Perspectives on Solid State Research at AFOSR

11 April 2008

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Physics & Electronics Directorate
Air Force Office of Scientific Research
Air Force Research Laboratory

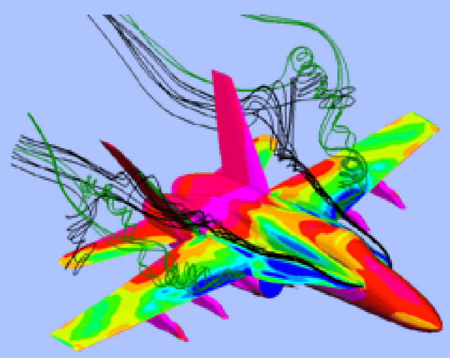
AFOSR is USAF
Basic Research Manager

- ***Identify Breakthrough Research Opportunities – Here & Abroad***
  - Regular interactions with leading scientists and engineers
  - Liaison offices in Europe and Asia, soon in Latin America
  - 238 short-term foreign visitors; 28 personnel exchanges
  - 95 summer faculty; 30 postdocs/senior scientists at AFRL
- ***Foster Revolutionary Basic Research for Air Force Needs***
  - 1181 extramural research grants at 227 universities in FY07
  - 239 intramural research projects at AFRL, USAFA, AFIT
  - 150 STTR small business - university contracts
  - 533 fellowships; 1390 grad students, 570 post-docs on grants
- ***Transition Technologies to DOD and Industry***
  - 100 workshops held & 144 conferences co-sponsored in FY07
  - 665 funded transitions (~55% response rate)

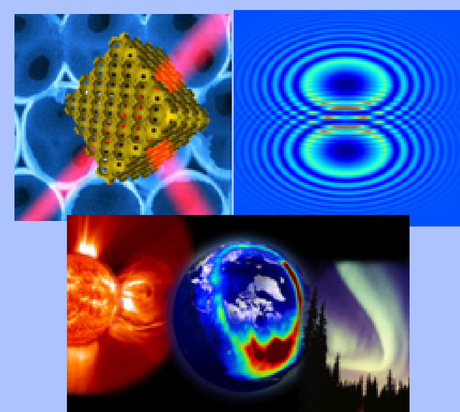
AFOSR Basic Research Areas

DIRECTORATES

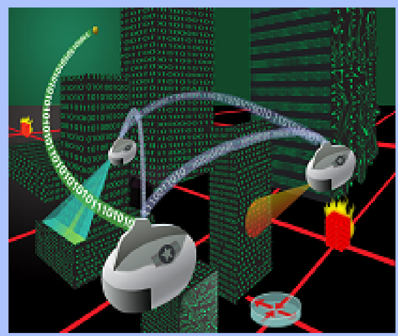
Aerospace, Chemical & Materials Sciences (NA)



Physics & Electronics (NE)



Mathematics, Information & Life Sciences (NL)



Sub-THRUSTS

Aerospace, Chemical & Materials Sciences (NA)

- Structural Mechanics
- Materials
- Chemistry
- Fluid Mechanics
- Propulsion

Physics & Electronics (NE)

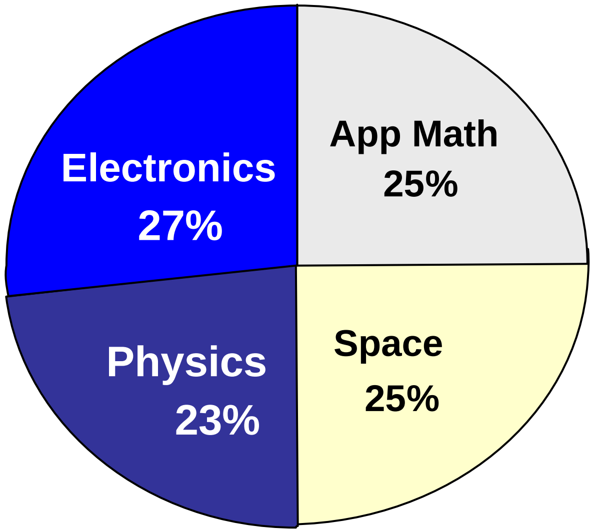
- Physics
- Electronics
- Space Sciences
- Applied Math

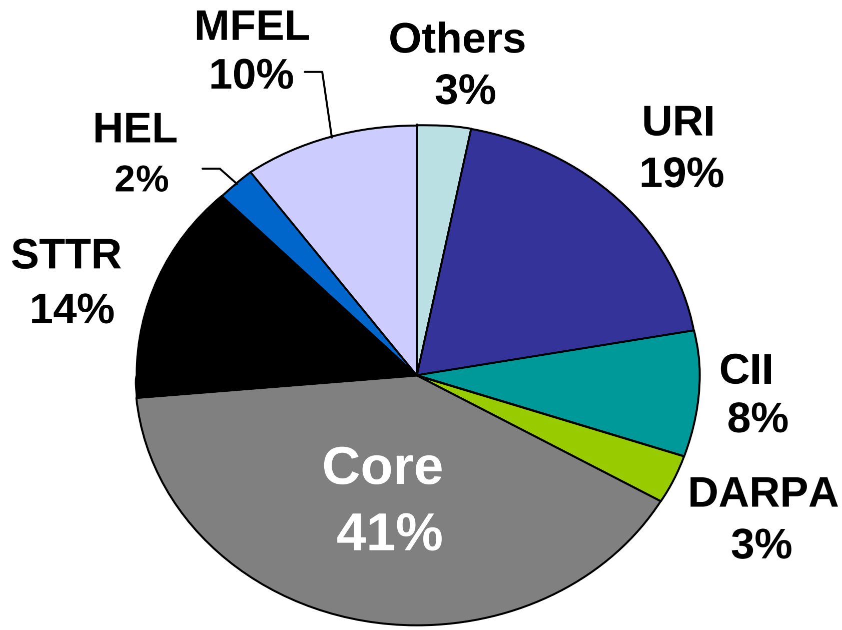
Mathematics, Information & Life Sciences (NL)

