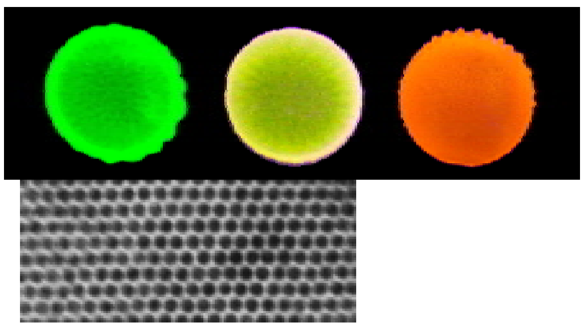
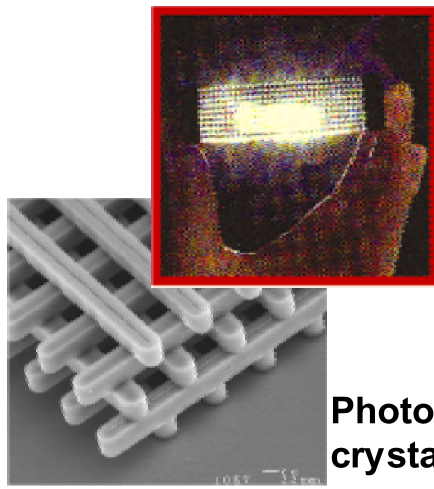
Center for Integrated Nanotechnologies:
Nanophotonics & Nanoelectronics

Exploring new frontiers in photonics and electronics

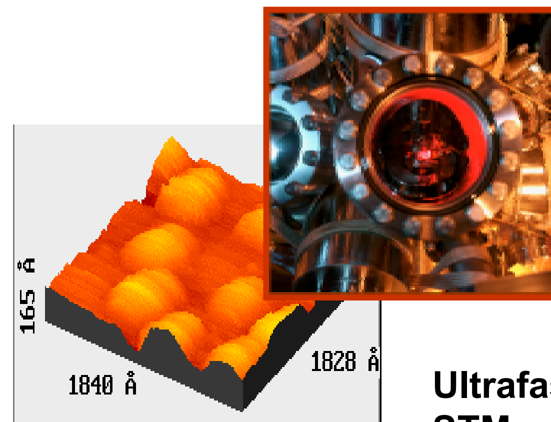
Novel materials | Novel phenomena | Novel tools



Quantum dot solids



Photonic crystals



Ultrafast STM

SNL	LANL
Jerry Simmons	Victor Klimov
Mike Sinclair	Toni Taylor
Mike Lilly	Darryl Smith
Shawn Lin	Stuart Trugman
John Reno	Chris Hammel
Joel Wendt	

Outline

- Thrust definition for Nanophotonics & Nanoelectronics
- Topics of interest
  - Current activities at Los Alamos and Sandia
  - Future directions
- How collaborations might work

Nanophotonics & Nanoelectronics: Thrust Description

Complex Functional Materials

Nano-mechanics

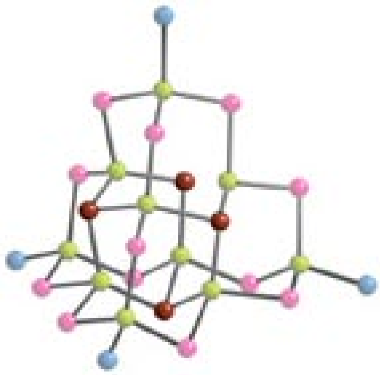
Nano-bio

- **Understanding electronic, magnetic, and optical phenomena at the nanoscale**
  - Inorganic and organic photonic, electronic, and magnetic nanostructures
  - Hybrid inorganic/organic nanocomposites and complex interfaces
- **New concepts for controlling electronic and optical properties of nanomaterials**
  - Tailored electronic wave functions and cooperative interactions
  - Tailored density of photon states and photonic interactions
  - Interplay between tunable electronic and photonic spectra/interactions

Theory

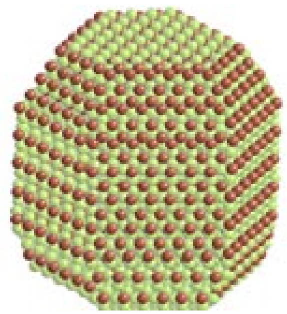
Novel instrumentation

Tailored Electronic/Optical Properties via Quantum-Size Effect

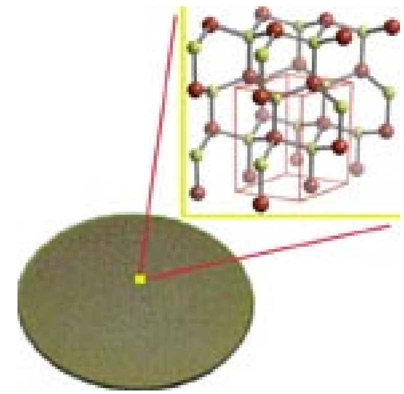


$Cd_{10}Se_4(SePh)_{12}(PPr_3)_4$

Cluster Molecule



Quantum dots



Bulk CdSe

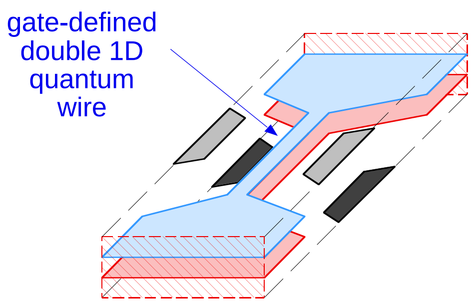
100 atoms | 100,000 atoms

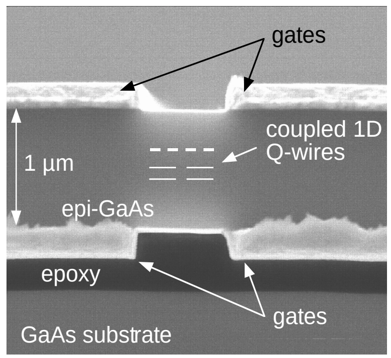
Nano-fabrication:	Colloidal dots	Epitaxial dots
Nano-mechanics:	Structural reconstruction	Strain effects
Theory:	Quantum chemistry	Effective mass

