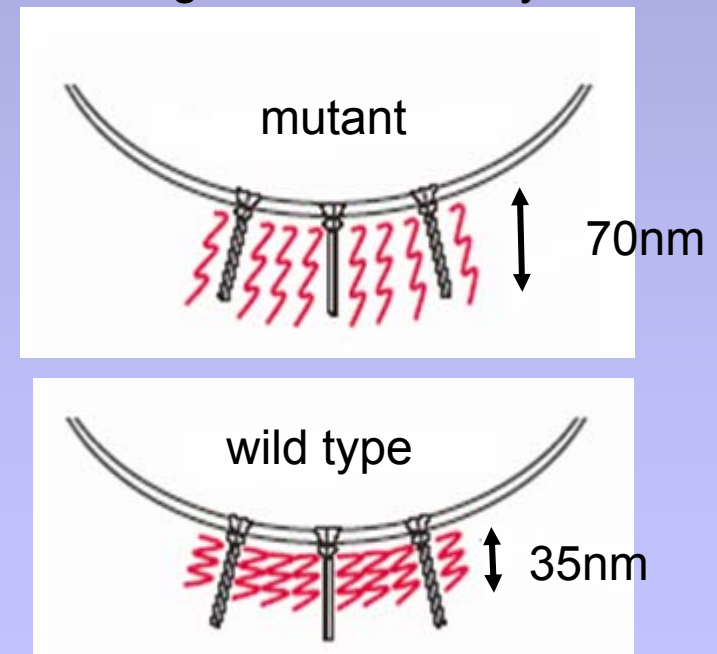
10⁻¹⁰ 10⁻⁹ 10⁻⁸ 10⁻⁷ 10⁻⁶ 10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 10⁰ (meters)

- Myosin and kinesin motion on Actin fibers



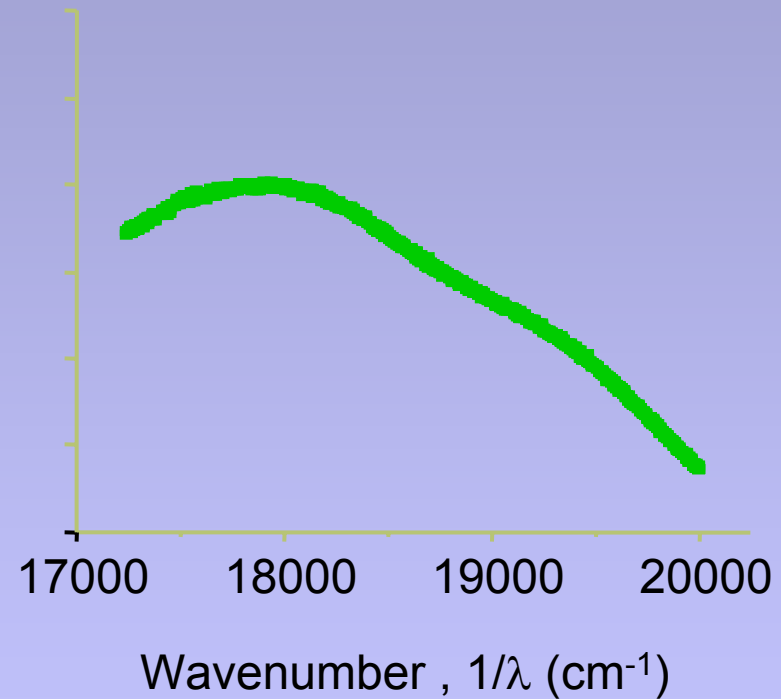
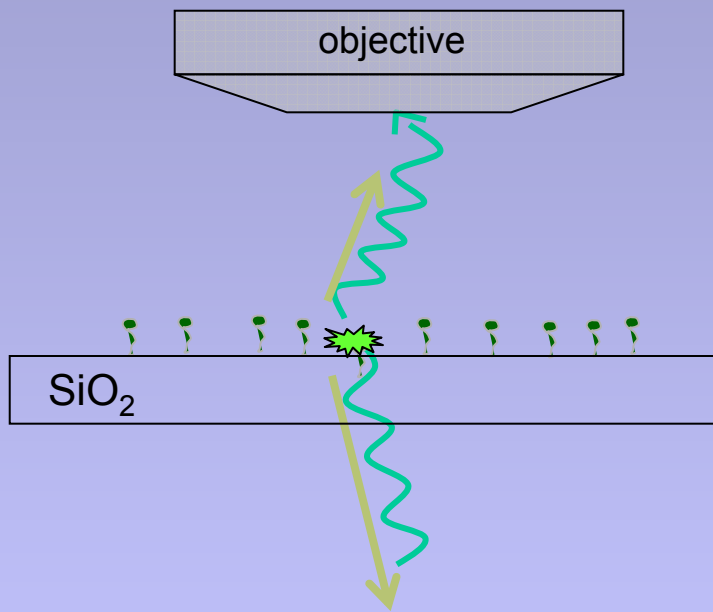
Science, Vol.300, 27 June 2003

- Shigella secretion system

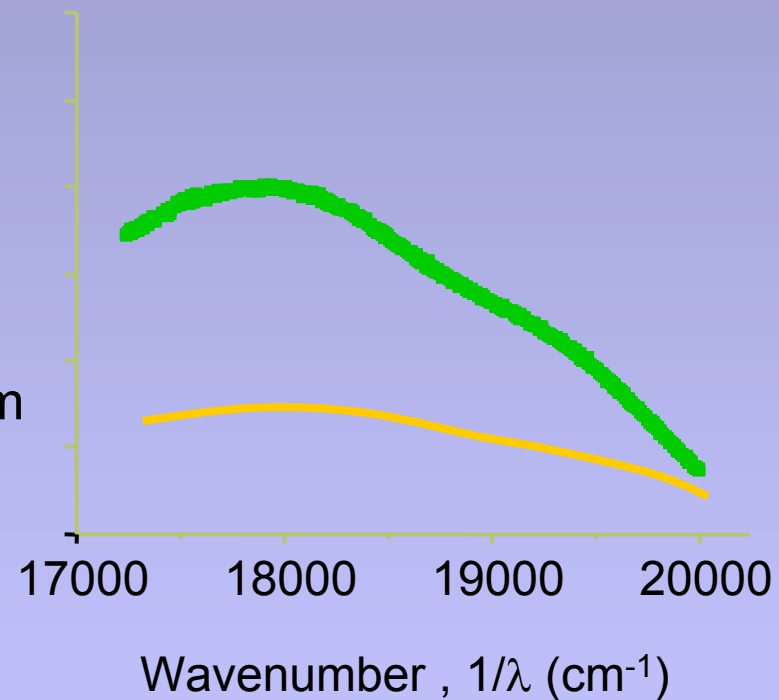
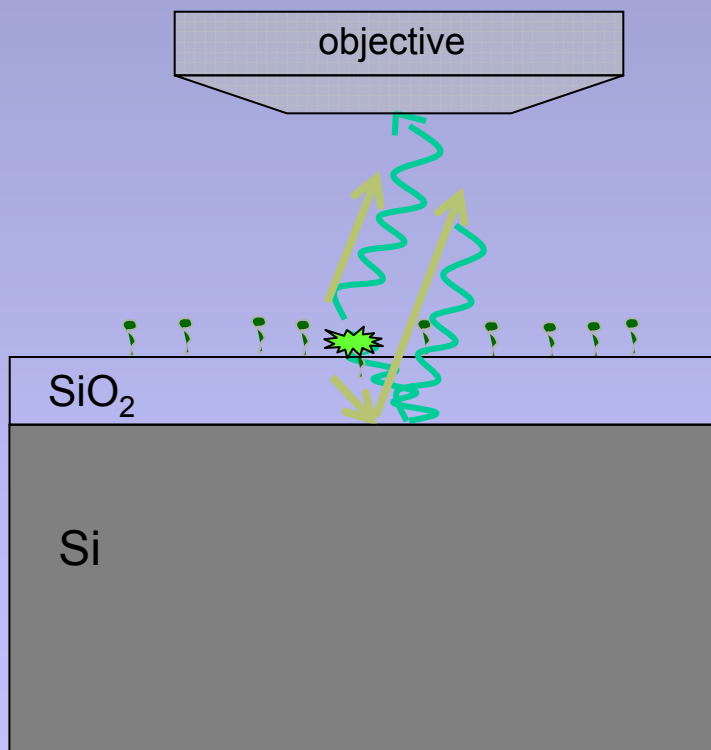