- Info Sciences
- Human Cognition
- Mathematics
- Biomimetics

AFOSR/NE FY07 Budget

CORE = $53 M





NE Total Budget = $140 M

FY07 Solid State Related Research ~ $52M

(FY08 ~$50-60 depending on final DoD awards)

6.1 Solid State Research Areas

* Negative index materials
* High-temperature superconductivity
* Adaptive multimodal sensing matl's/devices
* Novel semiconductor & electromagnetic matl's
* Nanoelectronics & nanostructures
* Nanophotonics & integrated photonics
* Optical data processing & storage concepts
* THz radiation sources and detectors
* Computational materials physics
* Quantum simulation of condensed matter

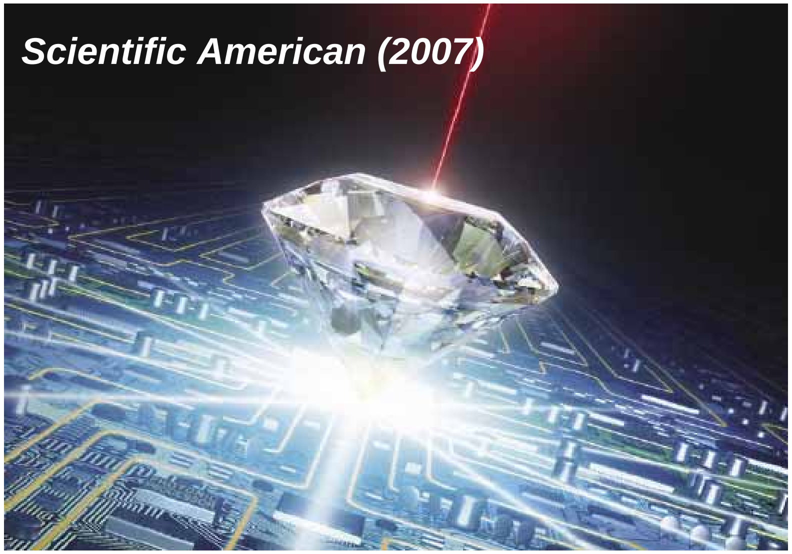
Example High Priority Areas

* Quantum computing
* Negative index materials
* Integrated nanophotonics
* Nanoelectronics/nanostructures
* High-temperature superconductivity

an example for each area will follow…

(out of ~245 grants/awards in solid state)

Quantum Engineering with Single Spins in Diamond: D. Awschalom, *UCSB*



Objectives and Approach

- Optical read-out & gigahertz manipulation of single electron spins in semiconductors
- Atomic channels to exchange information between spins for ultradense information processing
- Image individual nitrogen-vacancy (N-V) defects in synthetic diamond through spin-dependent emission
- Coherent electronic control for room temperature spin-based quantum optoelectronics

AFOSR Relevance

- Rapid advances in growth of synthetic diamond offer new opportunities: high speed low power dense nanoelectronics
- **Optoelectronic capabilities for quantum information processing**
- Extremely efficient heat sink for Silicon electronics to extend Moore's law
- **Integration of logic and (secure) high bandwidth communication**

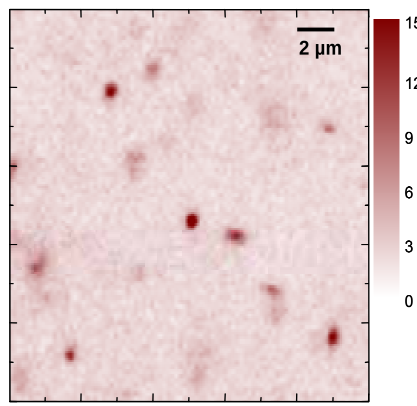
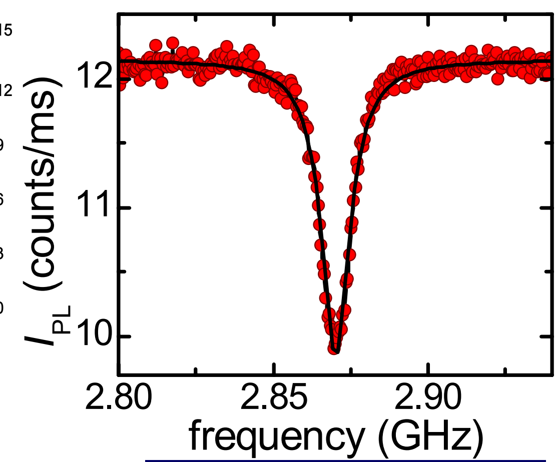