Characterization: TEM, Scan-Probes, Optical spectroscopies (time-resolved, single-dot, ...)

Novel Nanoelectronic Phenomena Arising from Tailored Electron-Electron Interactions

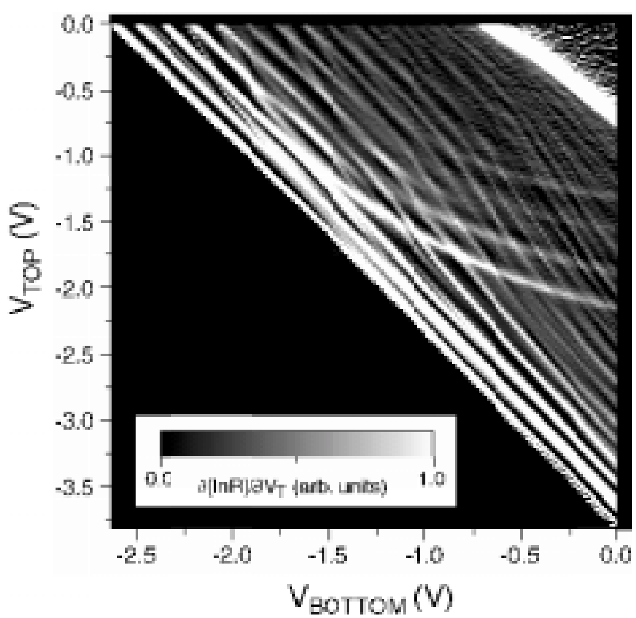
Coupled 1D Quantum wires: unprecedented control over individual 1D states.



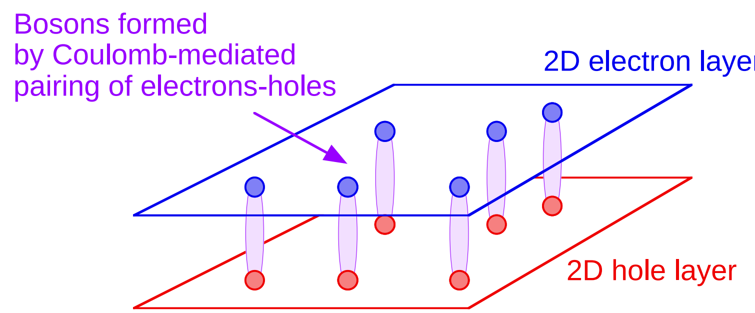


Energy spectroscopy of interacting 1D wires.

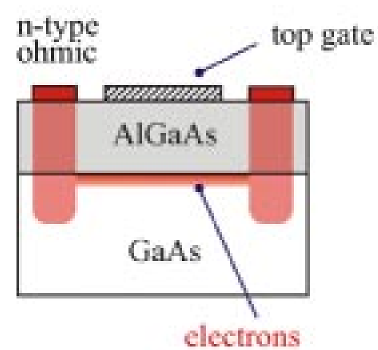
FUTURE DIRECTIONS: Luttinger liquids; quantum computing



FUTURE DIRECTIONS: Coupled electron-hole bilayers - Coulomb coupling leads to Bose condensation of e-h pairs, a novel superfluid or **"excitonic superconductor"** achieved by "engineering" of particle interactions.