Science, Vol.307, 25 February 2005

Spectral Self-interference Fluorescence Microscopy (SSFM)

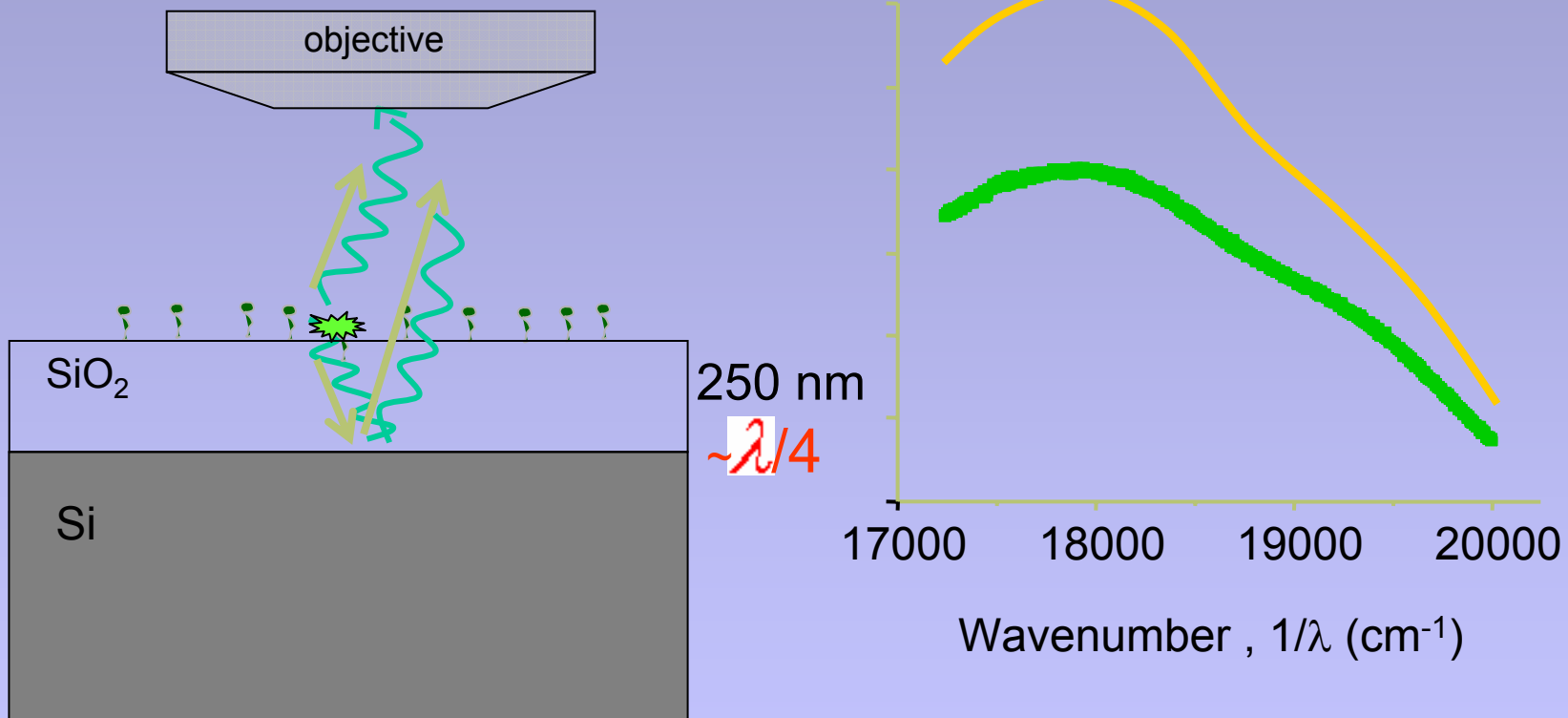


Spectral Self-interference Fluorescence Microscopy (SSFM)



- INTENSITY QUENCHED
- SiO₂ spacer $\sim 10\text{nm} \sim \lambda/50$

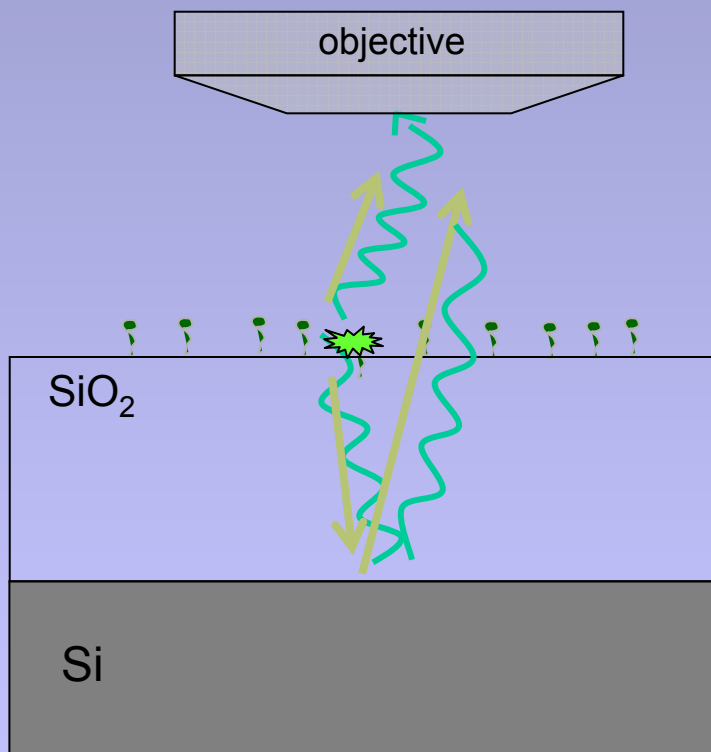
Spectral Self-interference Fluorescence Microscopy (SSFM)