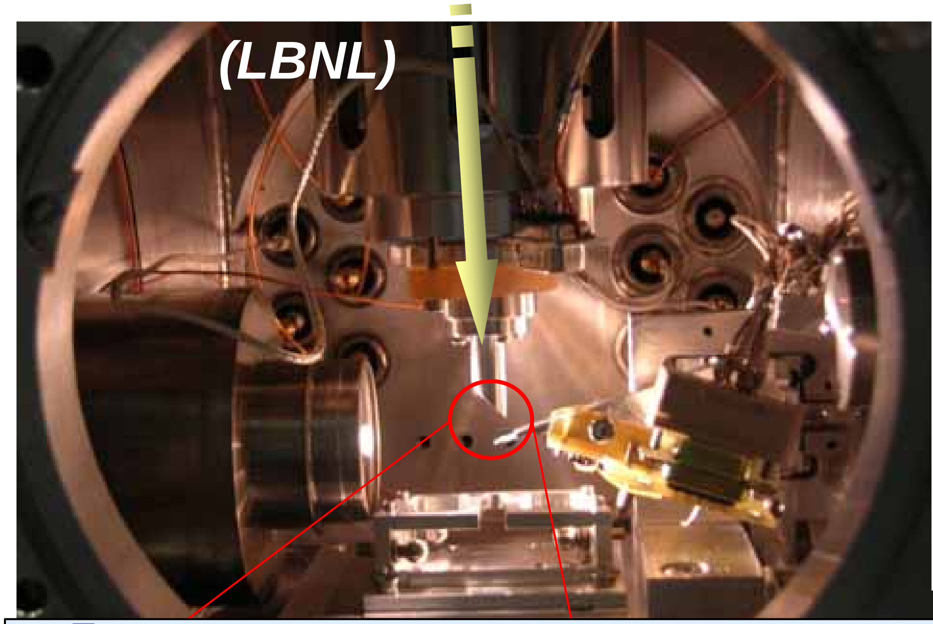
image of single electron spins



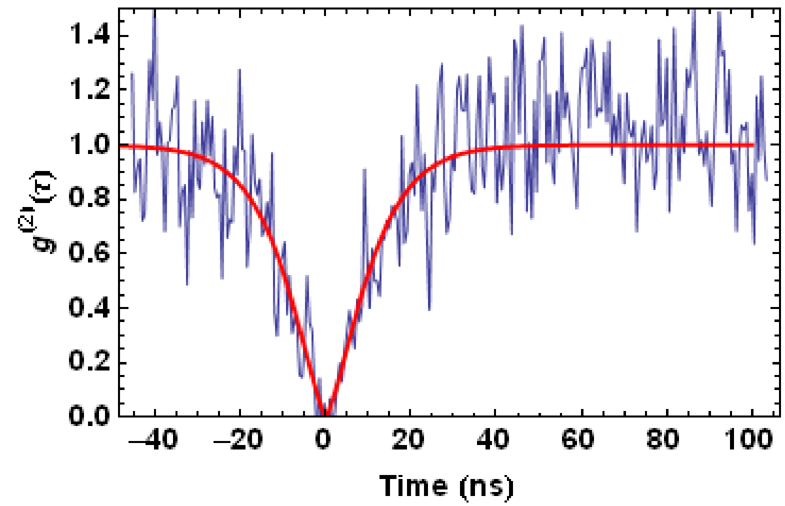
ESR of single electron spin

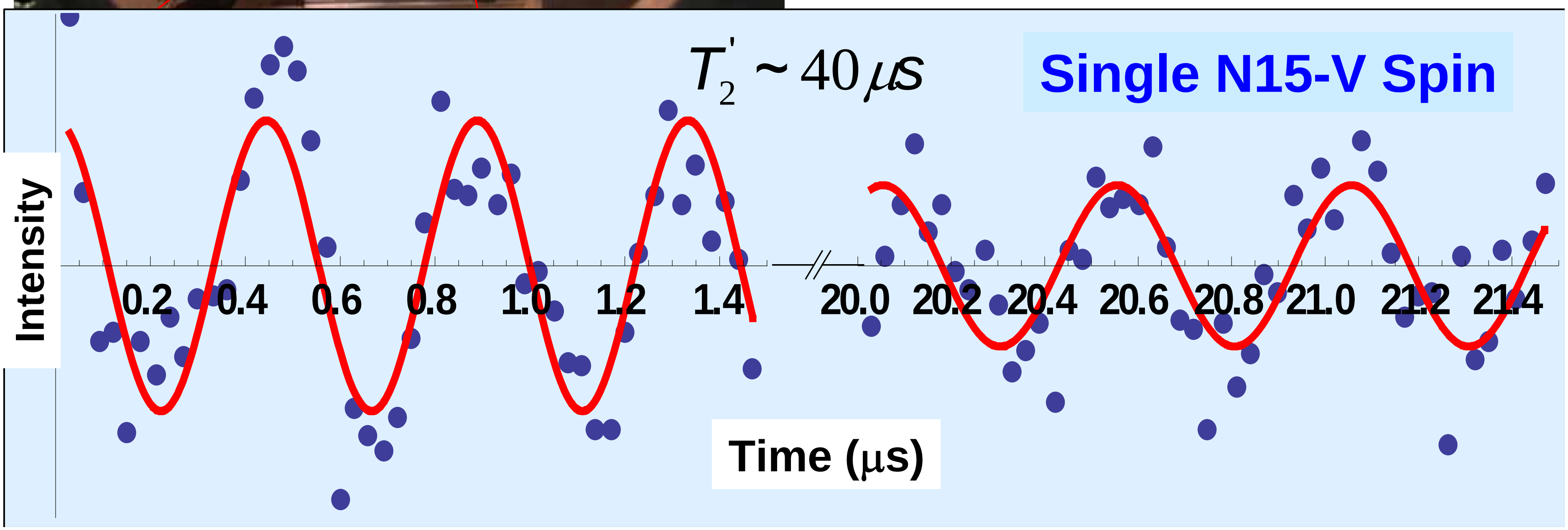
Engineering Single Spin Systems in Diamond