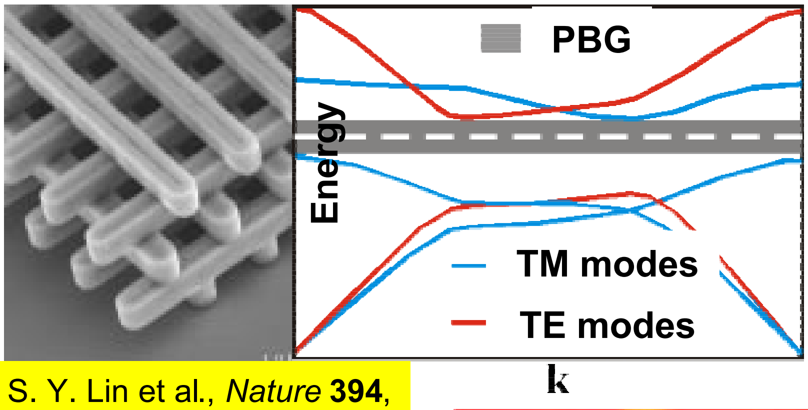


undoped heterostructure: Ultra-low disorder

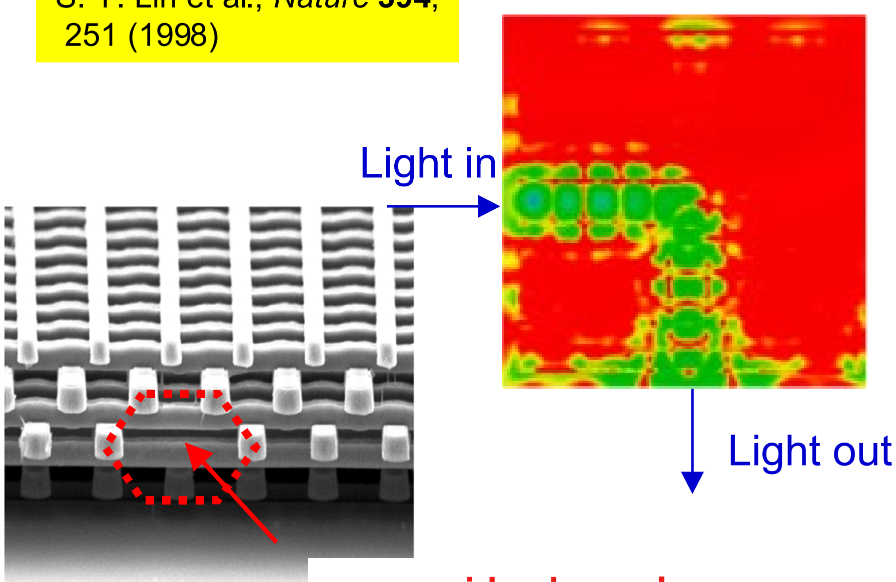


Photonic Crystals and Photonic Fibers:
Tailored Photonic Interactions

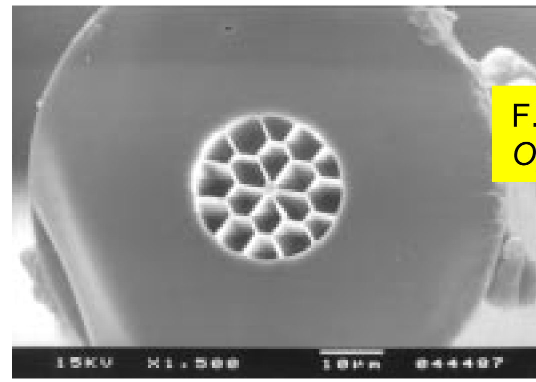
- **Photonic crystals:optical interconnects, filters, switches, microcavities, LEDs, etc.**



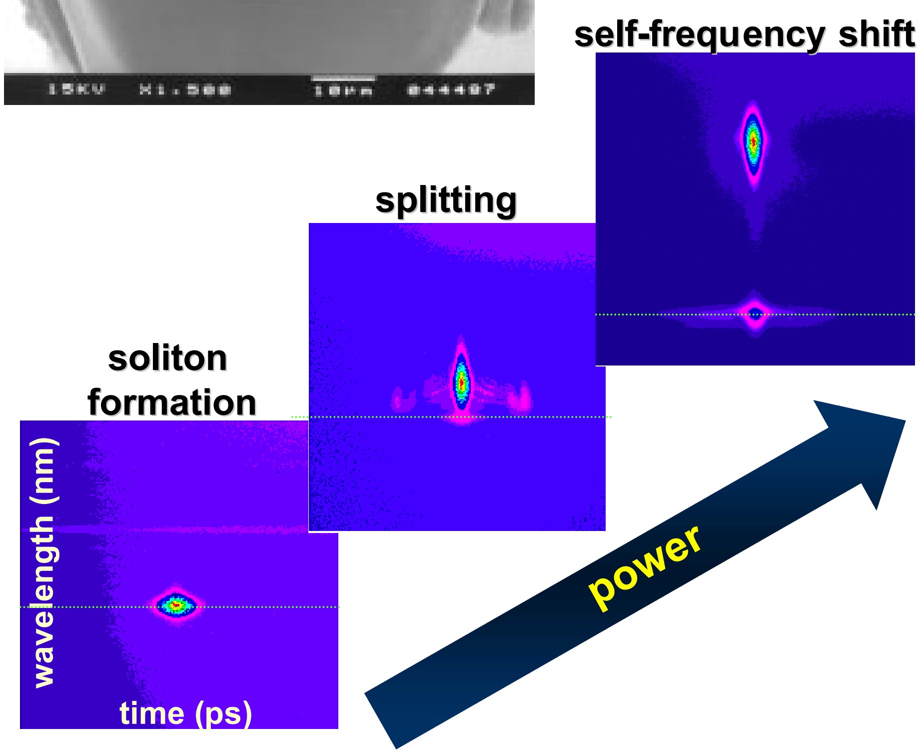
S. Y. Lin et al., *Nature* **394**, 251 (1998)



- **Photonic fibers: high-speed telecom, nonlinear optics**

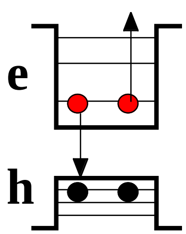


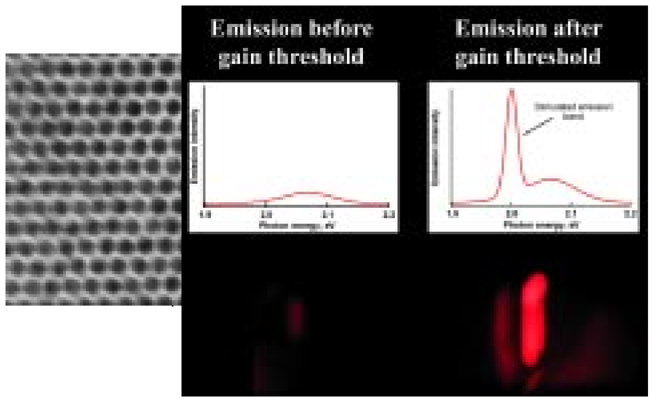
F. G. Omenetto et al., *Opt. Lett.* **26**, 1158 (2001)