- INTENSITY ENHANCED

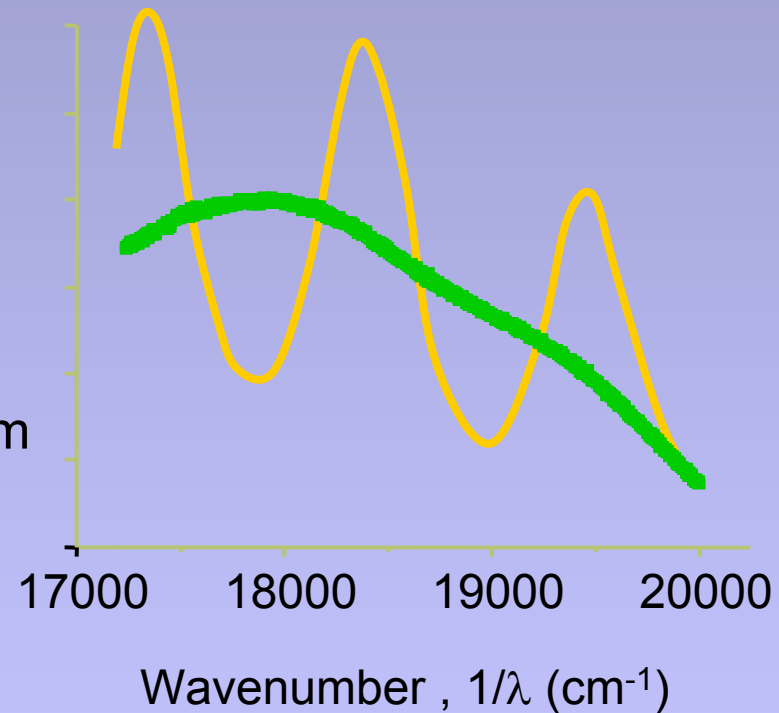
- SiO₂ spacer $\sim 250\text{nm} \sim \lambda/4$

Spectral Self-interference Fluorescence Microscopy (SSFM)



2.5 μm

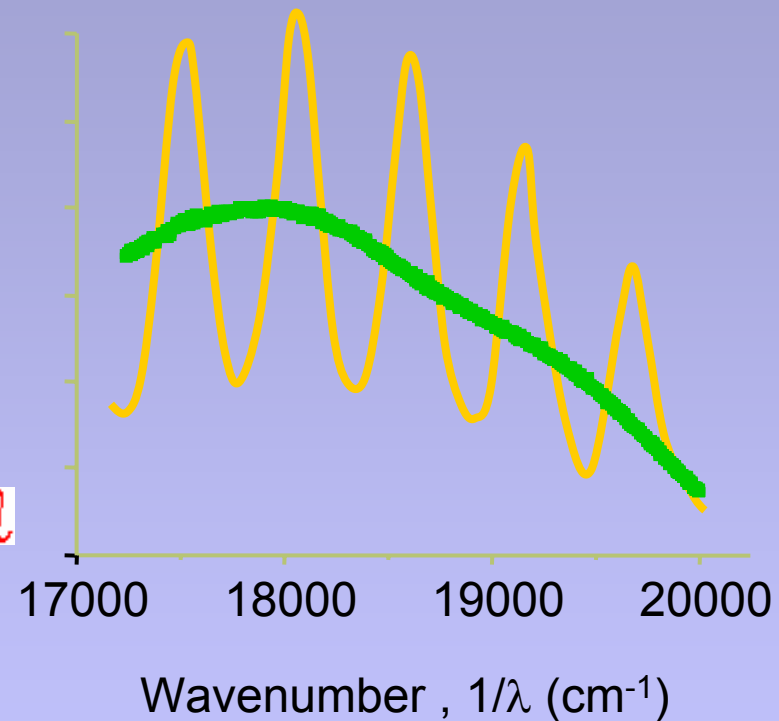
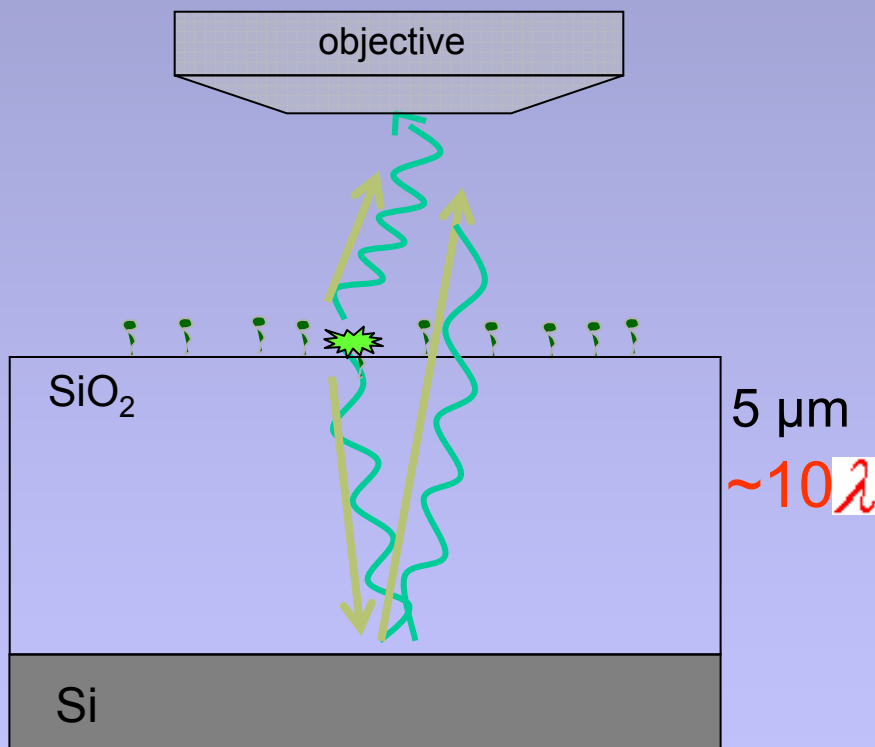
$\sim 5\lambda$



- SPECTRAL VARIATIONS

- SiO_2 spacer $\sim 2.5\mu\text{m} \sim 5\lambda$

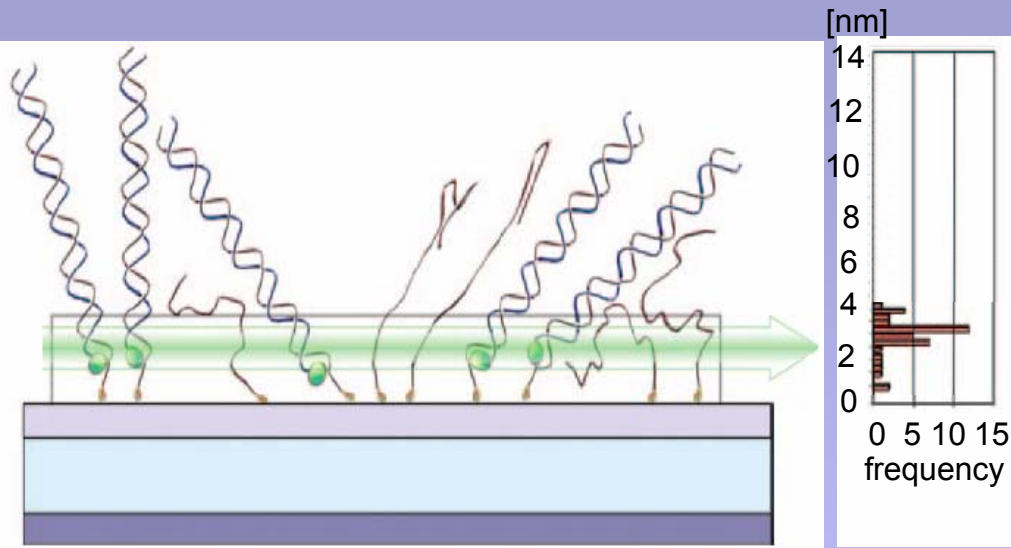
Spectral Self-interference Fluorescence Microscopy (SSFM)



- SPECTRAL VARIATIONS
- SiO₂ spacer ~ 5 μm ~ 10 λ

DNA Conformation Using SSFM

Moiseev, L. et al, PNAS , vol.103,no. 8, February 21, 2006

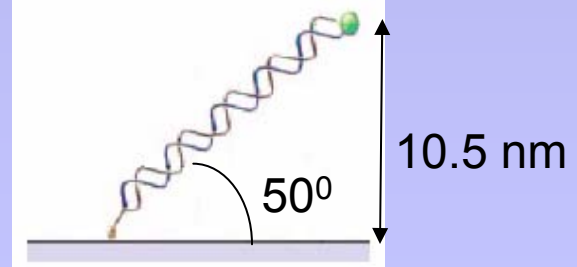


50bp Double Strand DNA
(Proximal end labeled)

50 bp double strand DNA : 17 nm

Measured average length : 10.5 nm

DNA as **rigid rods on hinges**



Conclusion: **Steric hindrance**

Wide Bandgap Semiconductors Laboratory

Theodore D. Moustakas

In this laboratory we address materials and device physics issues of the wide bandgap semiconductors InN, GaN, AlN and their alloys and heterostructures. Current projects are related to making visible and ultraviolet LED and laser structures, solar-blind, UV photodetectors, electronic devices (diodes, transistors, thyristors) and MEMS sensors.

