Nanoscale Science and Engineering Activities at the National Science Foundation

Second Korea-US Nanoforum
February 17, 2005

Geoffrey Prentice, Program Director
National Science Foundation
Engineering Directorate
Arlington, VA
gprentic@nsf.gov *703-292-8371*

NSF and the NNI

- Overview of NNI
- Federal funding for NNI
- Allocation of funds at NSF for NSE and NSEE
- Future directions
- Sample projects

Nanotechnology

Definition on www.nano.gov/omb_nifty50.htm (2000)

Working at the atomic, molecular and supramolecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure

NNI definition encourages new contributions that were not possible before.

- **novel phenomena, properties and functions at nanoscale, which are nonscalable outside of the nm domain**
- **the ability to measure / control / manipulate matter at the nanoscale in order to change those properties and functions**
- **integration along length scales, and fields of application**

Major Accomplishments during the First Four Years (FY00-04) of NNI

- **Research:** NNI supports about 2,500 active awards (of which NSF funds about 2000) in over 300 academic organizations and 200 private organizations in all 50 states; Developments faster than expected: Reducing the time of reaching commercial prototypes by at least of factor of two for several key applications. Setting new goals.

- **Education:** 8,000 students and teachers trained in 2004; All science and engineering colleges have introduced courses related to NSE. Earlier nanotechnology education.

- **Significant infrastructure:** in over 60 universities with user capabilities; Five networks (NCN,NNIN, OKN, DOE, NASA) have been established. About 40,000 workers

NNI: R&D Funding by Agency

Fiscal year (all in million $)	*2000*	*2001* Actual	*2002* Enact/Actual	*2003* Enact/Actual	*2004* Enact/Actual	*2005* Req./ Enact
National Science Foundation	97	150 /150	199 /204	221 /221	249 /254	305
Department of Defense	70	110 /125	180 /224	243 /322	222 /315	276
Department of Energy	58	93 /88	91.1 /89	133 /134	197 /203	211
National Institutes of Health	32	39 /39.6	40.8 /59	65 /78	70 /80	89
NASA	5	20 /22	35 /35	33 /36	31 /37	35
NIST	8	10 /33.4	37.6 /77	66 /64	62 /63	53
EPA	-	/5.8	5 /6	5 /5	5 /5	5
Homeland Security (TSA)	-		2 /2	2 /1	2 /1	1
Department of Agriculture	-	/1.5	1.5 /0	1 /1	10 /1	5
Department of Justice	-	/1.4	1.4 /1	1.4 /1	1.4 /1	1
TOTAL	270	422 /465	600 /697	770 /862	849 /961	982
		+72%	+50%	+24%		

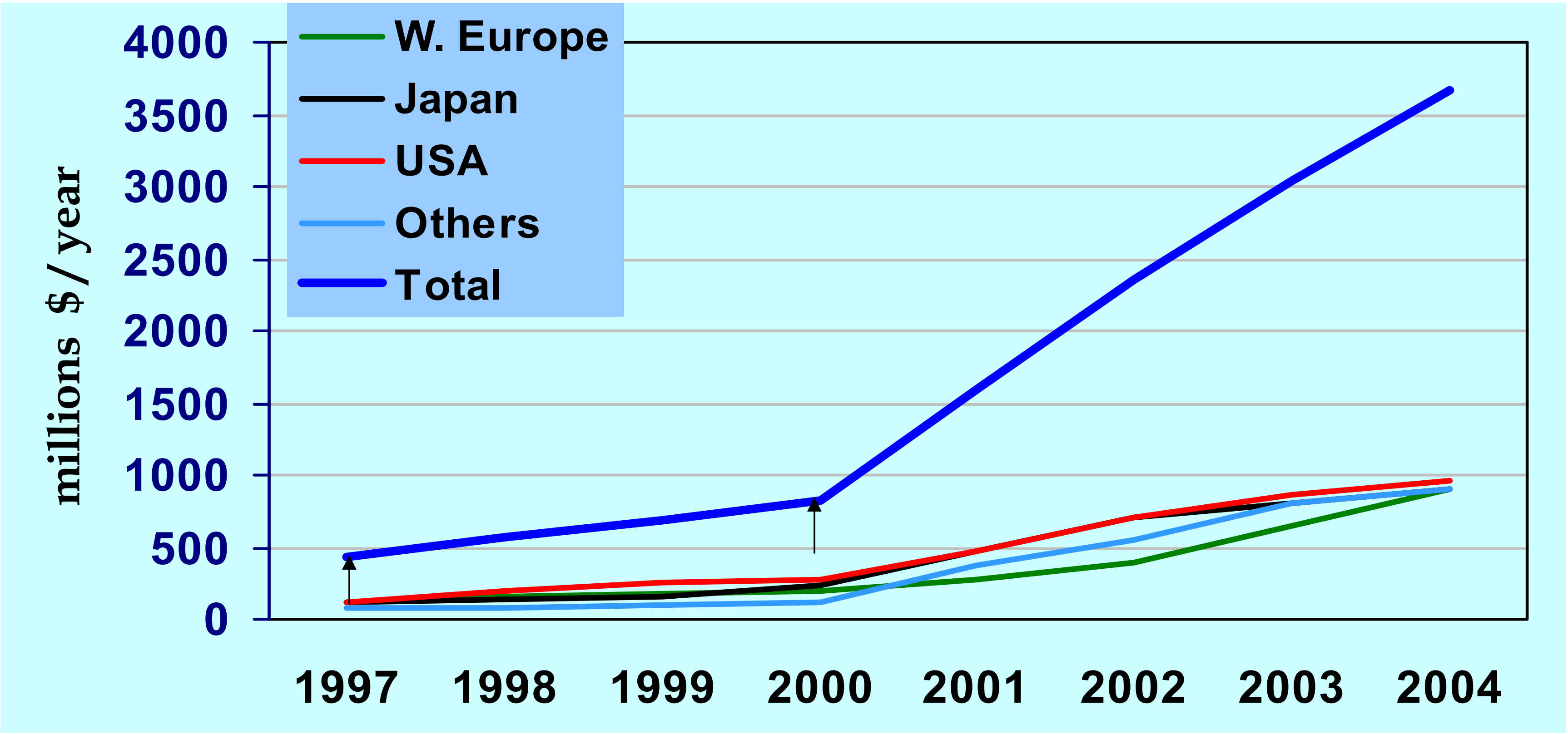
- Industry, state and local organizations: about 1.5 times NNI budget in 2003
- Other NNI (NSET) participants are: OSTP, NSTC, OMB, DOC, DOS, DOT, DOTreas, FDA, NRC, DHS, IC, NIOSH; partnerships with others.

Nanoscale Science and Engineering support at NSF in FY 2005

The FY05 NSE Budget: $305M

- **Program solicitations (about $90M, about 1/3)**
  - Nanoscale Science and Engineering - $81M, NSF 04-043
    - NIRT, NER, NSEC (nanomanufacturing; societal implications)
  - Nanoscale Science and Engineering Education - $8M, NSF 05-543
    - Center for Nanoscale Informal Education, NUE
- **Support in the core program (about 2/3) with focus on single investigator & other core**
  - Various research and education programs in all directorates
  - Interdisciplinary fellowships; STC, MRSEC and ERC centers
  - Instrumentation (REG, MRI); Collaboration industry (GOALI, PFI)
  - Network for Computational Nanotechnology ($3.8M/yr)
  - National Nanotechnology Infrastructure Network ($14M/yr)
- **SBIR/STTR** (about $12M)

Context – Nanotechnology in the World
Past government investments 1997-2004 (est. NSF)



<u>Note</u>:

- U.S. begins FY in October, six months in advance of EU & Japan (in March/April)

Exponential growth; About Half of the Highly Cited Papers in Key Journals Originate in the U.S.