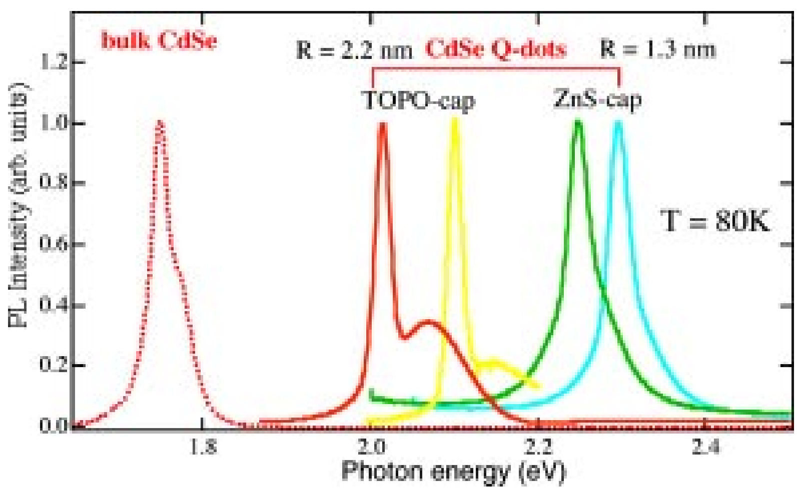


Nanocrystal Q-dots: Nanoscale Building Blocks with Tunable Optical Spectra

- Optical amplification and lasing in NQD solids

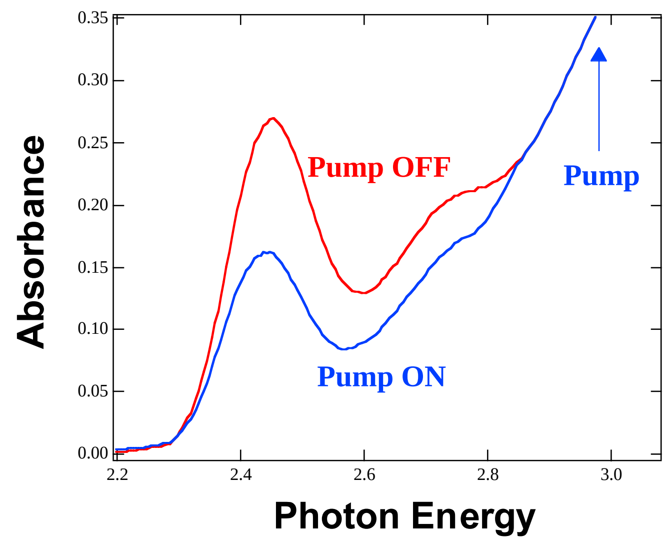






V. Klimov et al., *Science* **287**, 1011 (2000), *Science* **290**, 314 (2000)

- Resonant optical nonlinearities in NQD solids

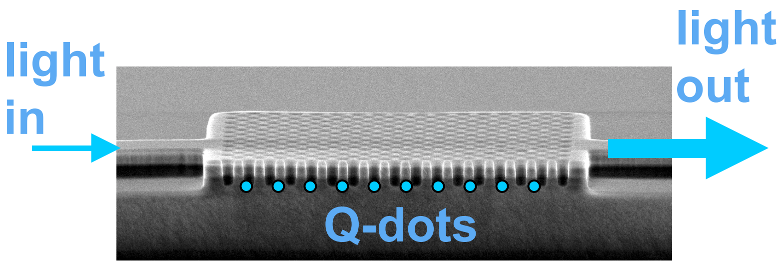


optical modulation/switching, optical logic, light steering, etc.

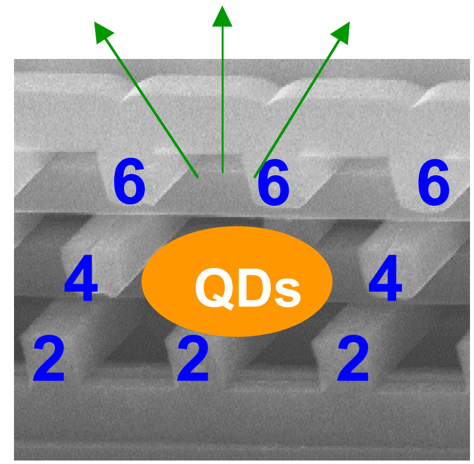
B. Kraabel et al., *Appl. Phys. Lett.* **78**, 1814 (2001)

FUTURE DIRECTIONS: Novel Photonic Devices via Combining Q-dots and Photonic Structures