ion-implantation of N-15 and subsequent annealing: designer spins



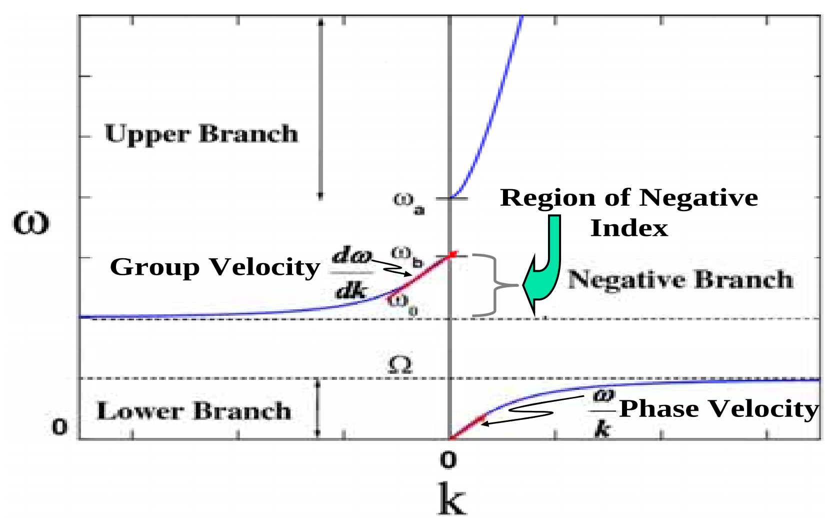
Anti-bunching indicates single spins





THz Generation from Nonlinear Negative Index Materials (NIMs): Chowdhury, Lucent

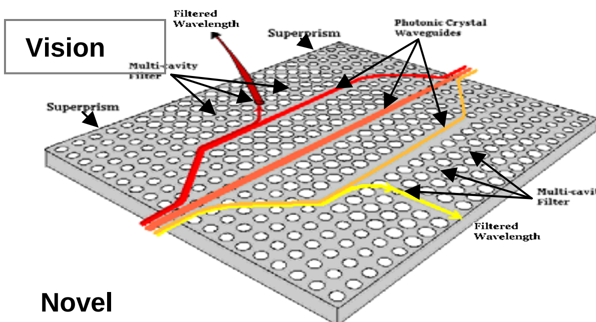
- Theoretically discovered that terahertz waves can be generated from optical pulses using a nonlinear NIM via long-wave / short-wave resonance → the first report indicating NIMs could generate THz
- THz radiation has many app's: security, imaging, sensing & spectroscopy



- Resonance occurs when the 'group velocity' of short wave (e.g. optical) matches the phase velocity of long wave (e.g. terahertz)
- For a medium possessing second-order nonlinearity, the coupling of the frequencies of the long & short waves is enhanced

Chip-Scale WDM Devices Using Photonic Crystals (PCs): A. Adibi, Georgia Tech

Goal: **To develop a dense integrated platform for on-chip optical processing functionalities**



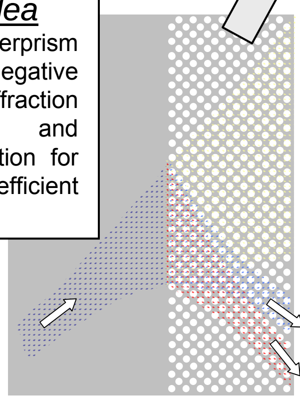
Novel Demultiplexers

Achievements

1. Design of the most compact PC demultiplexer with two orders of magnitude smaller size and world-record of wavelength resolution.
2. Design of biperiodic waveguides with lowest loss and largest bandwidth for single-mode guiding reported to date.
3. Demonstration of several complex functional devices for chip-scale photonics.
4. Novel theoretical, fabrication, and characterization techniques.

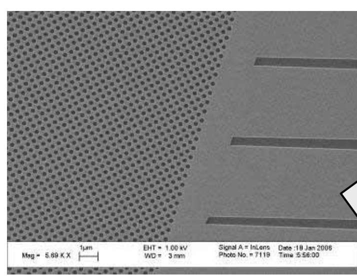
Device idea

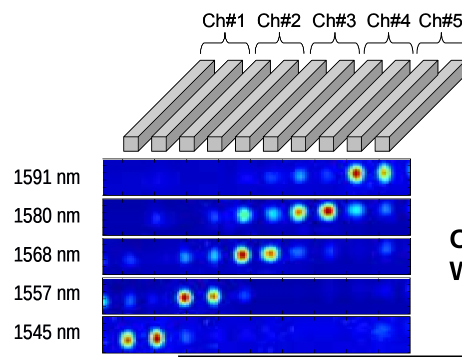
Combining superprism effect with negative diffraction (diffraction compensation) and negative refraction for compact and efficient demultiplexing



Fabrication

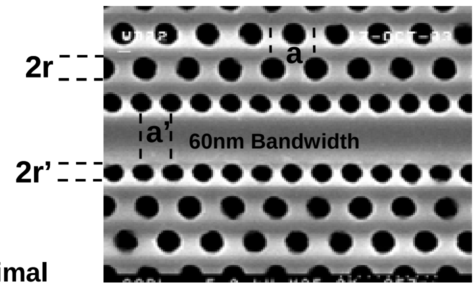
Developing the proper recipe for high-quality fabrication (small feature size, low roughness)



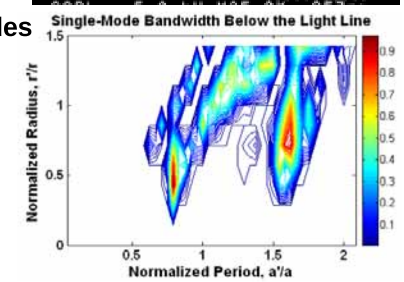


Characterization

Developing the optical characterization set-up and the appropriate measurement technique



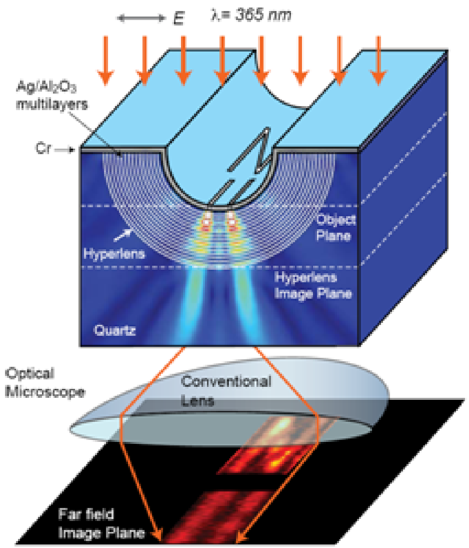
Optimal Waveguides



Air Force Payoff: Demonstration of practical building blocks that are essential for efficient integrated chip-scale photonic crystal platforms for WDM, communications, signal processing, and sensing.