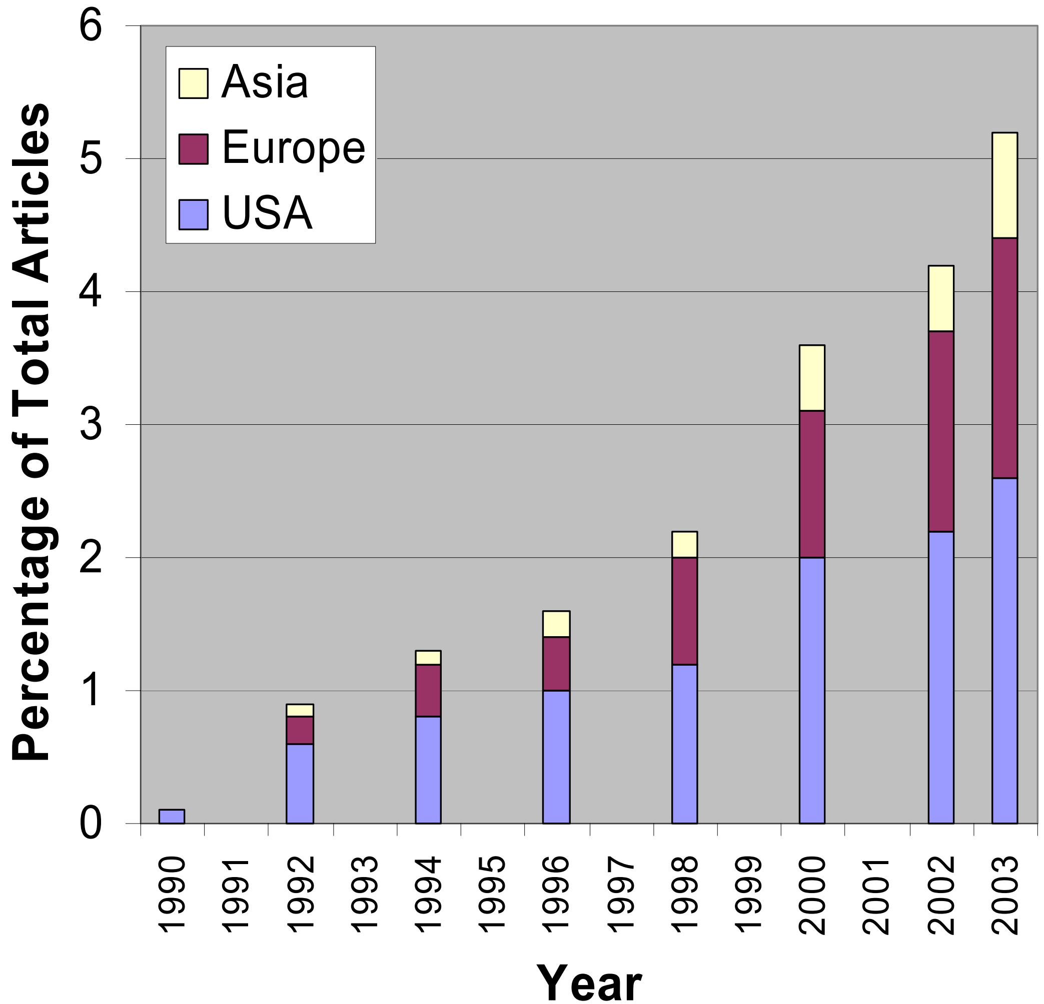
("nano*" keyword search, after NNI Report, 2005)

Journal ISI with high Impact Factors (2001):

Nature	27.9
Science	23.3
Physics Review Letters	6.6

All others journals have impact factors under 4

Correlates well with the overall papers with ISI high impact



Nanoscale Science and Engineering at NSF Principal Areas of Investigation (Fiscal year 2002)

- **Biosystems at the Nanoscale** 14%
  biostructures, mimicry, bio-chips
- **Nanostructure 'by Design', Novel Phenomena** **45%**
  physical, biological, electronic, optical, magnetic
- **Device and System Architecture** 20%
  interconnect, system integration, pathways
- **Environmental Processes** 6 %
  filtering, absorption, low energy, low waste
- **Multiscale and Multiphenomena Modeling** 9 %
- **Manufacturing at the nanoscale** 6%
- **Education and Social Implications** (distributed)

Nanoscale Science and Engineering (NSE) Modes of Support

Anticipated funding for NSE (04-043) in FY05: $82 million

- **Nanoscale Exploratory Research (NER)**

  One year $160K exploratory work

- **Nanoscale Interdisciplinary Research Teams (NIRT)**

  Teams of three or more, $2 million, four year

- **Nanoscale Science and Engineering Centers (NSEC)**

  Major activities incorporating public and private organizations in research and education, $3 million/year

NSE in the Engineering Directorate

Anticipated funding for all nanoscale research and education activities in Engineering: $135 million

- **For new NER, NIRT, and NSEC awards: $60 million**
- **Core programs: $40 million**
- **NSEE: $5 million**
- **Other activities and commitments from prior years: $30 million**

Nanoscale Science and Engineering Education (NSEE) Modes of Support

Anticipated funding for 05-543 in FY05: $8 million

- **Nanoscale Centers for Learning and Teaching (NCLT)**
  Create doctoral programs, develop and implement grades 7-12 material, $3 million/year (not in 05-543)
- **Nanoscale Informal Science Education (NISE)**
  Foster awareness through development of media projects (film, radio, television), $150K/year
- **Nanoscale Instructional Material Development (NIMD)**
  Major activities incorporating public and private organizations in research and education, $200K/year (not in 05-543)
- **Nanotechnology Undergraduate Education (NUE)**
  Introduce nanoscale science and technology into the undergraduate curriculum, $50K/year

NSE Results from FY04
Solicitation 03-043

Obligations for NSE FY04: $144.2 million

- **Nanoscale Exploratory Research (NER)**

  77 awards, $7.7 million

- **Nanoscale Interdisciplinary Research Teams (NIRT)**

  51 awards, $67 million

- **Nanoscale Science and Engineering Centers (NSEC)**

  6 awards, $69.5 million, ($14million in FY04)

Nanoscale Science and Engineering Centers in FY 2001

Six Centers awarded by NSF in September 2001:

- **Northwestern University**,
  Integrated Nanopatterning and Detection Technologies
- **Cornell University,**
  Nanoscale Systems in Information Technologies
- **Harvard University**,
  Science of Nanoscale Systems and their Device Applications
- **Columbia University**
  Electronic Transport in Molecular Nanostructures
- **William Marsh Rice University**
  Nanoscience in Biological and Environmental
- **Rensselaer Polytechnic Institute**
  Directed Assembly of Nanostructures

Note:

20 new centers and networks supported by NNI since 2001 including 8 NSF, 5 DOE, 4 NASA and 3 DOD

NNIN Award

Cornell University – as Lead Institution

for an Integrated National Network of 13 University User Facilities

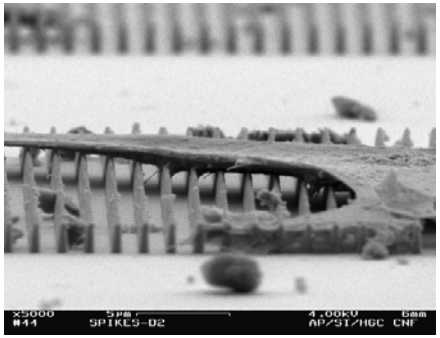
March 1, 2004
$70 Million over 5 years
Renewable to 10 years total