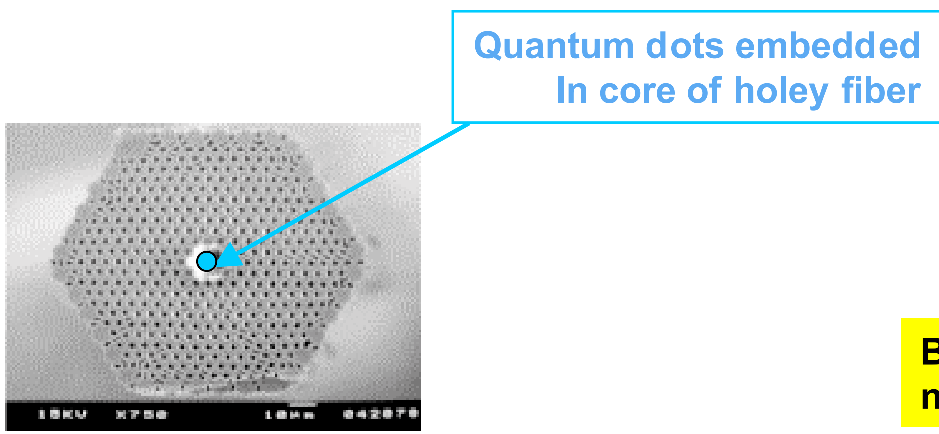
- Micro-lasers and amplifiers based on QDs inserted in cavities in photonic crystals

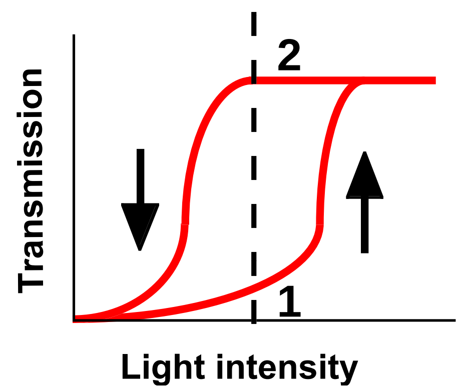


Optical amplification in QDs in 2D photonic crystals



- Nonlinear-optical elements based on QDs in photonic fibers and photonic crystals

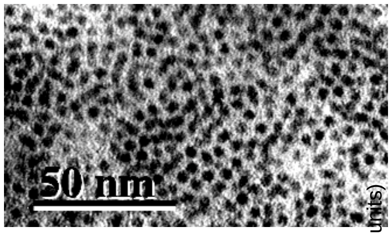


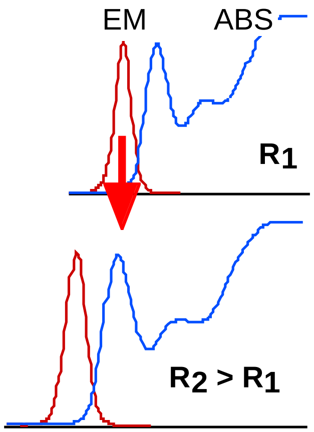


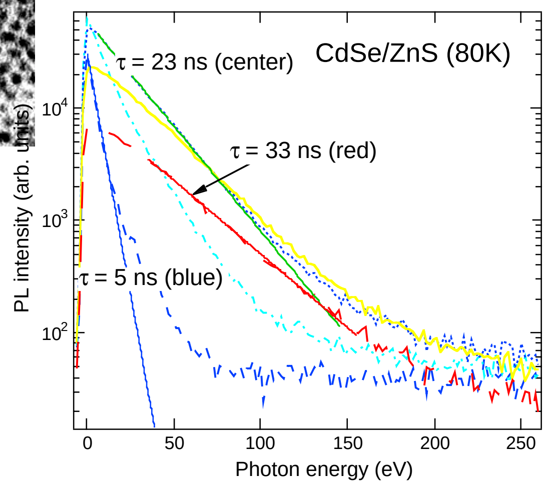
Bi-stable switching due to nonlinearity & positive feedback

FUTURE DIRECTIONS: Novel Optical Properties via Near-Field Coulomb Interactions

•Exciton transport in Q-dot assemblies

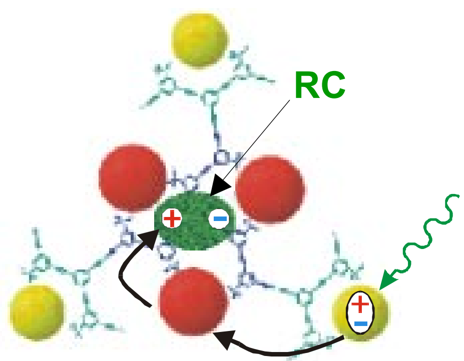






Nano-chemistry

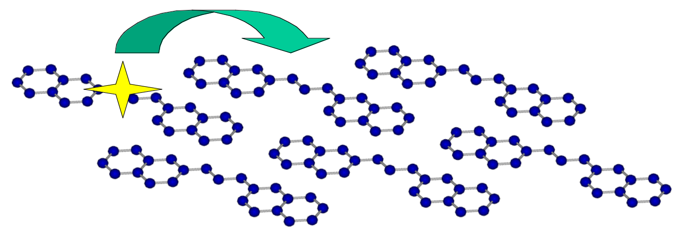
Nano-Bio



FUTURE: Bio-inspired light-harvesting structures

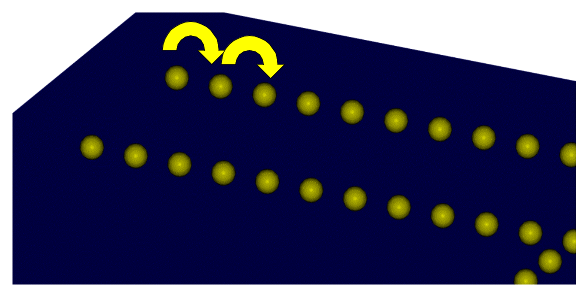
FUTURE DIRECTIONS: Energy transfer in organic aggregates