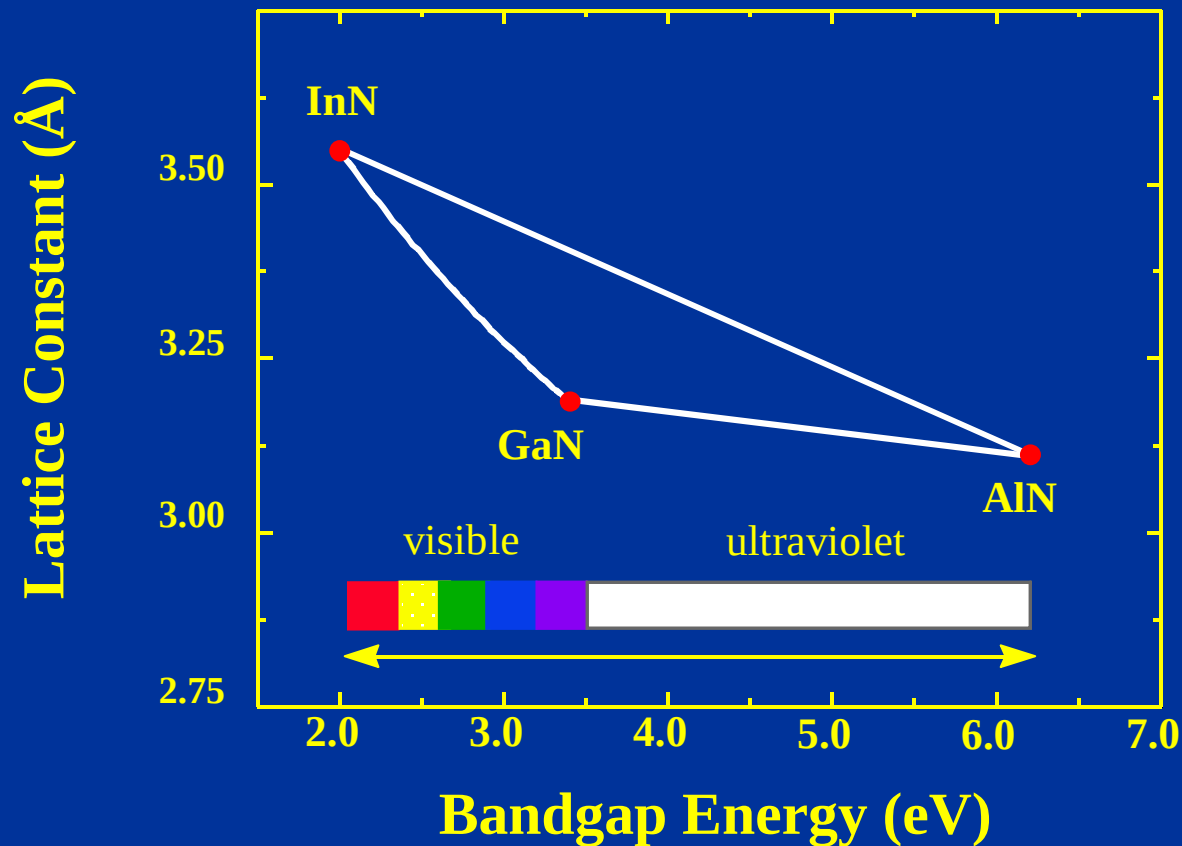
The materials and devices are grown by molecular beam epitaxy (MBE), vapor phase epitaxy (VPE) and gas cluster ion-beam deposition (GCIB).