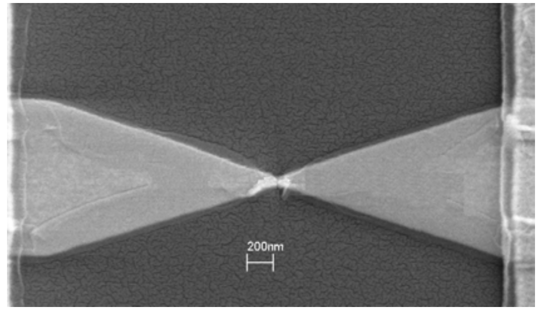
http://www.NNIN.org

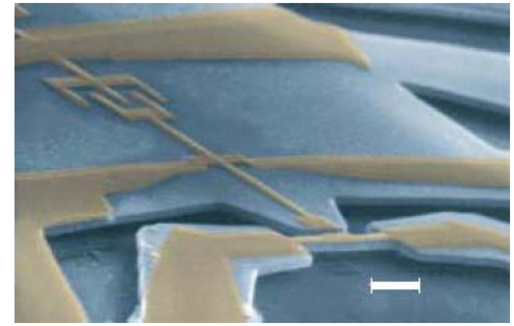
NNIN Attributes

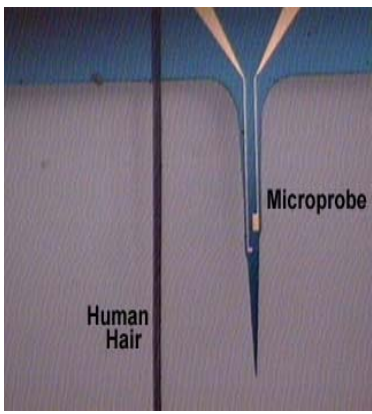
- Serves user communities across the broad science/engineering/technology domains
- Builds on successful model of the NNUN
- Technically specialized facilities, and integrated general facilities
- Open access to all qualified users
- Supports remote users and complex projects across facilities
- Education/outreach – attention to underrepresented youth
- Builds capacity in societal/ethical implications of nanotechnology
- Assessment/metrics guide network evolution and allocation of resource

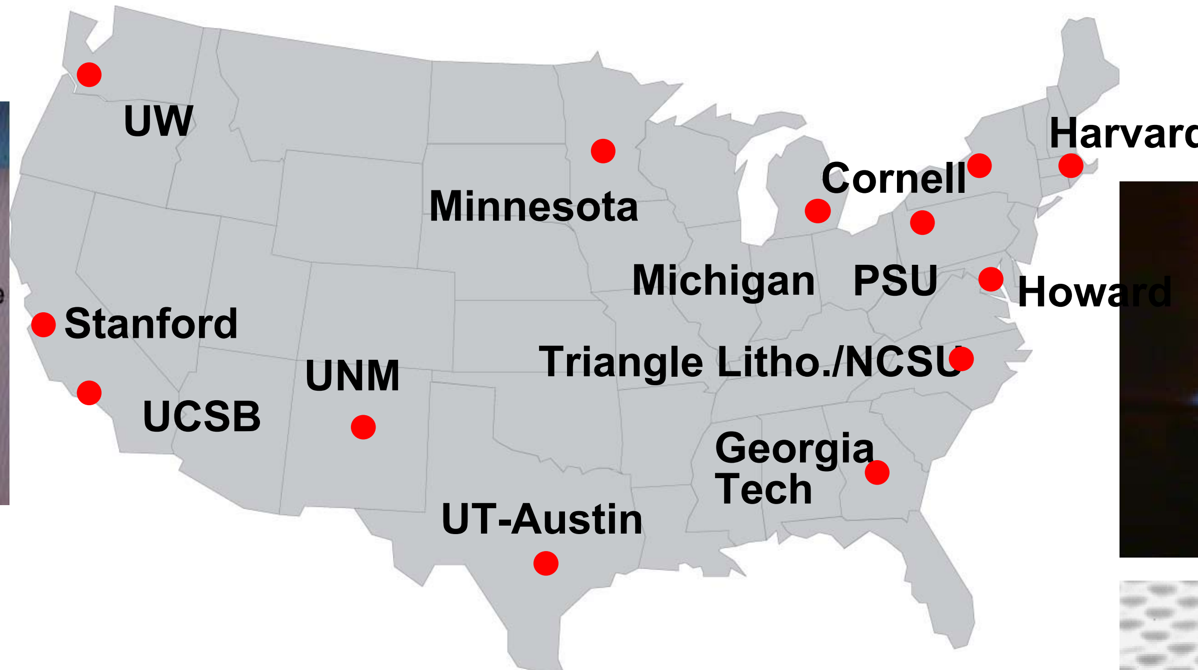
NNIN Sites

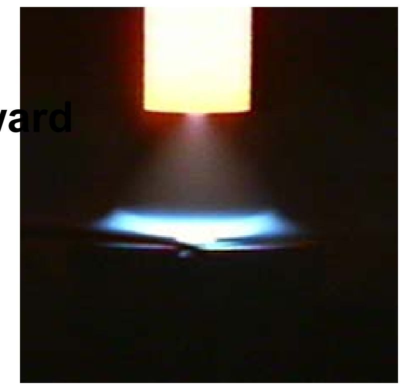


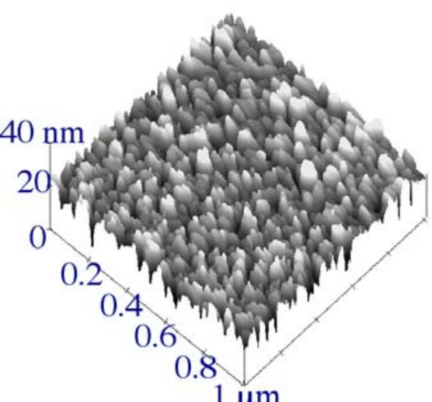

200nm

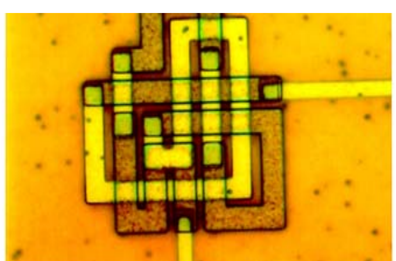


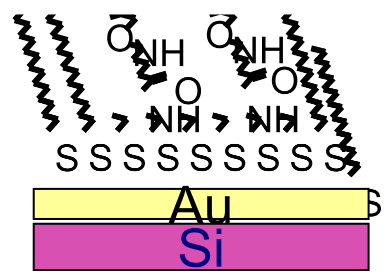

Microprobe
Human Hair

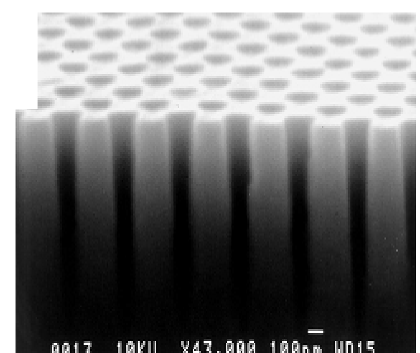

UW
Minnesota
Harvard
Cornell
Michigan
PSU
Howard
Stanford
UNM
UCSB
Triangle Litho./NCSU
Georgia Tech
UT-Austin




40 nm
20
0
0.2
0.4
0.6
0.8
1 µm




NH
O
NH
S S S S S S S S S
Au
Si


0013 10KV X43,000 100nm WD15

NNI Issues in the Future

Need for coherent 5-10 year programs:

The 12/3/03 authorization (PL 108-153) provides a plan for long term NNI funding for NSF (continuing to $476 million in FY08).