Exciton delocalization



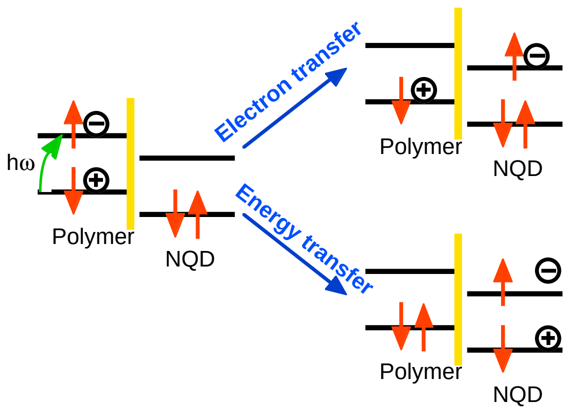
FUTURE DIRECTIONS: Energy transport in nanoparticle chains

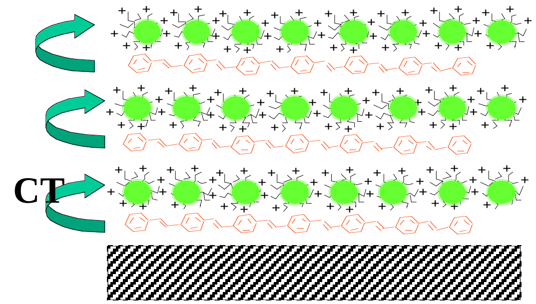
Plasmonic Wires



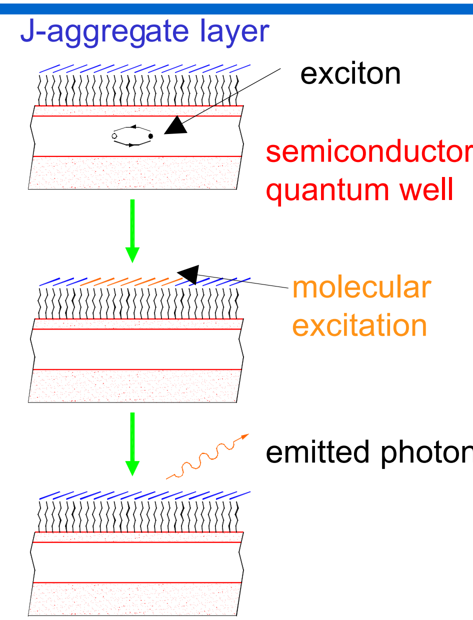
FUTURE DIRECTIONS: Hybrid Inorganic-Organic Photonics and Electronics

Energy/charge transfer at organic/inorganic interfaces: light harvesting, photovoltaics, LEDs





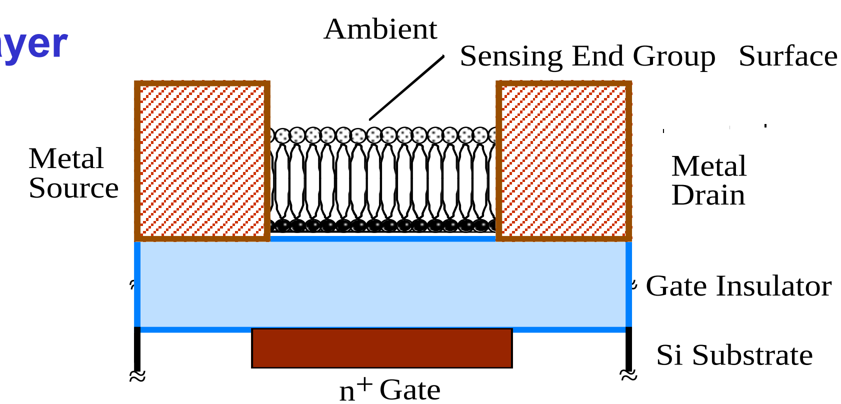
Energy/charge transfer at Q-dot/polymer interfaces



Exciton transfer between QWs and molecular J-aggregates

Chem/bio-sensing: change in monolayer mobility in response to changes in environment

I. H. Campbell and D. L. Smith, *Sol. St. Phys.: Adv. Res. Appl.* **55**, 1 (2001).



FUTURE DIRECTIONS: Magnetic Nanostructures and Spin Interactions

Studies of super-paramagnetic transition in Co nanoparticles

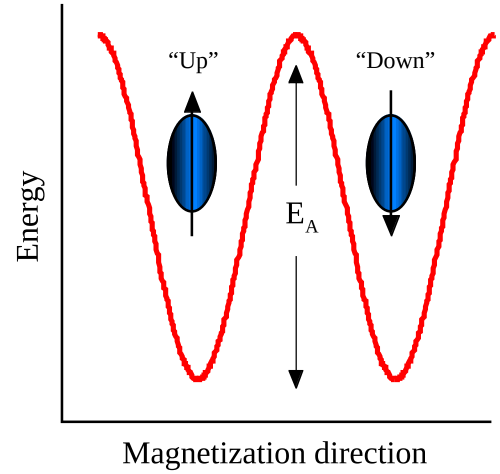
LANL/ MIT/CalTech collaboration:
(Hammel, Klimov, Bawendi, Roukes)

