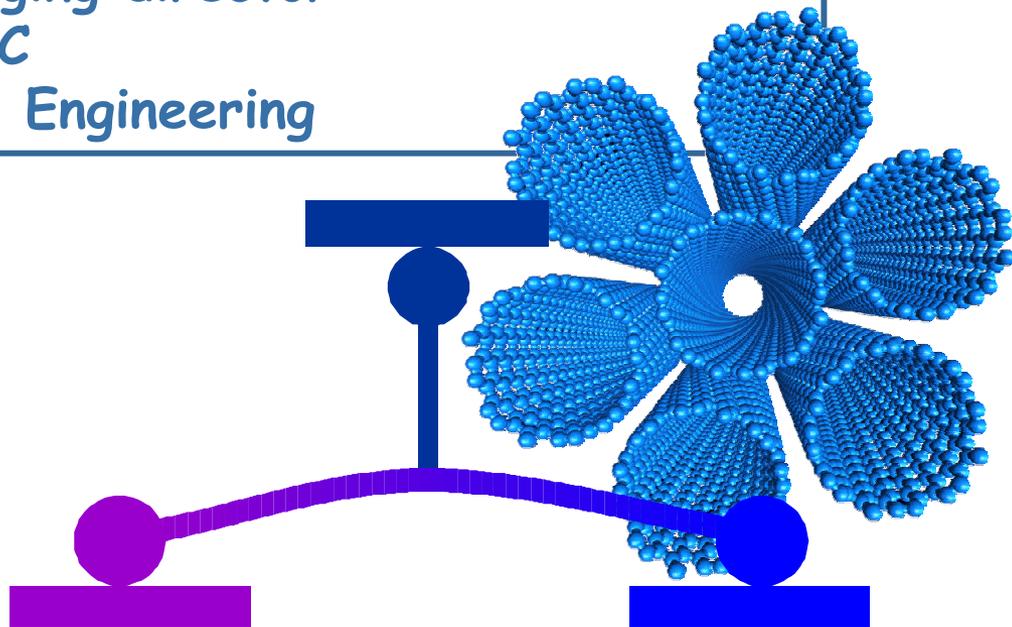




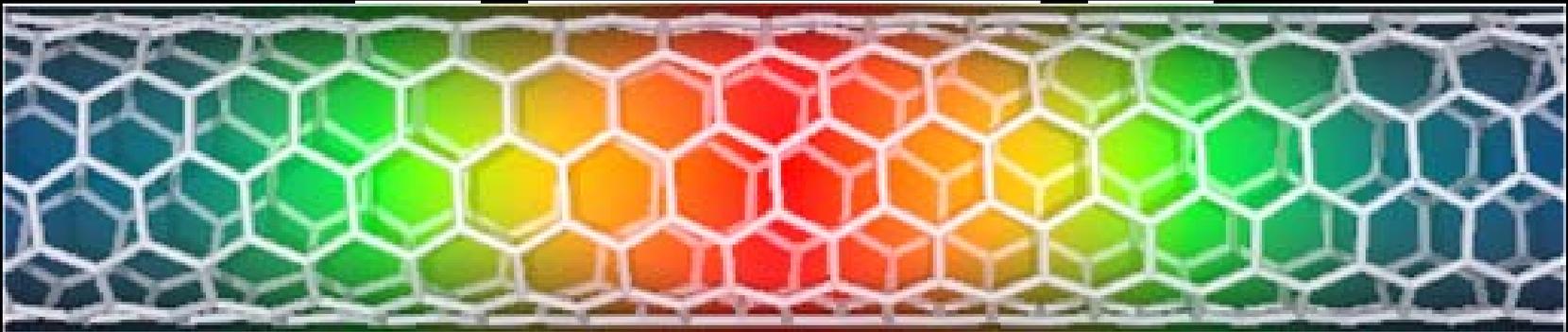
# Nanoscale Science and Engineering Centers (NSEC): Research and Education

## US-Korea Forum on Nanomanufacturing Research and Education

James T. Yardley, Managing director  
Columbia University NSEC  
Department of Electrical Engineering