Increasing focus on:

- Manufacturing and Infrastructure
- Silicon Nanoelectronics and Beyond (SNB)
- Human performance and societal issues
- International collaboration and competition
- Education: Grades 7-16, NSEE ($8 million)

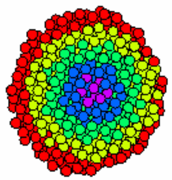
10-20 years vision

Timeline for beginning of industrial prototyping and commercialization

Increased integration, system approach

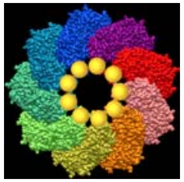
Converging science and engineering

- **1st Generation: Passive nanostructures ~ 2000**



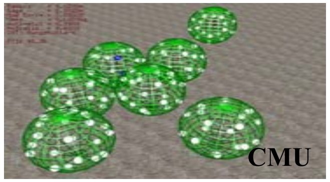
Ex: coatings, nanoparticles, nanostructured metals, polymers, ceramics

- **2nd Generation: Active nanostructures ~ 2005**



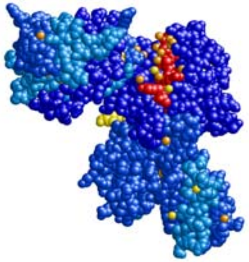
Ex: transistors, amplifiers, targeted drugs, actuators, adaptive structures

- **3rd Generation: Systems of nanosystems ~ 2010**



Ex: guided molecular assembling; 3D networking and new system architectures, robotics, supramolecular

- **4th Generation: Molecular nanosystems ~ 2020**



Ex: molecules as devices/components 'by design', based on atomic design, hierarchical emerging functions, evolutionary systems

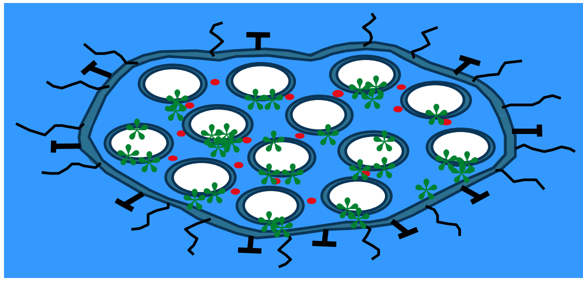
AIChE Journal, 2004, Vol. 50 (5), MC Roco

Sample Projects

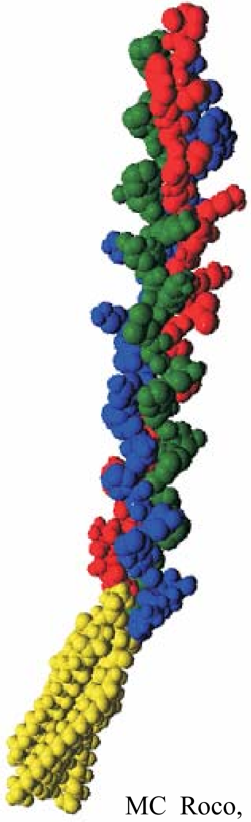
Example:

Synthesis and control of nanomachines

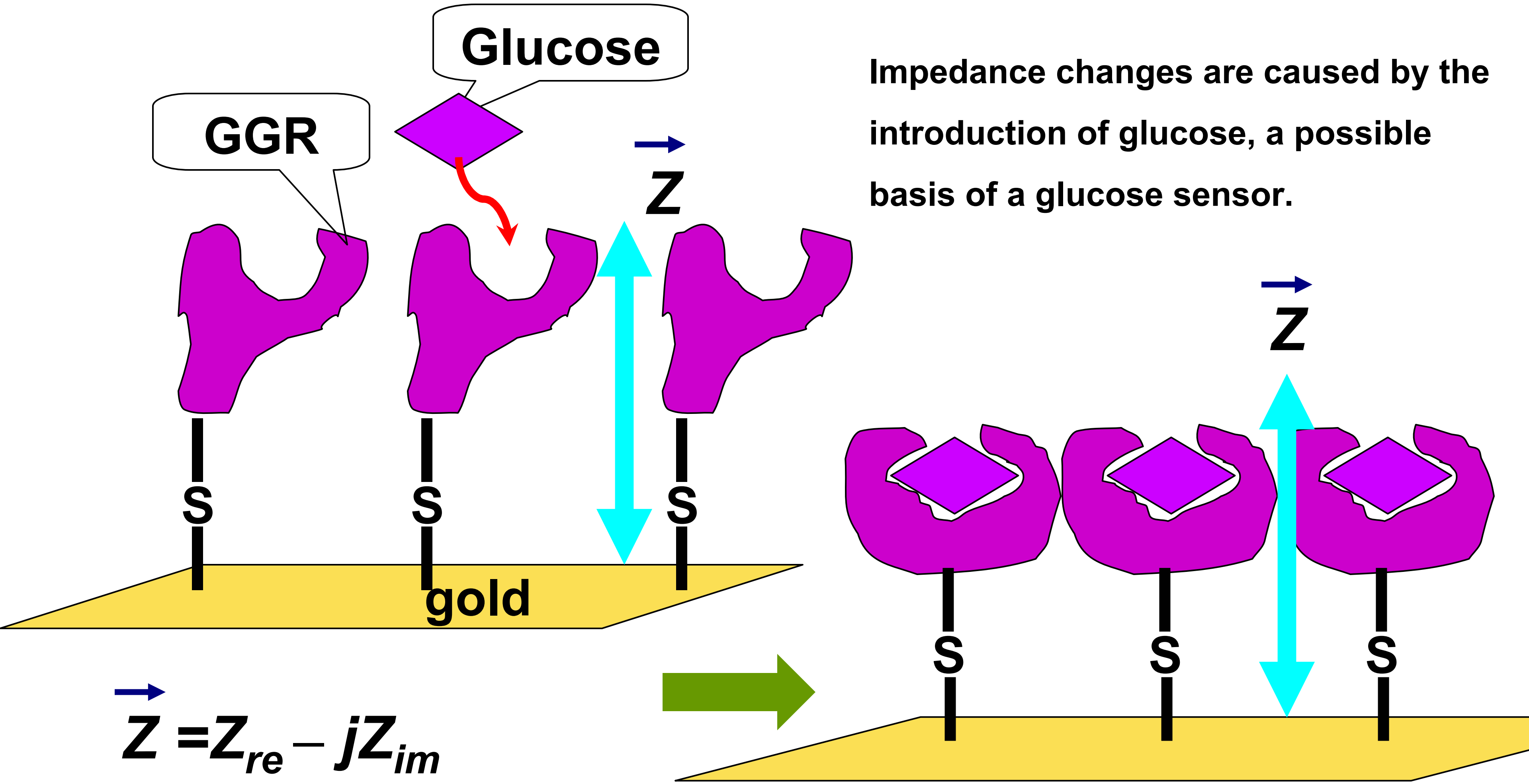
(examples NSE in 2004, www.nseresearch.org - 250 projects)



- **Self-assembly processing** of nanoscale bio-materials and devices for micromachines components (UCSB)
- Chemistry to synthesize components of **nano machines to work on surfaces** and be activated by external electromagnetic fields (UCB)
- **Light driven molecular motors** (U. Nevada)
- **Combinatorial engineering of nanomachines**, with application to membranes and filters (U. Penn.)
- **Nanoengineering surfaces** for probing viral adhesion (UC Davis)