Wide Bandgap
Semiconductors Lab

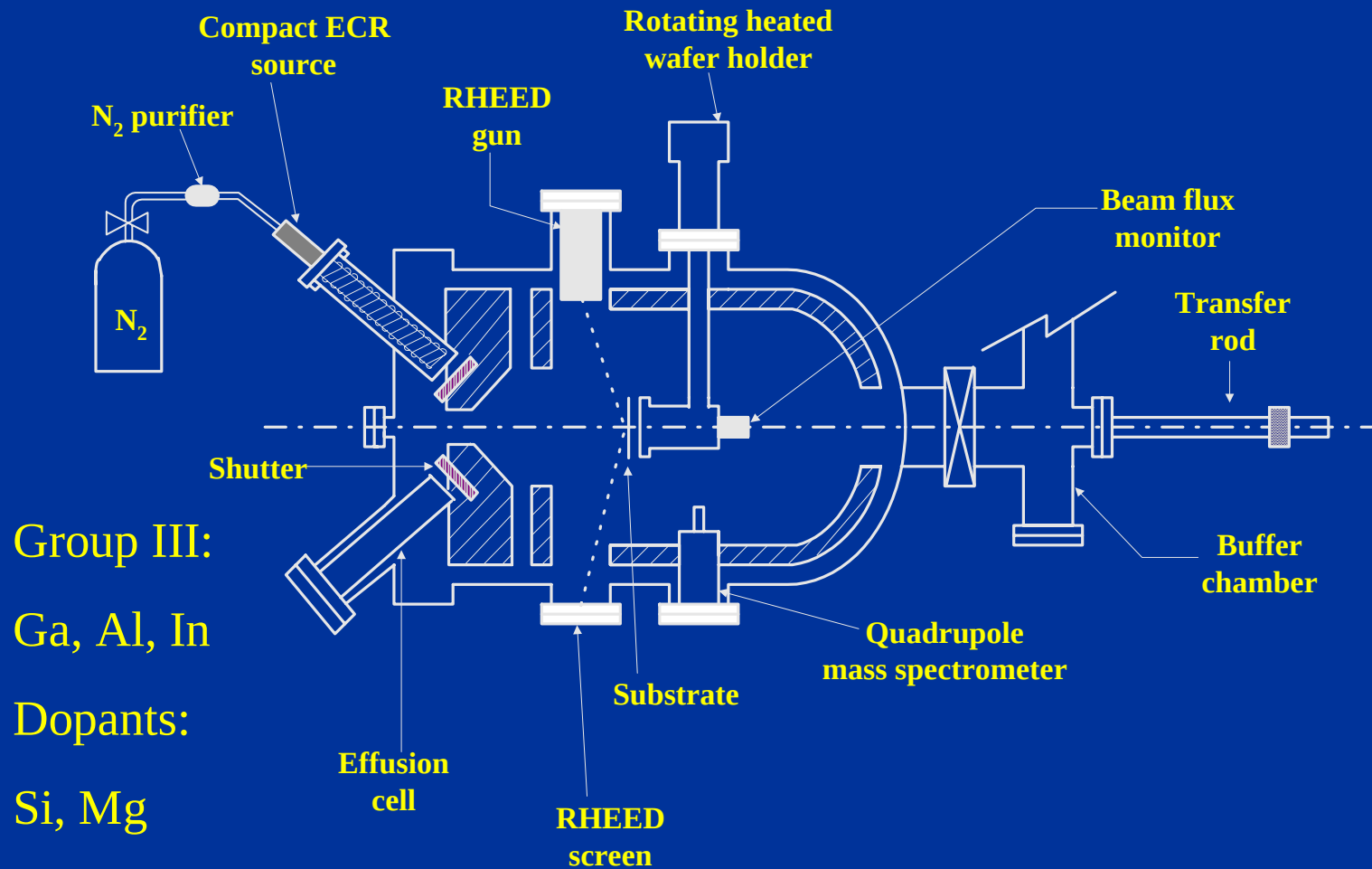
PHOTONICS CENTER

BOSTON
UNIVERSITY

Bandgap-lattice constant



Schematic of the ECR-MBE system



Wide Bandgap
Semiconductors Lab

PHOTONICS CENTER

BOSTON
UNIVERSITY

A scanning electron micrograph (SEM) of a micro-machined device, likely a MEMS actuator or sensor. The device features a central horizontal beam with a thin vertical crossbar, all supported by a series of vertical pillars. The structure is surrounded by a rectangular frame. The image is in grayscale and shows fine details of the micro-fabrication process.

*Laboratory for Nanometer Scale
Mechanical Engineering*

Kamil L. Ekinici
ekinci@bu.edu

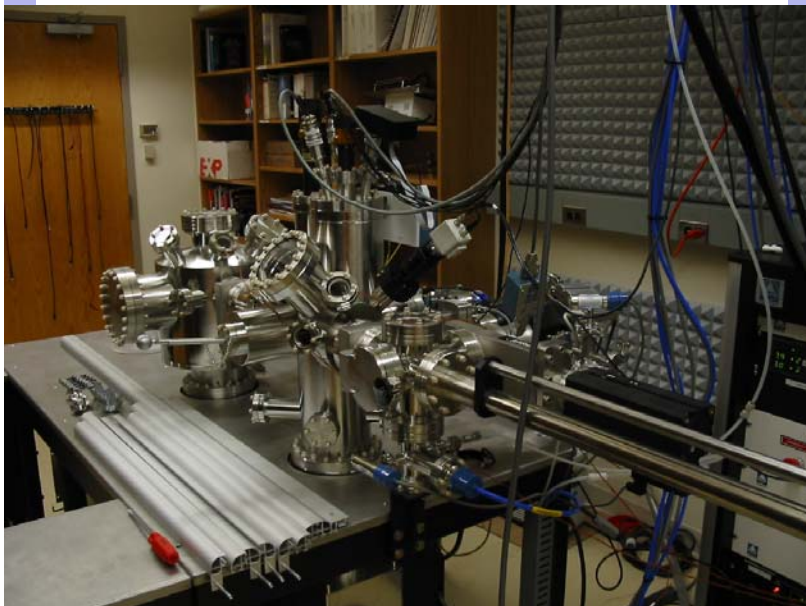
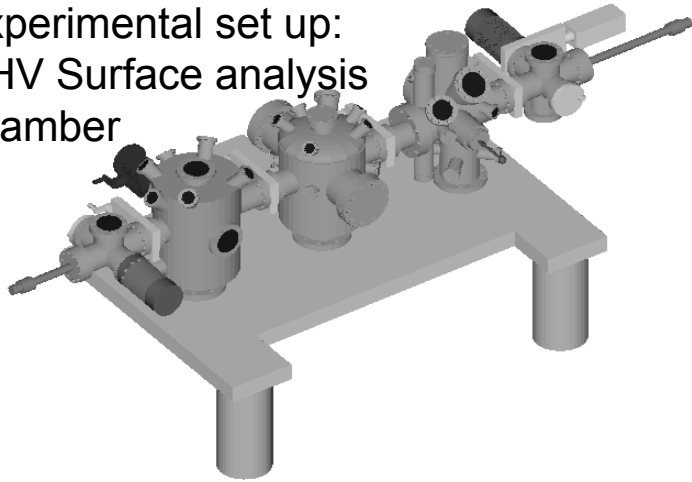
CIT 40KV 10µm X3,500 46mm

Nanomechanics at BU

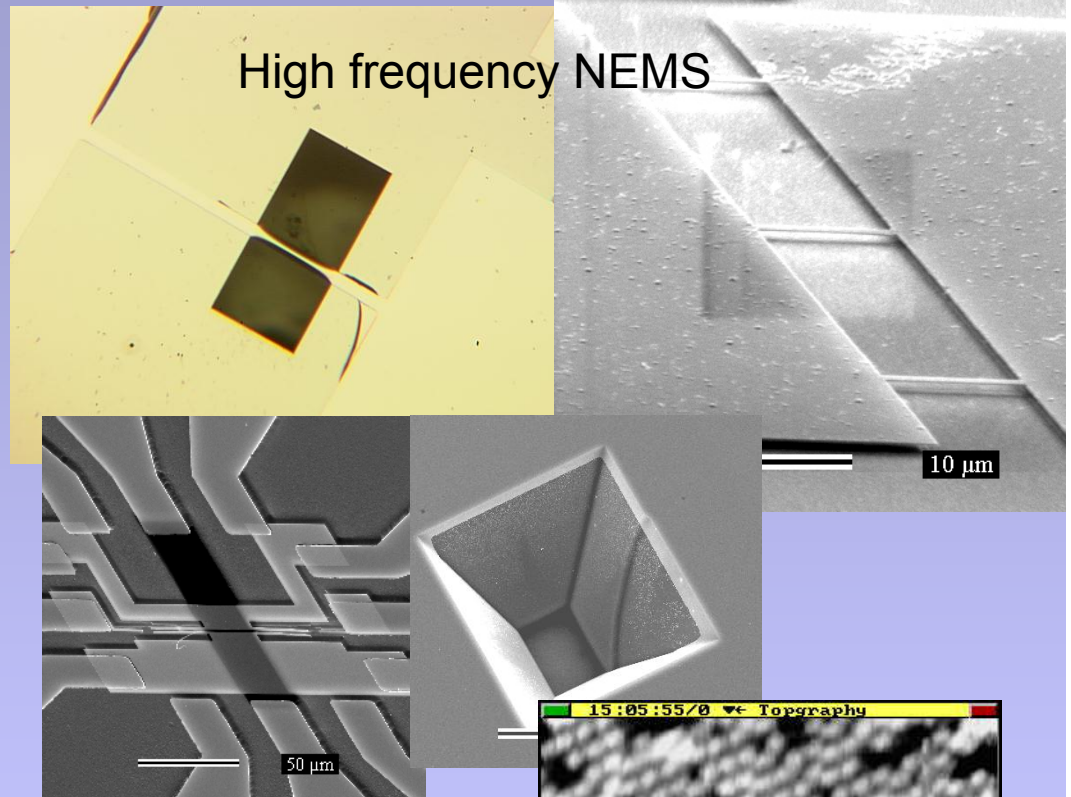
Focus areas:

1. Surface analysis and engineering of nanostructures at the atomic scale
2. Nanoelectromechanical Systems (NEMS) sensors and signal processing components