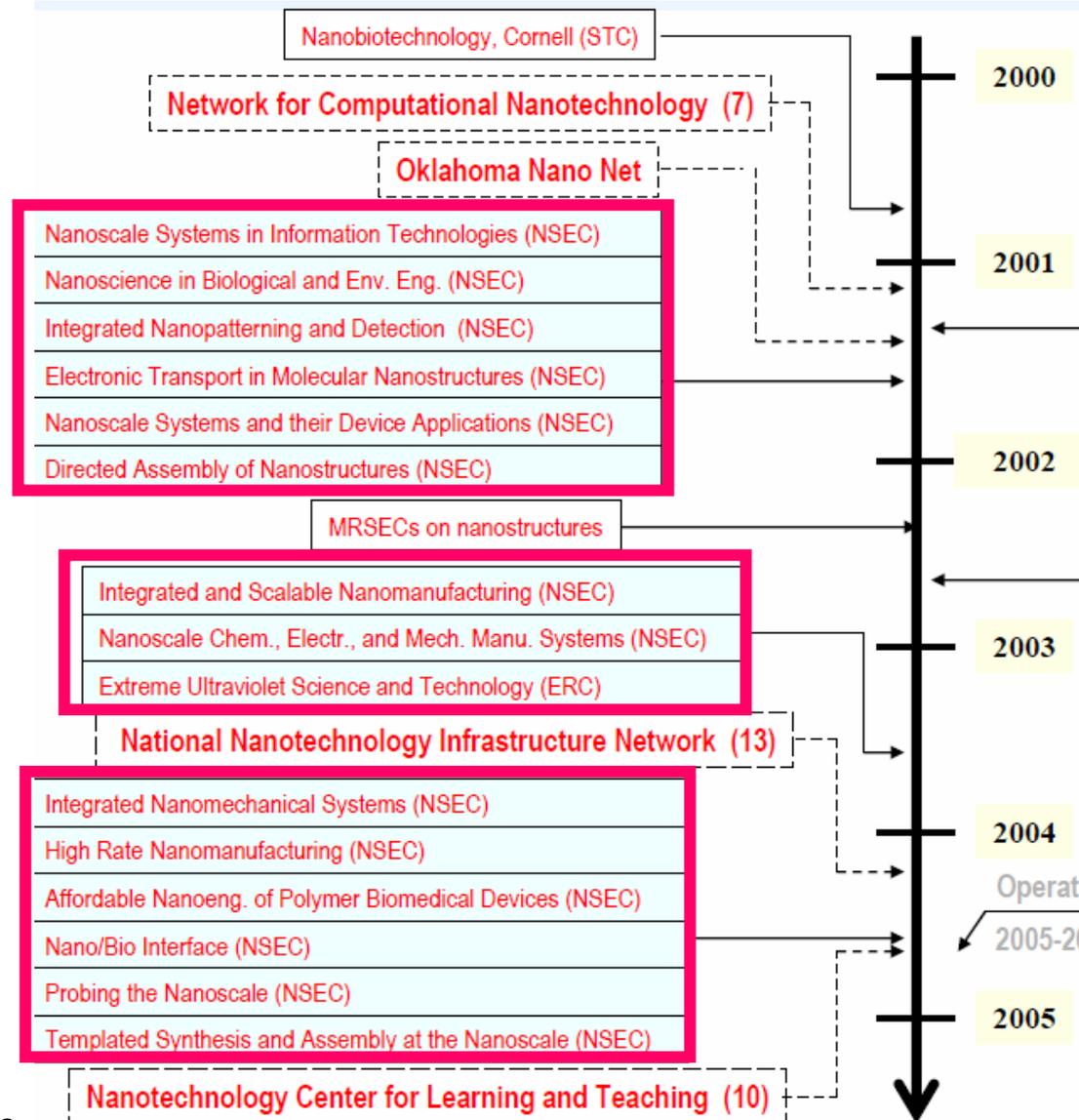
**NSF Nanocenters**  
**(NSEC): what are**  
**they?**



# NNI Infrastructure 2001-4: R&D Centers, Networks, User Facilities.

## Seven NNI themes:

- Biotechnology,
- Nanostructures 'by design' and novel phenomena,
- Device and system architecture,
- Environmental Processes,
- Multiscale modeling,
- Nanoscale manufacturing;
- Societal implications and Improving human performance



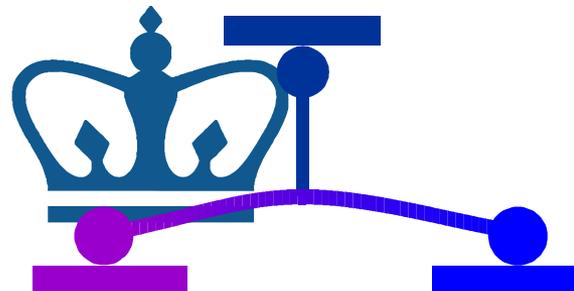
Source: Mike Roco

# What does a Nanocenter actually do anyway ?

- Research concept and theme.
- People: broadly based single university or group of universities.
- Leadership and management structure.
- Identified primary thrusts (evolving).
  - Suborganization varies...
  - Could be project, or collaborations...
- Outreach and education resources and program.
- International (optional)
- Industrial interaction and collaboration.

• A logo

• Other elements...