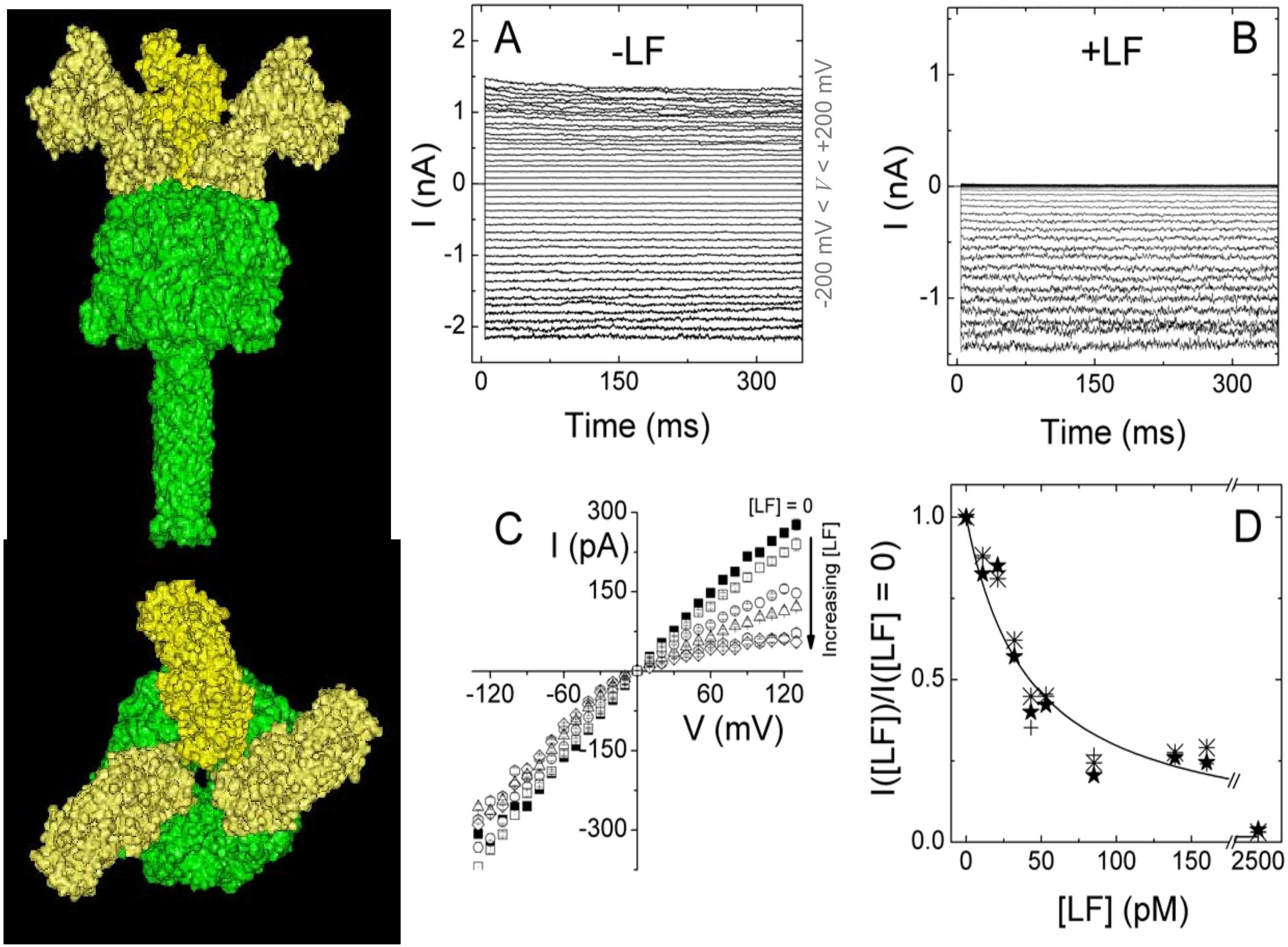
New Glucose Biosensor



Impedance changes are caused by the introduction of glucose, a possible basis of a glucose sensor.

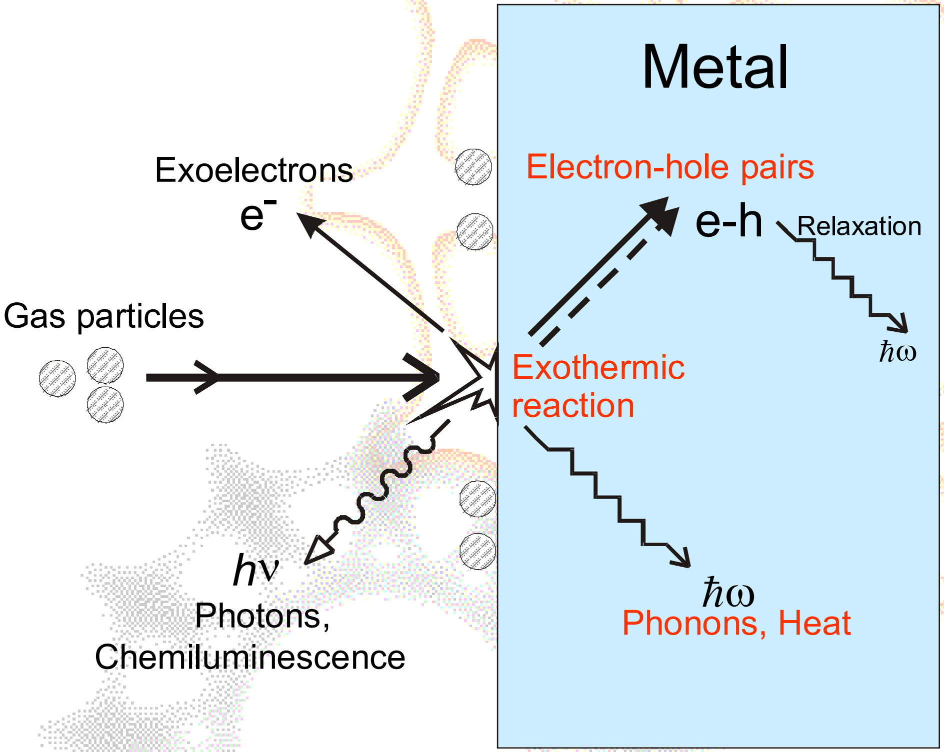
$$\vec{Z} = Z_{re} - jZ_{im}$$

NIRT: Nanoscale Engineering of Bilaterally Accessible Biomembranes



The binding of Lethal Factor (yellow) to the antigen ion channel (green). The graph (A) shows that a current can be detected through the ion channel with no Lethal Factor present, but with the Lethal Factor present (B), the current is blocked. Loesche 0304062