Novel Devices for Plasmonic and Nanophotonic Networks: H. Atwater; Caltech

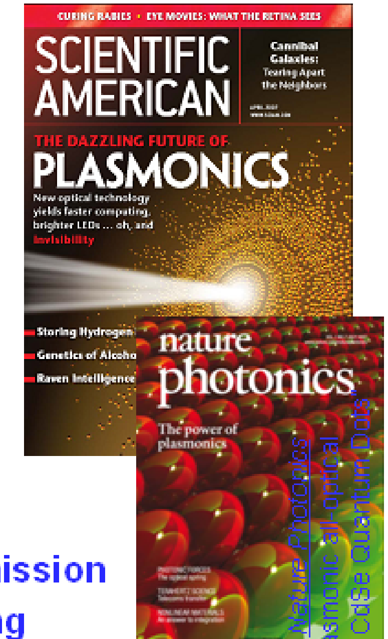
Major Technical Accomplishments: Fall 2006- Fall 2007



Optical Hyperlens, Zhang, Berkeley

- Optical Hyperlens (transition)
- 2D Far Field Superlens (transition)
- PlasMOSter: Si Field Effect Plasmon Modulator
- Plasmonic Electro-Optic Modulation
- Visible Frequency Negative Index Metamaterial
- Double Metal Plasmon Enhanced Mid-IR Detectors
- Plasmonic Quantum Cascade Laser Antenna
- Bowtie Plasmonic Laser Antenna
- Opto-Mechanical Plasmon Resonators
- Quantitative Model for InGaN Plasmon Enhanced Emission
- Experimental Demonstration of Dimple Lens Focusing

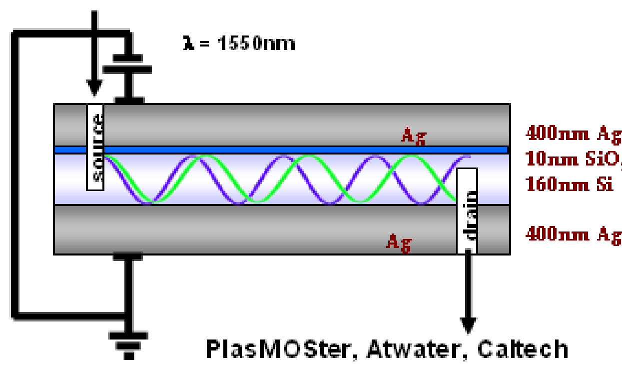
H.A. Atwater, *Scientific American* April 2007



Cover article, Nature Photonics July 2007 "Plasmonic all-optical modulation in CdSe Quantum Dots"

Transitions

- **Electro-Optic Plasmonic Materials and Devices**
  Harry Atwater(with Hiroshi Komine, Northrop Grumman)
  Electro-optic beam steering and tunable metamaterials
- **Hyper-spectral/polarization Mid-IR detectors**
  Oskar Painter (with Tom Nelson, AFRL).
  Enhanced D* and tunable spectral response in MWIR detectors
- **Fiber Optic Plasmonic Coupled Antenna Array Device**
  Federico Capasso (DARPA *Microfluidics and Plasmonic Systems* Center*; Dennis Polla, DARPA-MTO)). Ultrasensitive (single molecule) chembio detection using SERS.

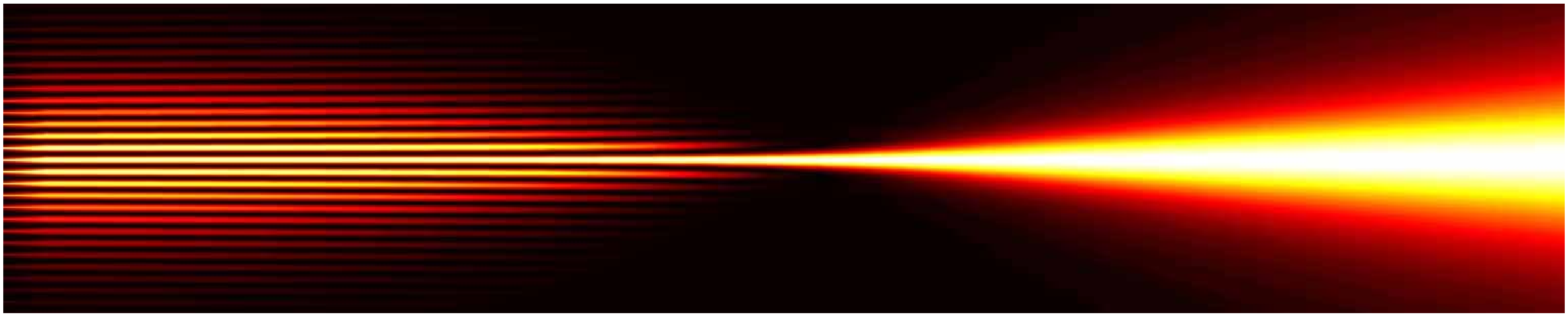


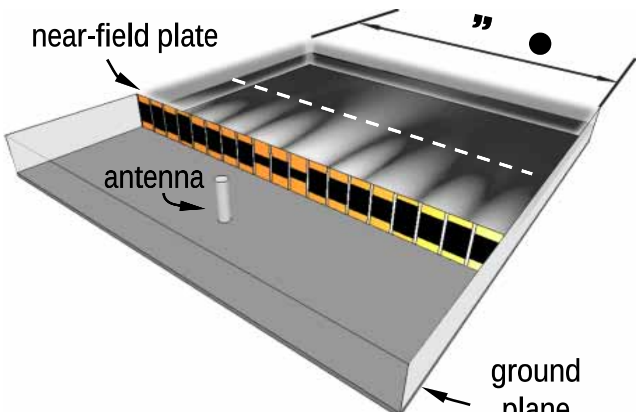
PlasMOSter, Atwater, Caltech

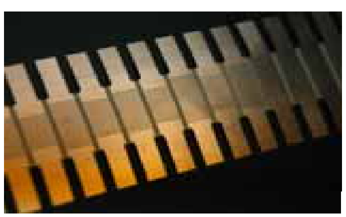
http://www.plasmonmuri.caltech.edu/index.html

Near-Field Plates: λ/20 Focusing at 1 GHz
FY06 MURI: Grbic, Jiang & Merlin, U. Michigan