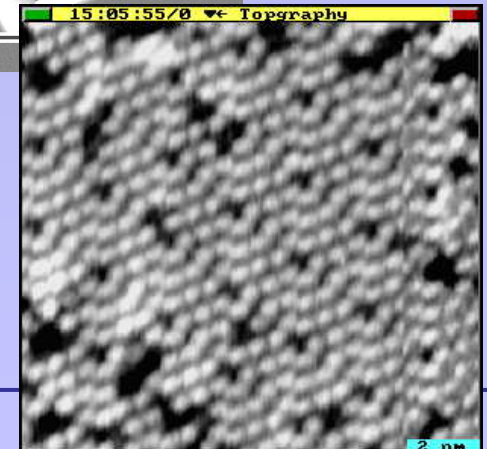
Experimental set up:
UHV Surface analysis
chamber



High frequency NEMS



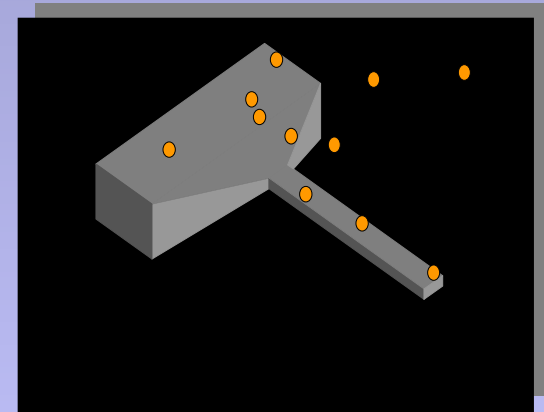
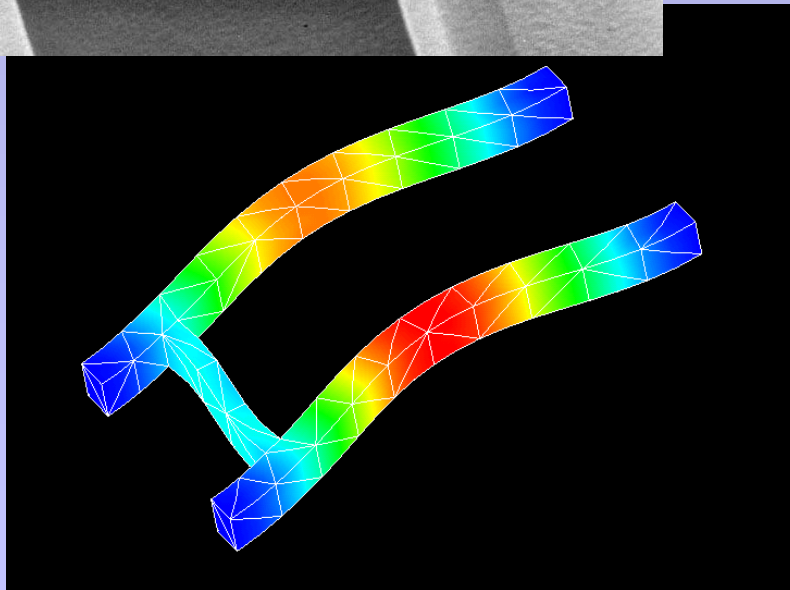
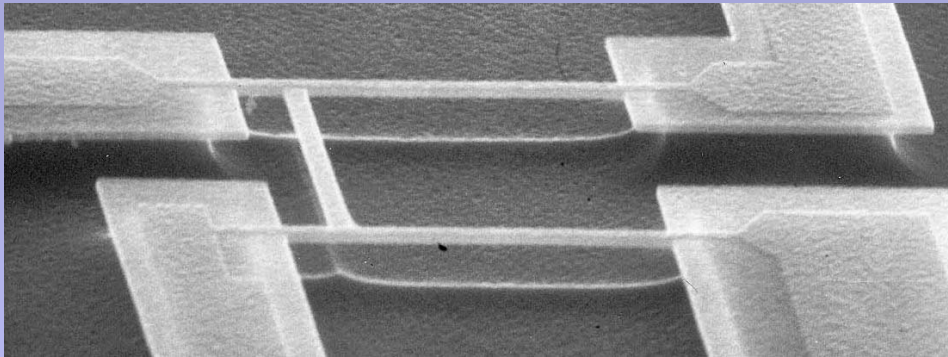
Silicon atoms on the
surface of a device



NEMS to measure single molecules

Nanomechanical system moves nanometers at ultra high frequency => Sensitive to tiny amounts of material

magnetomotive actuation and transduction



single molecule detectors

- single molecule chemical sensors
- mass spectrometry

Contacts and Information

Near-field and Picosecond Spectroscopy: <http://ultra.bu.edu/>

Quantum Imaging Laboratory: <http://www.bu.edu/qil>

Biomedical Optics: <http://bme.bu.edu/faculty/bigio.html>

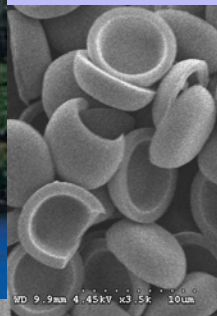
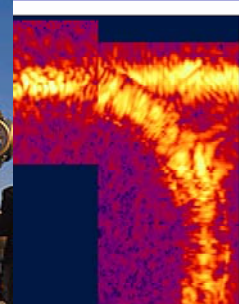
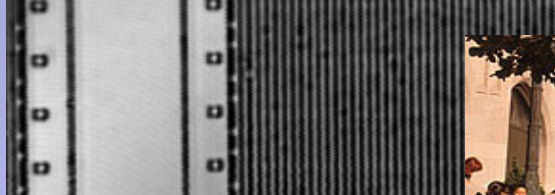
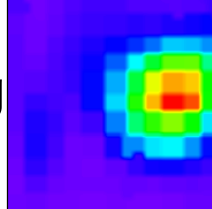
Cellular and Subcellular Mechanics Lab: <http://bme.bu.edu/faculty/evans.html>

Semiconductor Device Research Lab: <http://people.bu.edu/efs/>

Nanotechnology Research @

BOSTON
UNIVERSITY

Bennett Goldberg
Electrical and Computer Engineering
Physics



selim@bu.edu

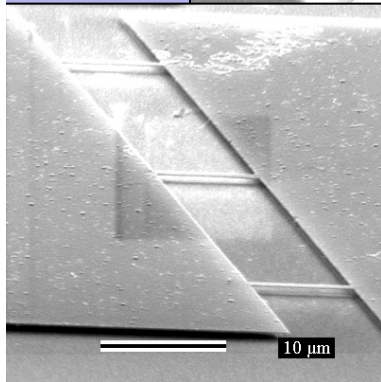
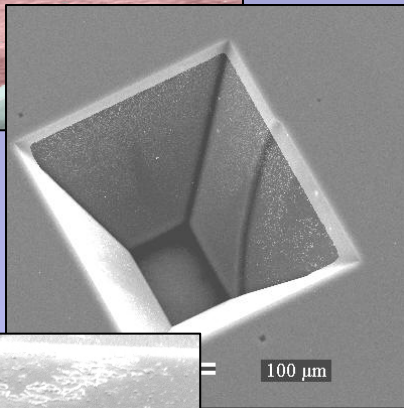
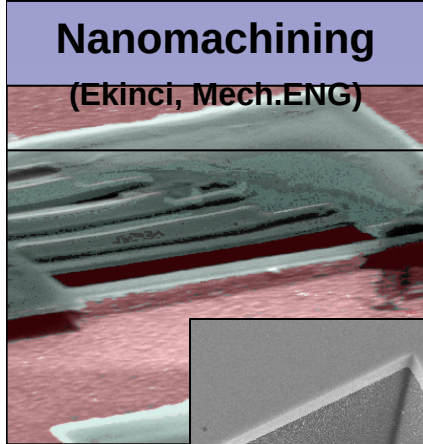
goldberg@bu.edu