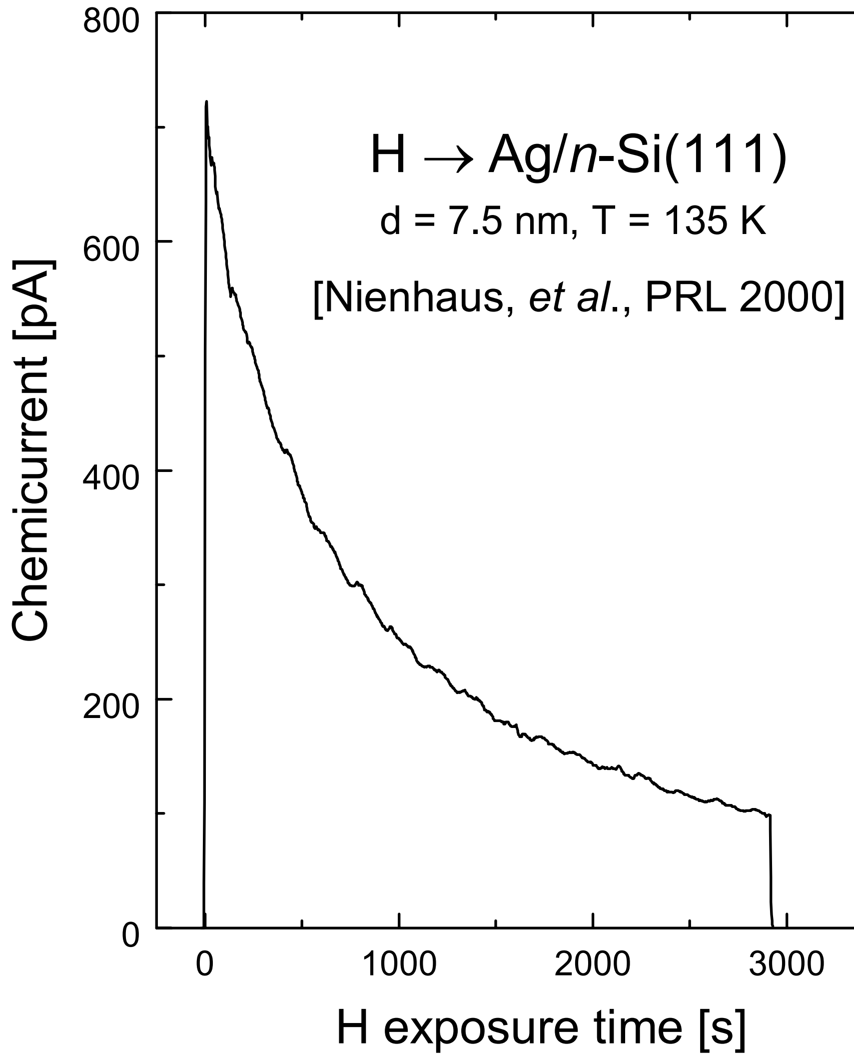
Chemicurrent from Adsorbed Gas Molecules



- **Electron-hole pairs are produced when gas particles strike the thin metal film**
- **Resulting "chemicurrent" can be detected**
- **May form the basis for a sensor**

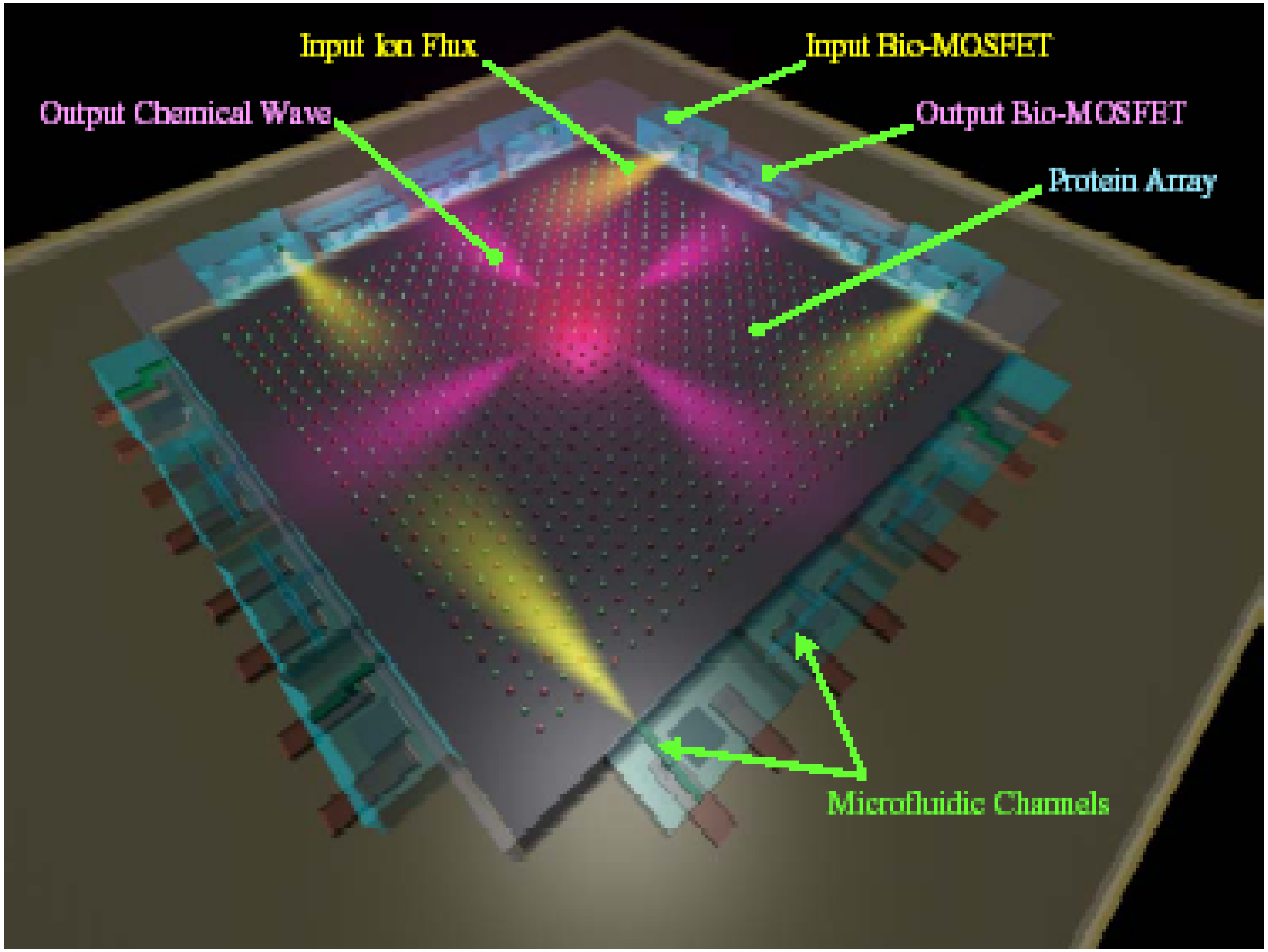
Eric McFarland (CTS-9820134)

Ag/n-Si Sensor: Atomic H Adsorption



Eric McFarland (CTS-9820134)

Biologically-inspired Computational Chip



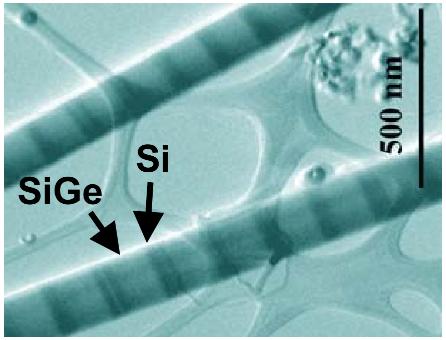
Lyding, 0103447.

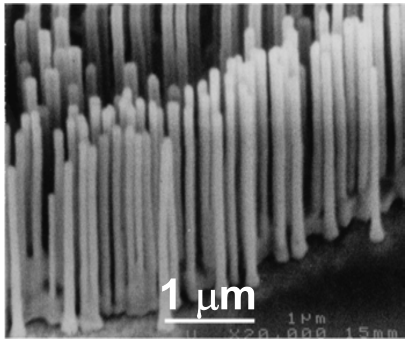
Central protein array interfaces with a surrounding Bio-MOSFET.