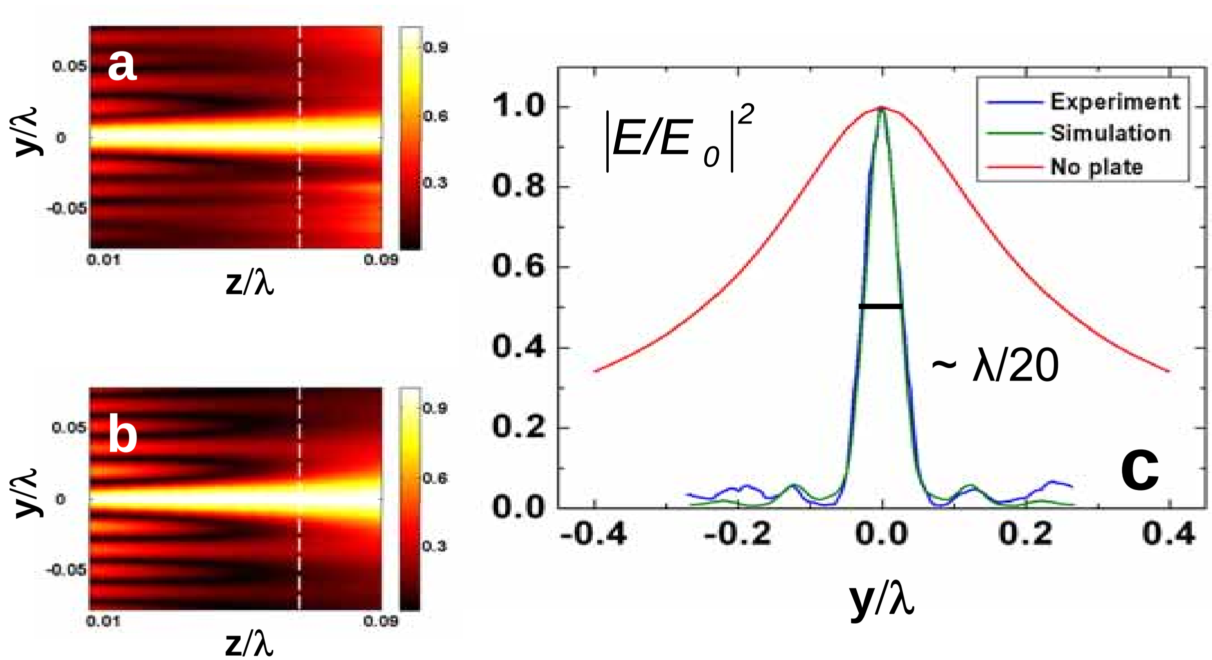
- an entirely new perspective in electromagnetic field manipulation and control
- sub-wavelength focusing by radiationless interference



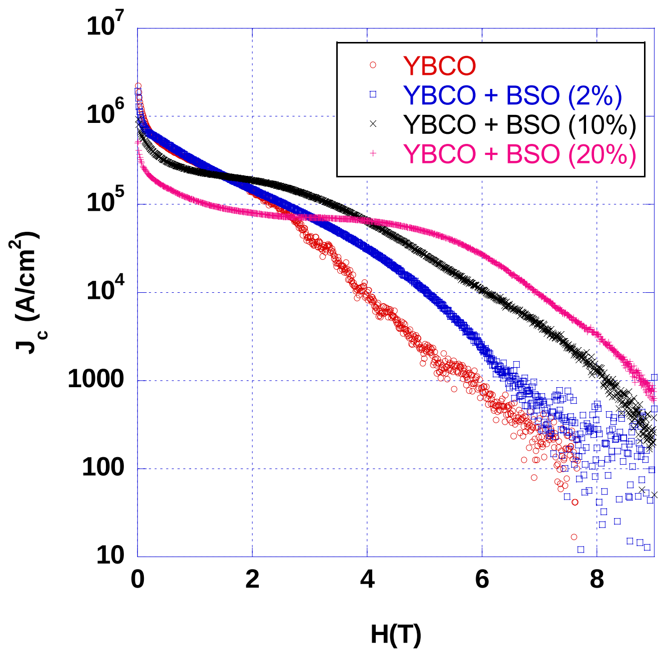




near-field
plate

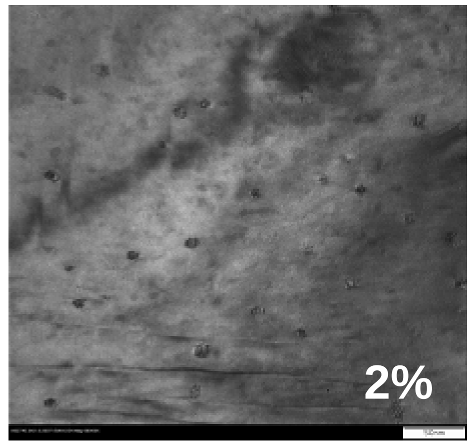


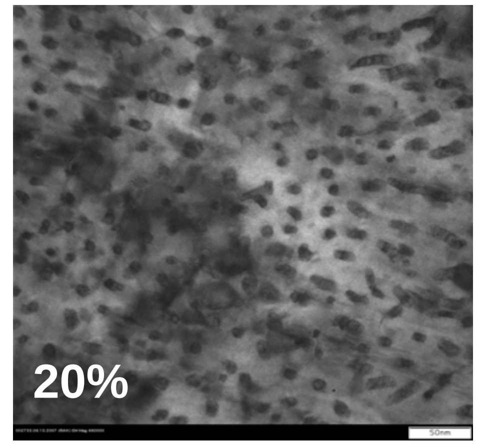
Varying Density of $BaSnO_3$ Nanorods:
P. Barnes, AFRL/RZ



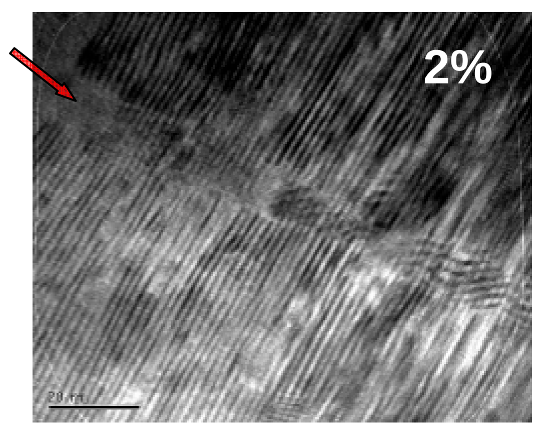
Higher amounts of BSO greatly increases J_c in high fields, although Jc decreases in low field