Material Synthesis & Device Fabrication

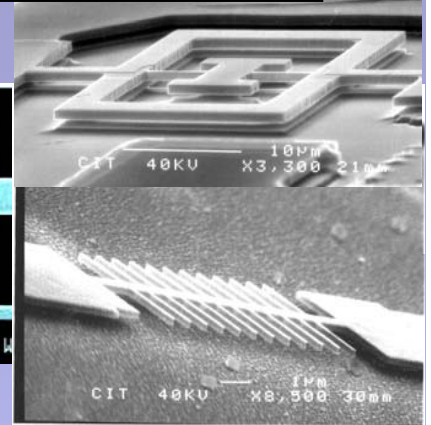
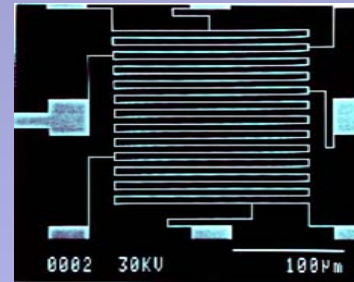
Nanomachining

(Ekinci, Mech.ENG)

Advanced E-beam lithography &
surface micromachining (Mohanty, Physics)

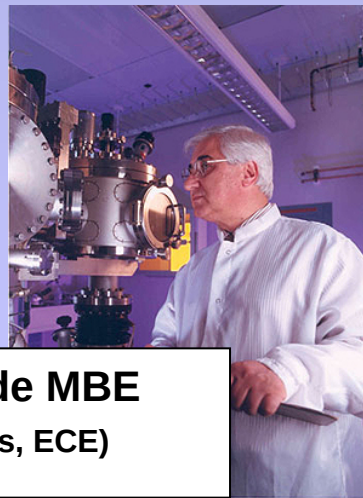


BioMEMS/NEMS (Desai
and Tien, BME)

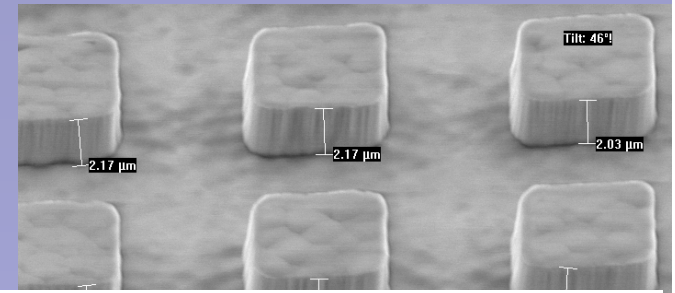


- Optoelectronics Processing Facility
- Lightwave Technology Laboratory

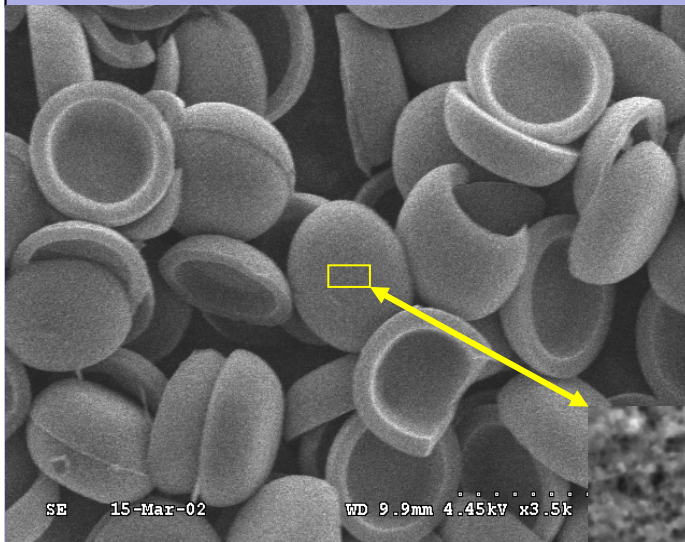
III-V Nitride MBE
(Moustakas, ECE)



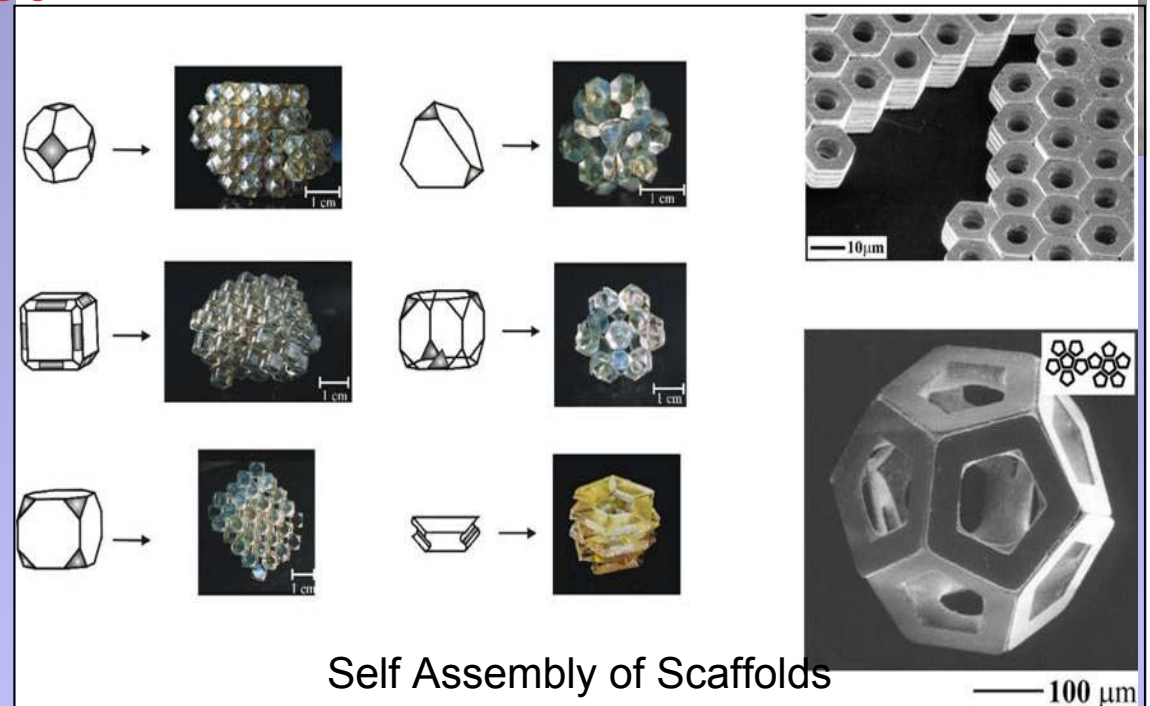
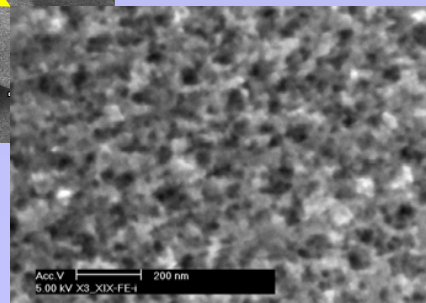
Applications in Biology and Biomedical Engineering : Nano-Bio-Technology