Chemical wave generated in the protein array drives the output Bio-MOSFETs, which electronically gate an ion flux passing through microfluidic channels.

Novel Energy Conversion Devices Based on Nanowire Heterostructures

Nanoscale Interdisciplinary Research Team (NIRT) 0103609



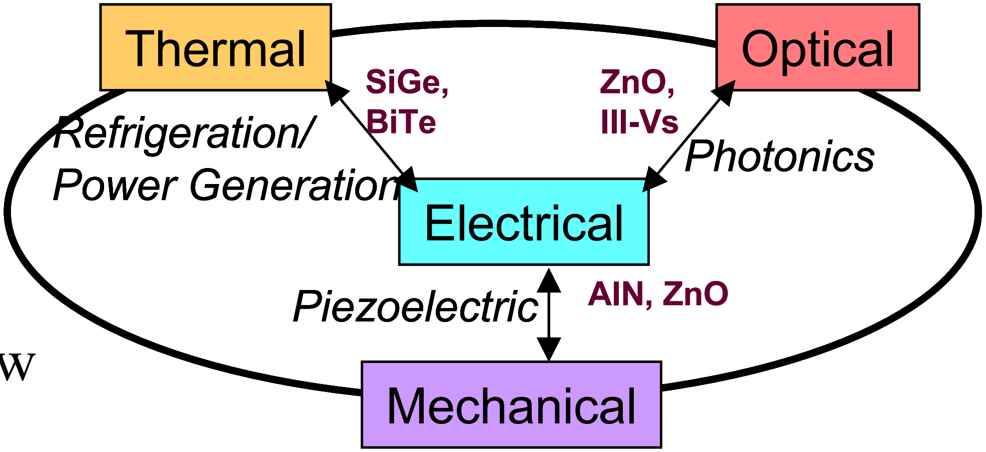


A. Majumdar
P. Yang
T. Sands
University of California, Berkeley

A. Shakouri
University of California, Santa Cruz

V. Narayanamurti
Harvard University

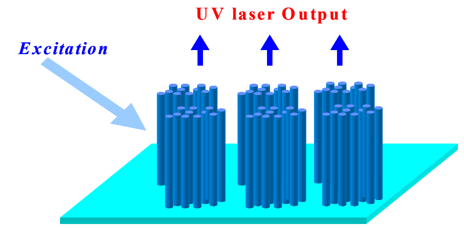
- Nanowire heterostructures contain two or more semiconducting materials under 1-D confinement in such a way that their electronic, thermal, optical, and piezoelectric properties can be manipulated in new and unique ways.



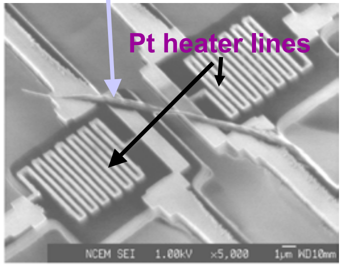
- This group studies the synthesis and physics of single nanowire heterostructures, while utilizing nanowire arrays for various energy conversion devices.

Novel Energy Conversion Devices Based on Nanowire Heterostructures *(continued)*

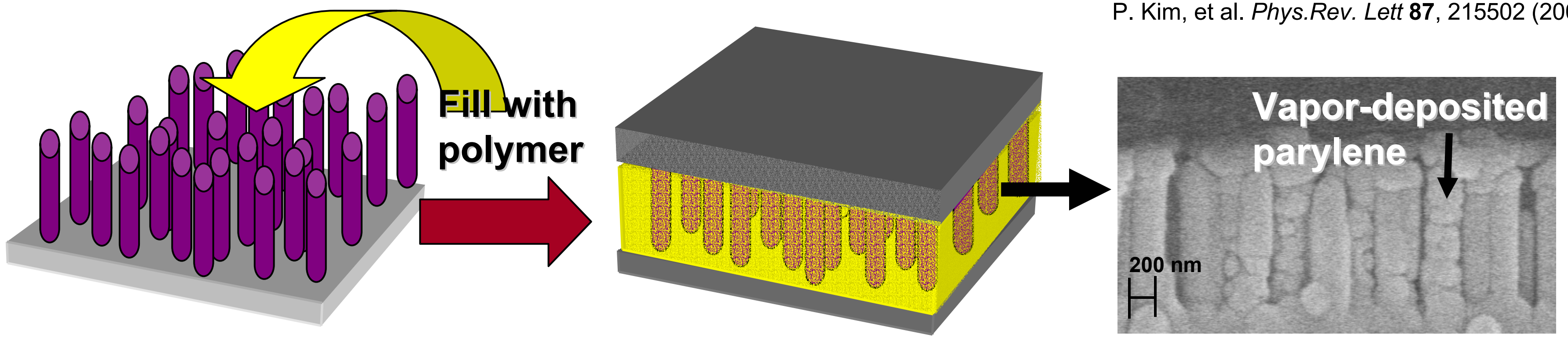
- Ultraviolet Nanolasers have been demonstrated using ZnO nanowires under optical pumping.
- Single nanowire thermal, thermoelectric, and electrical properties have been measured with a new micro-instrument.
- Nanowire array is filled with polymer to make nanocomposites with desirable electrical, optical, thermal, and mechanical properties for various energy conversion devices.



M. Huang *et al.*, *Science* **292**, 1897 (2001)



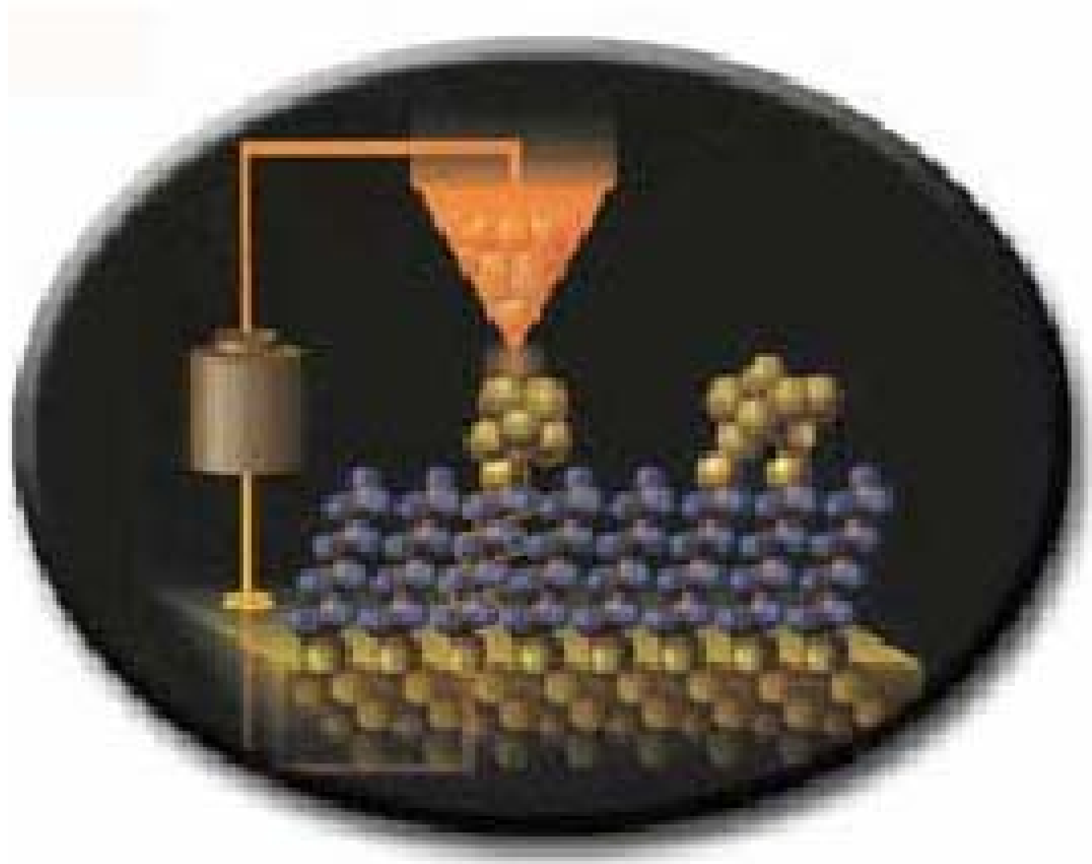
P. Kim, et al. *Phys.Rev. Lett* **87**, 215502 (2001)