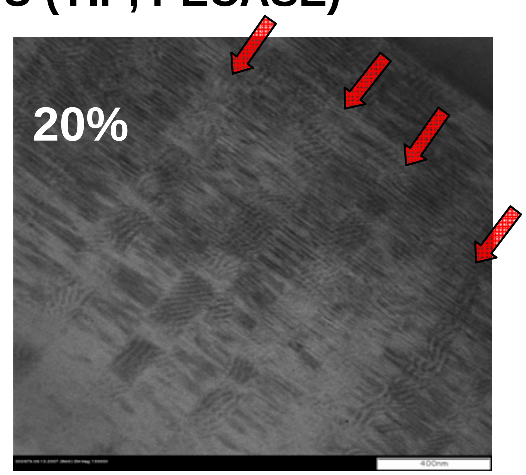
<u>operating magnetic field is what really matters</u>





Plan View TEM of YBCO + 2% BSO, YBCO + 20% BSO
TEM by H. Wang, TAMU (YIP, PECASE)





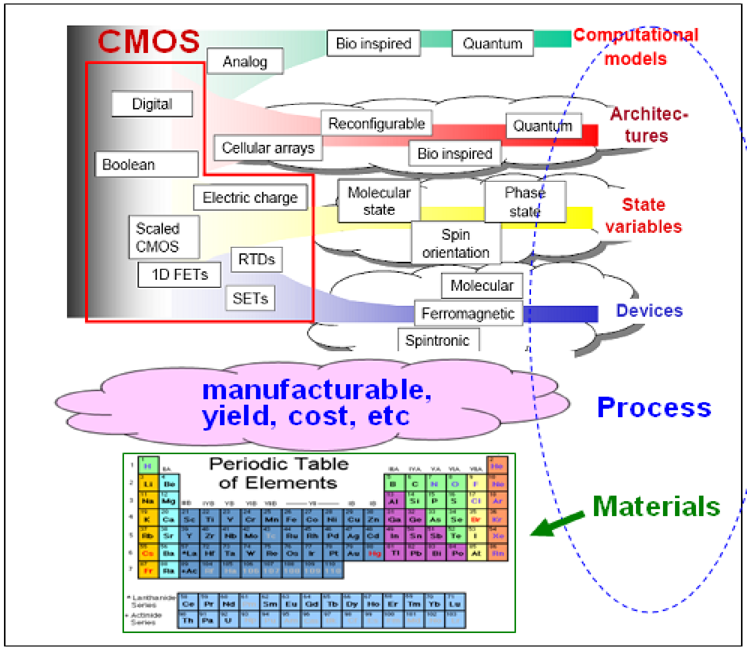
Cross-sectional TEM YBCO + 2% BSO, YBCO + 20% BSO, # of Nanorods increased as BSO % increased

Tbps/THz-Speed Electronics Vision

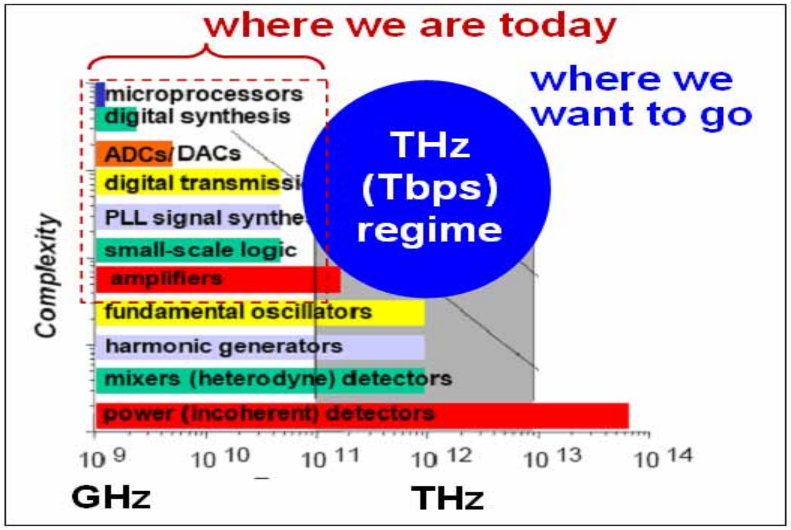
Performance beyond end-of Moore's Law (Si) projections

Discover novel means of physically representing, processing, storing, & transporting information at Tbps speeds via new materials, processes, device structures, state-variables, architectures, & computational models.

Information Technology Interactive Layer Hierarchy



GHz-THz-Speed Electronics



For e.g., III-V CMOS is becoming a reality - could potentially breach Tbps!

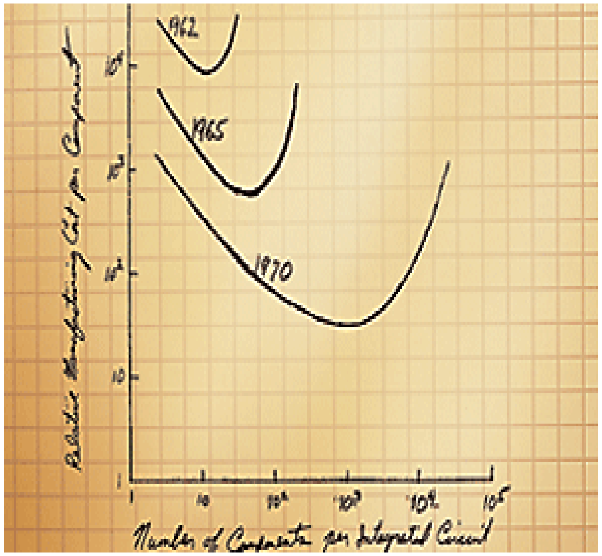
2008 “Beyond Moore’s Law” Winter School

January 7-11, 2008, Kenting, Taiwan

Main organizer was Dr. Harold Weinstock

Goals:

Bring together world-class researchers and leaders in alternative materials & technologies that are potentially enabling for addressing key challenges facing continued increased density and faster logic and memory architectures.