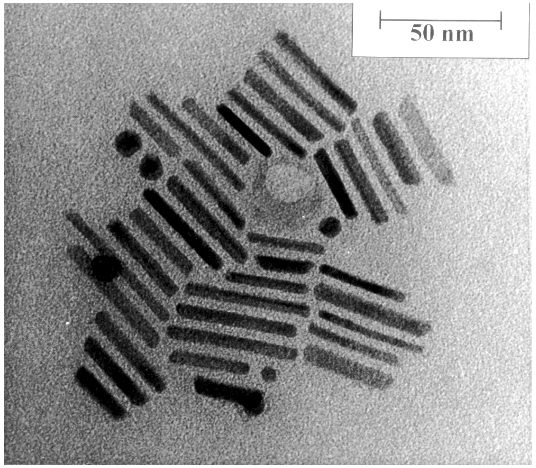
MIT/LANL

- Sample fabrication: size- and shape-controlled Co nanomagnets

LANL/Caltech

- Single nanoparticle studies using MRFM: correlation between shape and magnetic anisotropies

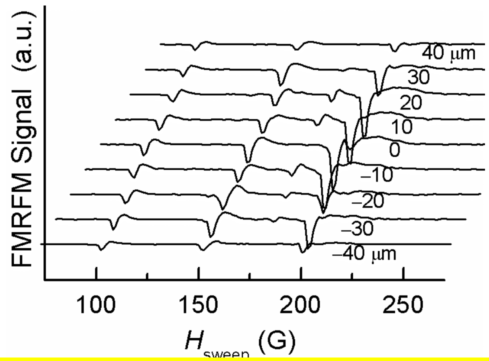




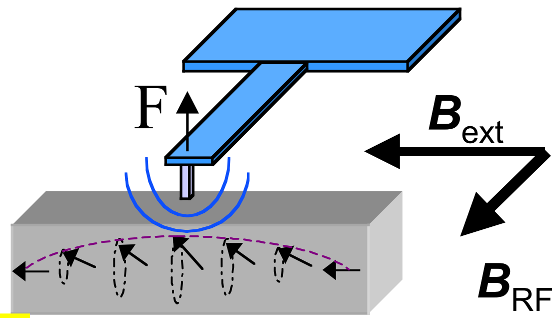
Colloidal Co nanoparticles (Bawendi, MIT)

FUTURE DIRECTIONS: Novel Nano-Scale Probes

- Magnetic resonance force microscopy



Spatially-resolved MRFM signals from YIG islands (C. Hammel)

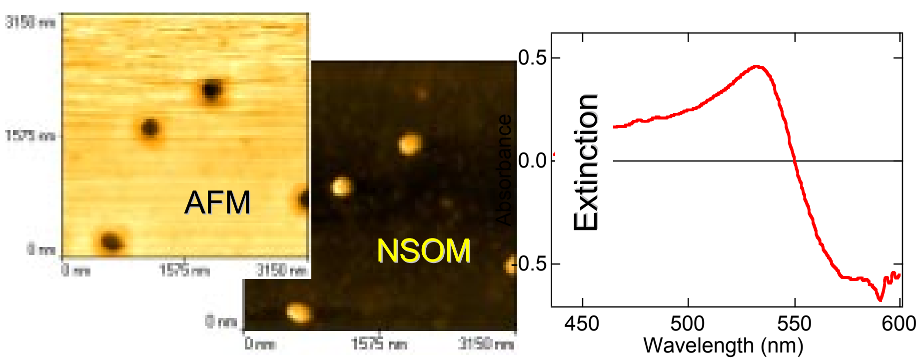


$$F = (m \bullet \nabla)B$$

Force detection (available):
$5x10^3$ spins (R = 20 nm)

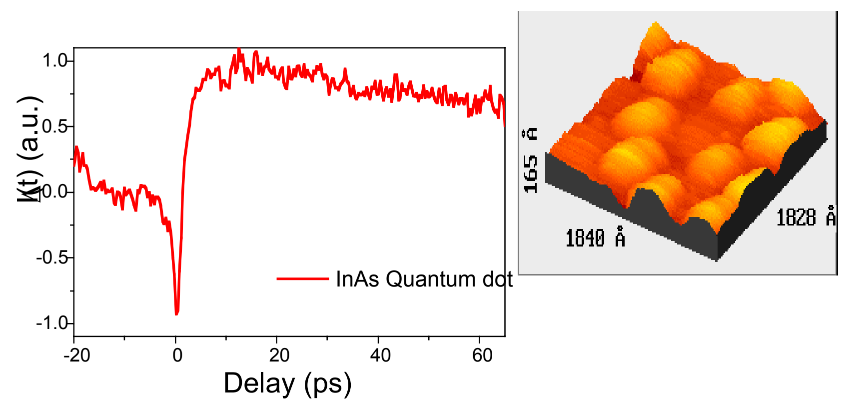
Force detection (improved):
10 spins (R = 2.5 nm)

- Time-resolved NSOM



Single-50-nm Au QD extinction spectrum
(A. Mikhailovsky and V. Klimov)

- Ultrafast STM



Single InP QD dynamics
(T. Taylor)