Nanoscale Molecular Electronics

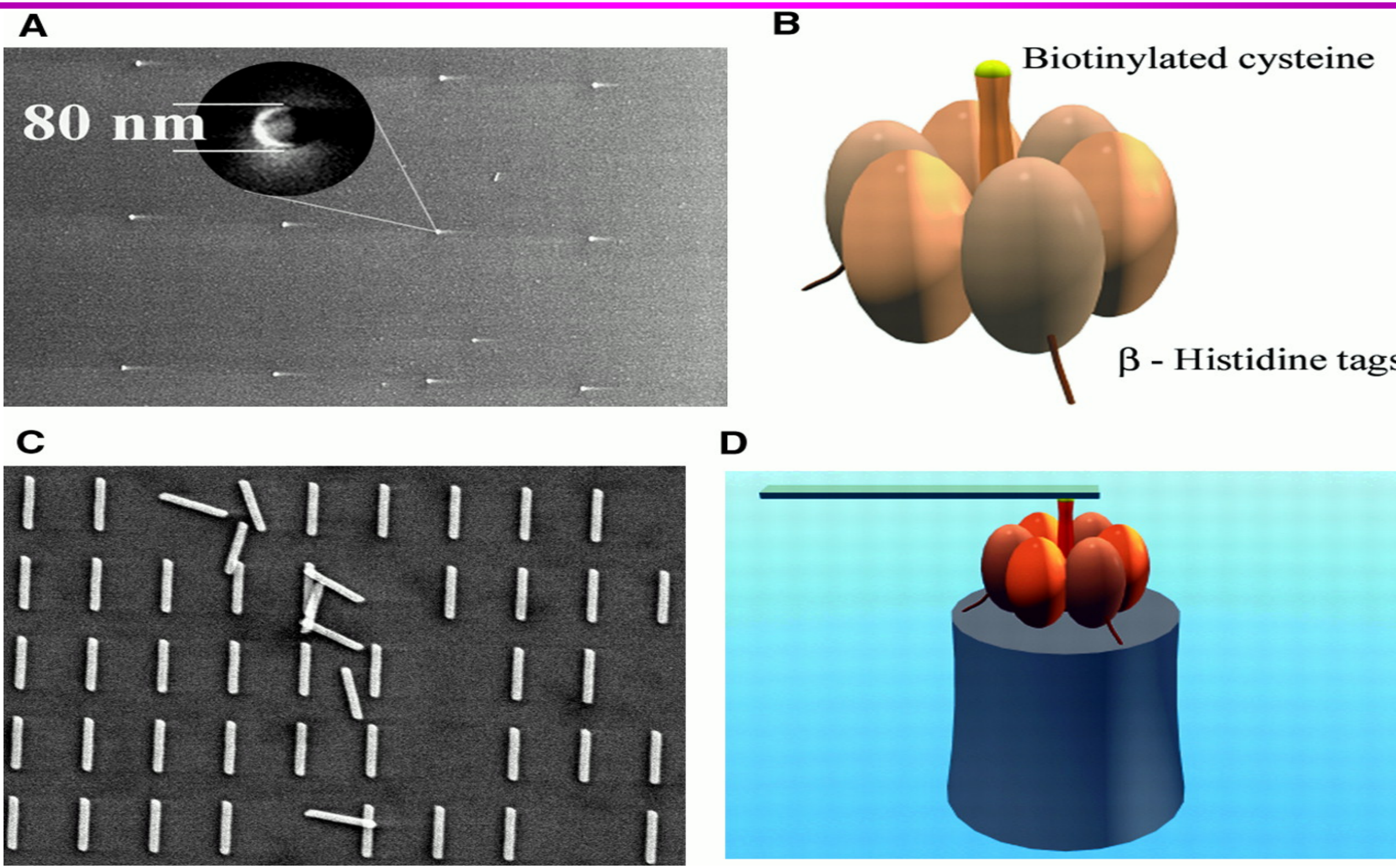
A gold-coated conducting atomic force microscope (CAFM) probe is pushed into a gold nanocrystal covalently attached to one end of a thiol, and the other end is covalently attached to a gold surface.

The objective is to use molecules as electronic components: switches, amplifiers, sensors, etc.



Lindsay, 0103175

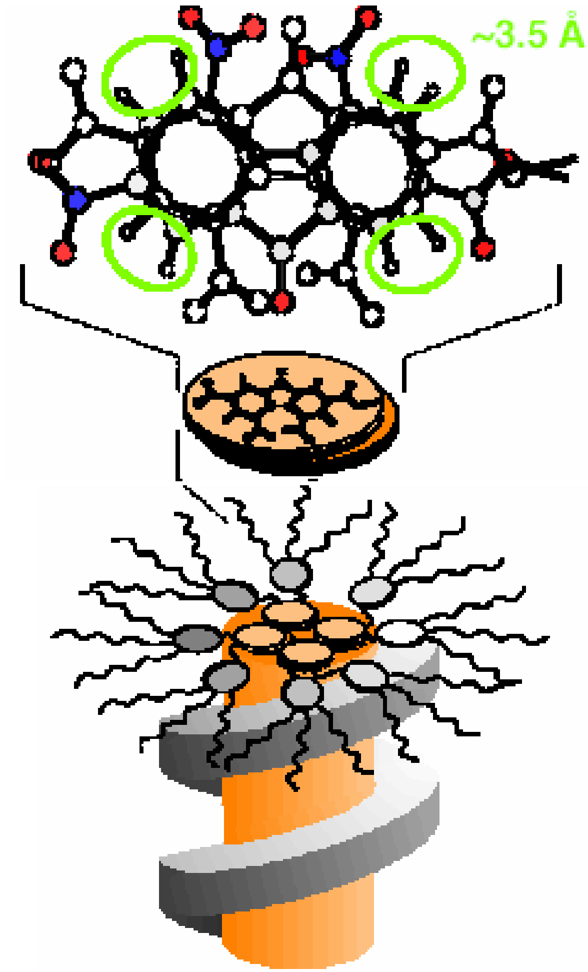
Integration of Nanoscale Technologies into Living Systems: First Bionic Motor the Size of a Molecule (Craighead, 9876771)



Single-molecule Functional Nanostructures

Two stacked nitro-flourenone moieties with proton-proton separation of 3.5Å. These are stacked in the center of a helical dendron coat responsible for the self-assembly of the sandwiches.

The electron and hole mobilities are in a range useful for molecular devices



Percec, 0102459

Websites for Information on NNI, NSE, NSEE

NSE and NSEE News:

http://www.nsf.gov/news/priority_areas/nano/index.jsp

NSE Grantees' Meeting 12/04:

http://www.nseresearch.org/

NNI Information:

www.nano.gov