Moore’s Law: “The number of transistors on a chip will double every 18 months.”

Organizers/Sponsors: US Air Force Office of Scientific Research, Taiwan National Nanoscience Program, Korean Nano-Technology Research Society

Participants: 11 world-class research lecturers; over 75 international senior scientists, and more than 125 graduate/undergraduate students

2008 "Beyond Moore's Law" Winter School

… world-class research-instructors

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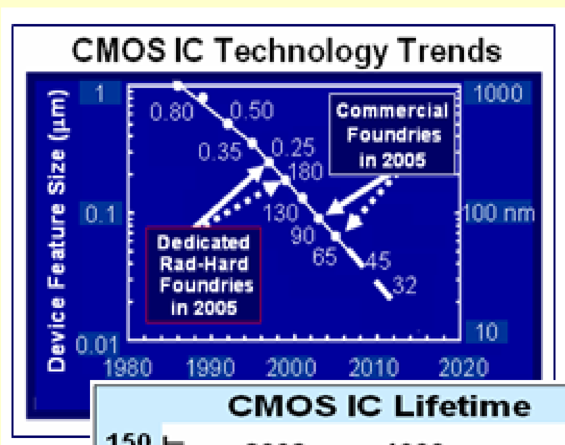
… lectures are available on disc per Harold Weinstock

Critical Issues Facing 'End-of-Moore's Law' and Beyond Deeply-Scaled Digital Electronics

Performance is great (speed, flops, etc), but at what cost to reduced reliability for DoD applications??

- **The issue is more changes in IC technology and materials in past five years than previous forty years → driven my Moore's Law → SiGe, SOI, strained Si, alternative dielectrics, new metal systems**
- And **reliability has/is being traded for performance!!**
- **Future space and defense systems will require greater under-standing of reliability & radiation effects in advanced technologies**



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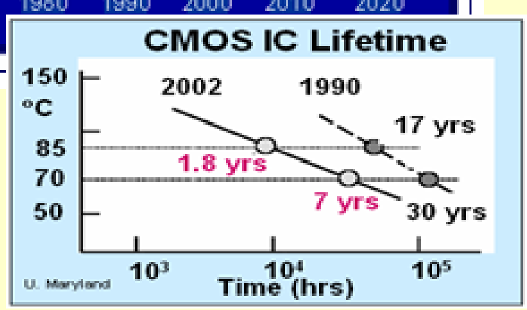

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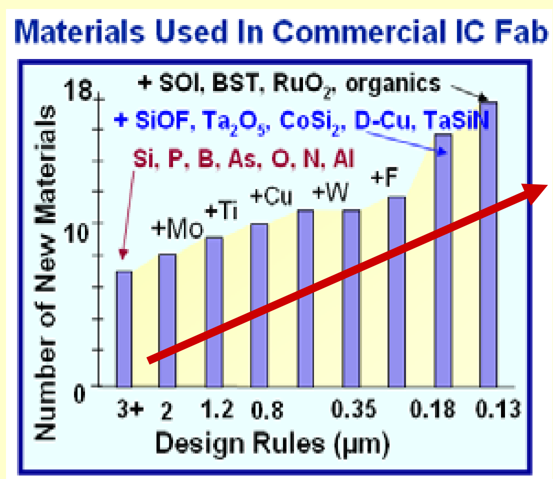


\+ **radiation**

totally unknown rad. & reliability behaviors & sensitivities

2 AFOSR MURIs:
'Radiation Effects on Emerging Electronics'
& '21st Century Approach for Electronics Reliability'

Compact Space Power via Nanoelectronics

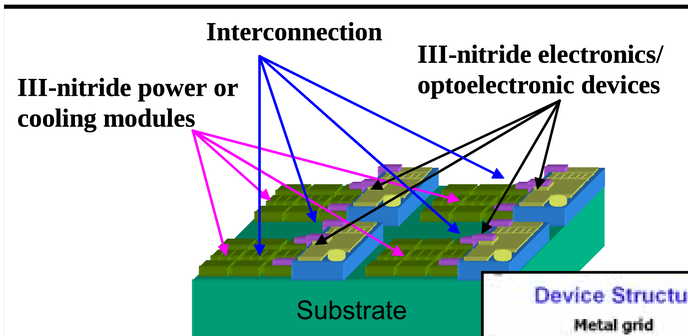
Objective: Increase specific power for solar arrays, fuel cells and power storage systems for high power space platforms.

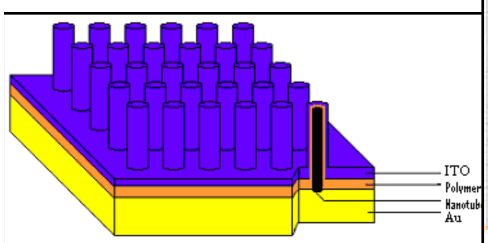
Approach:

- **Quantum Dots to enhance IR absorption**
- **Multicharges/photon QDs in Organic Cells**
- **Thermoelectrics Using Si Nanowires**
- **III-Nitrides for Hydrogen Fuel Cell**
- **Hierarchical Junction Hybrid Solar cells**
- **Carbon Nanotube Based Supercapacitors**
- **Organic Photovoltaic Cells w/ Aligned CNT**

Payoff:

- **Provide Power Source for High Power Space Assets such as Space Based Radar and Space Based Laser**
- **Low cost power for Launch on Demand assets**
- **Reduce overall satellite weight and decrease cost of satellite launch**
- **Enable smaller and more compact satellites**
- **Increase satellite lifetime, reliability and capabilities**





Accomplishments

- **Total 12 projects ($1.6M in FY07) funded, including 1 lab task (ML)**
- **Radiation hardness of Organic cells demonstrated (AFRL/VS and UCLA)**
- **4x increase in energy density of supercapacitors (Georgia Tech)**
- **Demonstrated solar cell with branched crystals (UC Berkeley)**
- **Enhanced QD response in the IR active regions (U of New Mexico)**
- **Completed the construction of a new cell and experimental setup for water splitting efficiency measurement (Kent State U)**