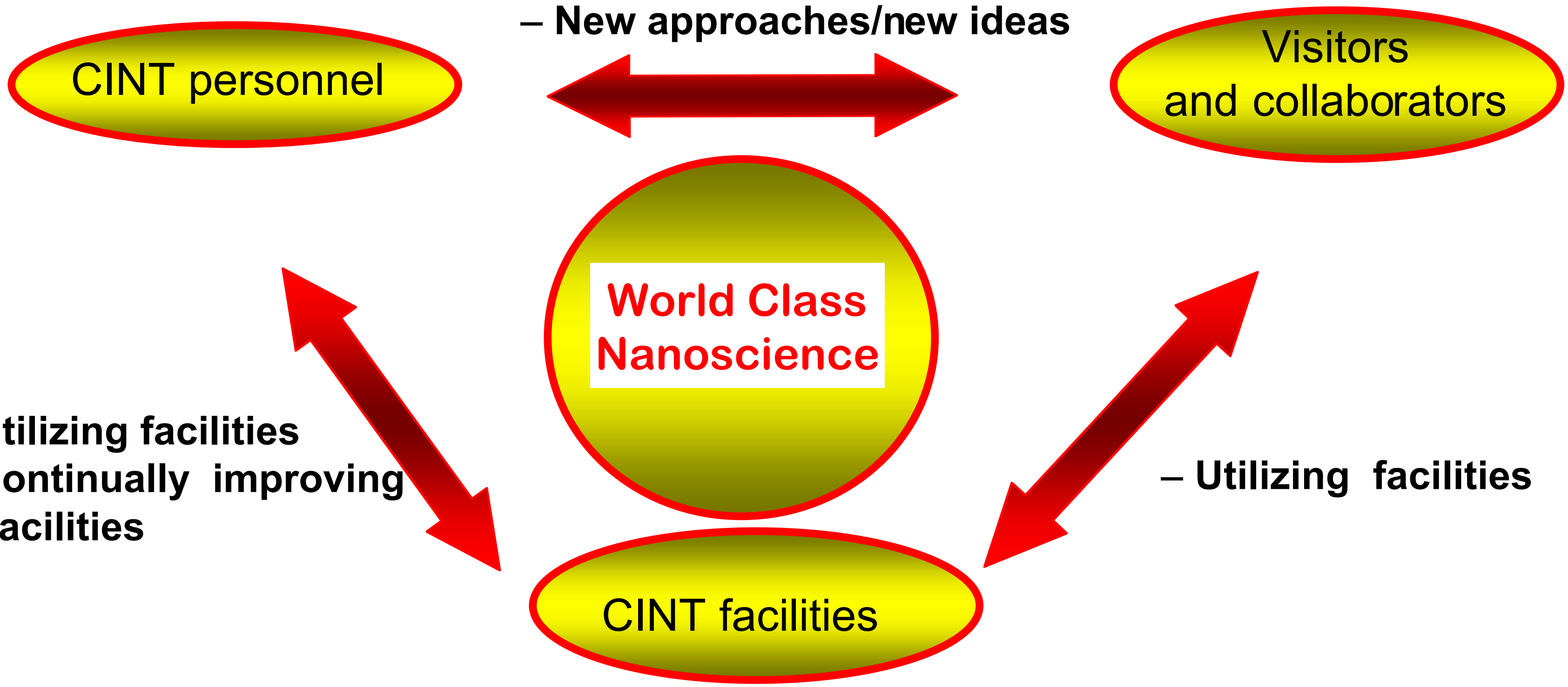
New Nanoscience
Enabled by Novel Materials and Novel Tools

- **Comprehensive studies of nanoscale phenomena using a suite of CINT complementary tools**

  - Cooperative electronic interactions (exciton delocalization, superconductivity, cooperative magnetic interactions)
  - Coherent photonic interactions in photonic structures (photon bound states, photon tunneling, hopping, etc.)
  - Tailored electron-photon interactions in hybrid electronic/photonic structures
  - Measurements and manipulation of quantum and classical spins
  - Charge/energy transfer at nanointerfaces; single D-A pair energy/charge transfer
  - Single nano-object microscopy/spectroscopy (optical, atomic force, tunneling current, magnetic; also time-resolved)

Collaborative Interactions Will Benefit All Parties

– Sharing intellectual resources
– Cross-fertilization
– New approaches/new ideas



– Utilizing facilities
– Continually improving facilities

– Utilizing facilities

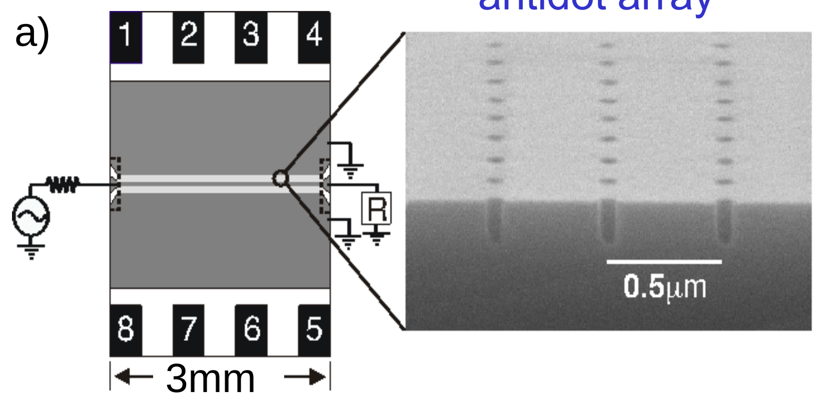
– High-mobility MBE growth
– High-resolution e-beam lithography
– Novel scan-probe techniques
– Ultrafast spectroscopies

How Collaboration Might Work

NHMFL/ Princeton/ Sandia collaboration:
(Ye, Engel, Tsui, Simmons, Wendt, Vawter, Reno)

Microwave magnetoconductance of a 2DEG with antidot array -- FQHE edge states, composite fermions

50 nm diameter antidot array



NHMFL/ Princeton/ Sandia:

- Sample design, mask design
- optical lithography

Sandia:

- High mobility MBE growth (to 10^7 cm^2/Vs)
- antidot electron beam writing
- reactive ion beam etching

NHMFL:

- Low temperature (mK)
- high B field (to 33 T)
- high frequency (10 GHz) measurements