5 μm Nanoporous Silicon (pSi) Particles



Volume (Particle) = 68 fL
Volume (RBC) = 76 – 100 fL

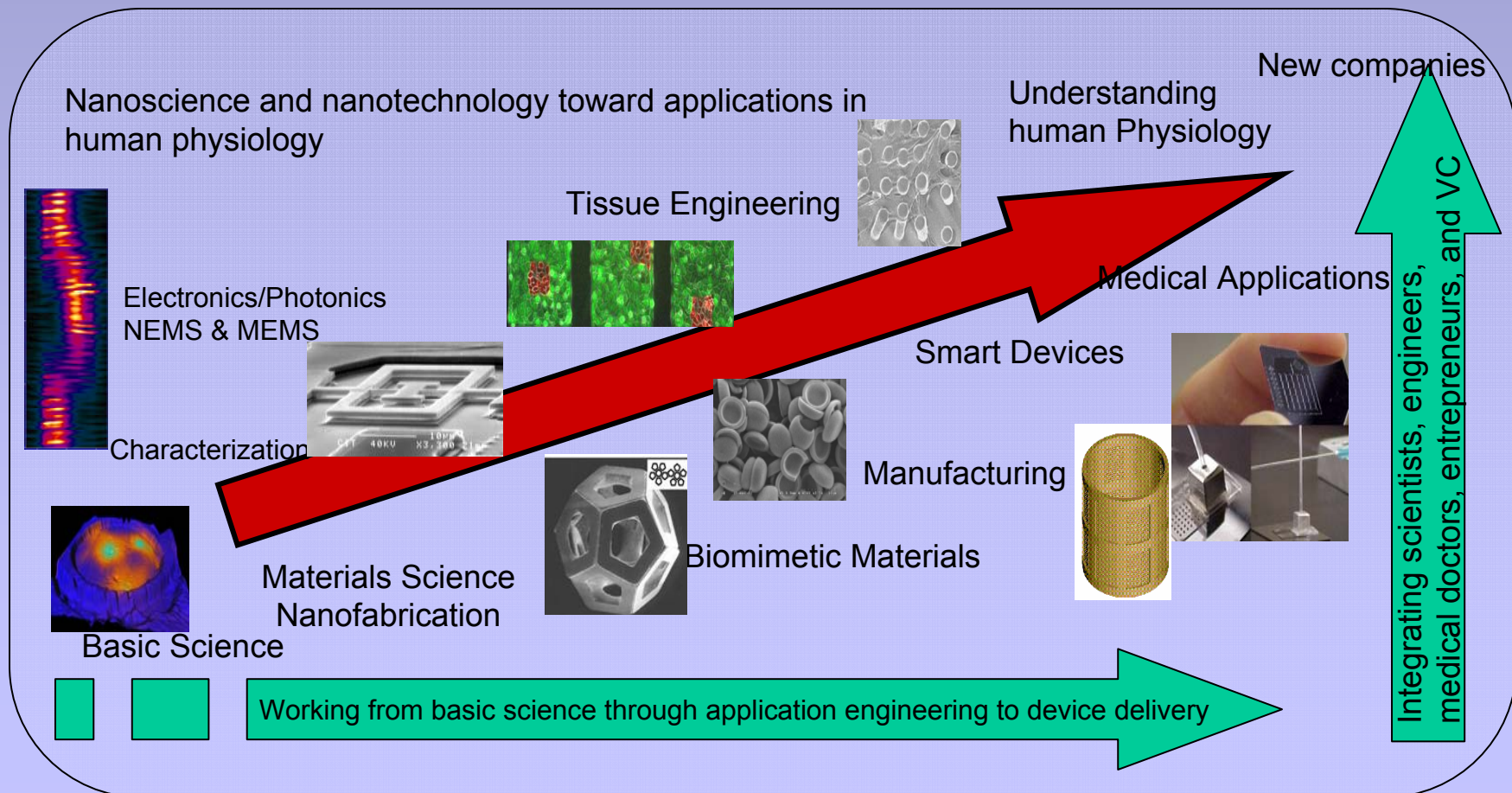


- High Resolution Biological Imaging
- Interdisciplinary Research Teams

Center for Nanotechnology Integration

CNI combines

- horizontal integration across disparate scientific disciplines
- vertical integration from basic science through transitional technologies to market opportunities



NANOTECHNOLOGY

Physical Sciences

Life Sciences

Electronics/Optics/IT

Need Identified

Enrico Bellotti
Thomas Bifano
Kamil Ekinci
Shymasunder Erramilli
Bennett Goldberg
Raj Mohanty
Ted Morse
Ted Moustakas
Bahaa Saleh
Anna Swan
Selim Ünlü

Characterization

Rama Bansil
Bennett Goldberg
Todd Murray
Anna Swan
Selim Ünlü

Manufacturing

Thomas Bifano
Tejal Desai
Kamil Ekinci
Raj Mohanty
Andre Sharon
Joe Tien
Xin Zhang

Smart Devices

Thomas Bifano
Irving Bigio
Tejal Desai
Kamil Ekinci
Shymasunder Erramilli
Evan Evans
Maxim Frank-Kamenetski
Rosina Georgiadis
Bennett Goldberg
Raj Mohanty
Ted Morse
Todd Murray
Anna Swan
Selim Ünlü
Joyce Wong
Xin Zhang

Biomimetic Materials

Tejal Desai
Russell Giordano
Catherine Klapperich
Joe Tien
Joyce Wong
Xin Zhang

Tissue Engineering

Tejal Desai
Evan Evans
Russell Giordano
Catherine Klapperich
Joe Tien
Joyce Wong

Energy

Srikanth Gopalan
Uday Pal
Vinod Sarin

Materials Science

Kevin Smith
Bennett Goldberg
Karl Ludwig
M. Selim Ünlü
Ted Moustakas

Homeland Security

Bennett Goldberg
Shymasunder Erramilli
Raj Mohanty
Ranjith Premisiri
Selim Ünlü

Biology

James Deshler

Genomics & Proteomics

Charles Cantor
Jim Collins
Michael Christman
Charles Delisi
Jim Deshler
Shymasunder Erramilli
Maxim Frank-Kamenetski
Rosina Georgiadis
Catherine Klapperich
Cassandra Smith
Zhiping Weng

Core Nanoscience efforts at Boston University

- Nano-optics in materials science
 - Nanoscale Interdisciplinary Research Team developing optical techniques for at length scales of $\lambda/10$. NSF
 - MURI with U of R
- Nano-optics in subcellular bioimaging and medicine
 - Using new techniques in interference microscopy to image fluorophores *in vivo* with nanometer resolution. NIH+NSF
- Nano-electromechanical systems
 - Nanosensor arrays for molecular detection using UHF cantilevers. NEMS for microengines, active mirrors, rapid and variable genomic and protein array fabrication
- Nano-electronics
 - Nanowires, dots, and devices for coherent transport for secure communications and quantum computing
- Whitaker Laboratory for Micro and Nano Biosystems
 - Nanotherapeutics: Targeted drug delivery, nanoporous membranes, smart nanoparticles
 - Cellular scaffolding, polymer tethers
 - 3D self assembly
 - Nanomechanics of biosystems: Individual chemical bonds
 - Dip-pen nanolithography, polymers
- Infrared microscopy to 100nm, femtogram spectroscopy and breast cancer screening using a single strand of hair
- Biosensing and homeland security
 - Surface Plasmon Resonance, Array-based, multichannel sensors
 - Ring resonators and fiber-based systems
 - Proteomics and genomics