# Columbia NSEC program team and collaborators.



Phaedon Avouris  
Cherie Kagan  
Norton Lang



Christian Kloc  
Robert Willett  
Dave Lang



Graciela Blanchet

*Bridging postdocs assure close and real collaboration.*

*Center encompasses approximately 70 researchers at a significant level of involvement.*



## Chemistry

Ronald Breslow \*  
Louis Brus  
George Flynn  
Richard Friesner  
Ann McDermott  
Colin Nuckolls

## Electrical Engineering

Tony Heinz

## Applied Physics

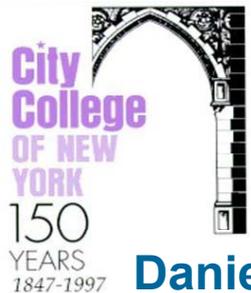
Irving Herman  
Stephen O'Brien  
Aron Pinczuk

## Physics

Philip Kim  
Horst Stormer \*

## Chemical Engineering

James Yardley ‡



Daniel Akins



Robert Krchnavek

**BARNARD**  
Linda Doerrer

*Senior Research Scientists:*  
Shalom Wind  
Mark Hybertsen  
*Research Assoc.*  
Latha Venkataraman



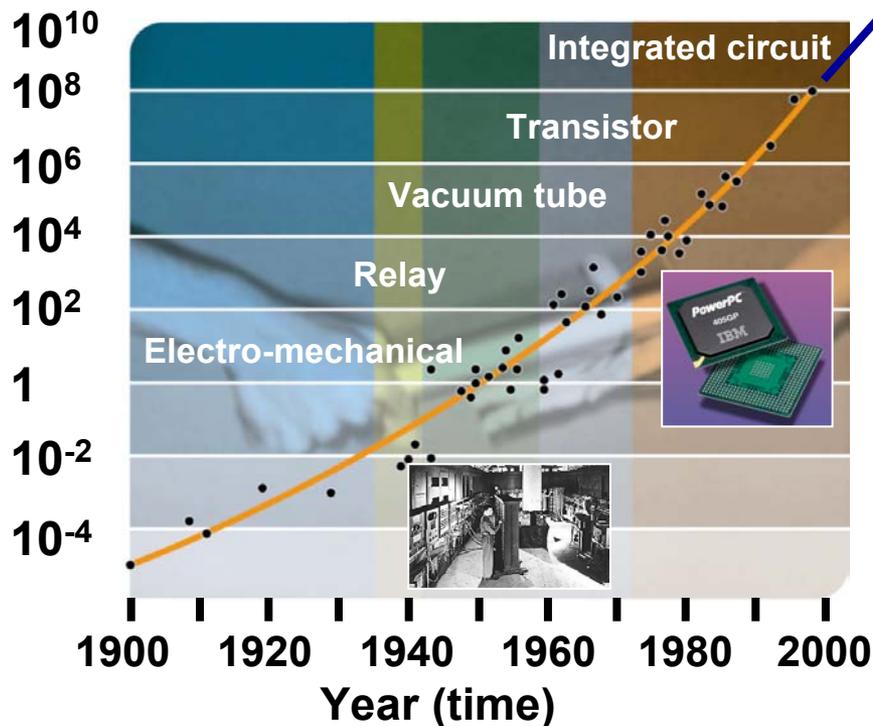
\* Scientific director  
‡ Managing director



# Conceptual basis for Center program.



## Calculations per second per \$1000



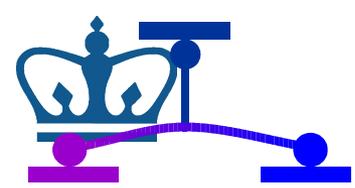
*Fundamental physics:  
projected limit for  
conventional silicon-based  
integrated circuit.*

**What will be the new paradigm?**

**Hypothesis: Molecules provide an attractive alternative to silicon for electronic information processing.**

## Heart of the Columbia University Nanocenter:

- Understanding of charge transport in nano-scale molecular materials.
- Synthesis of new materials and new nano-fabrication schemes.
- Measurement and control of charge transport in individual molecules.
- Collaboration with major industrial capability.

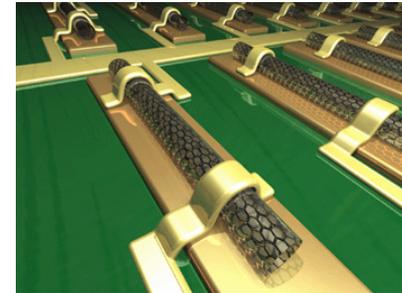


# Research: seeking fundamental understanding.



## Transport in single walled carbon nanotubes.

Vision: practical CNT FET



Bachtold, et al., *Science*, Nov. 2001

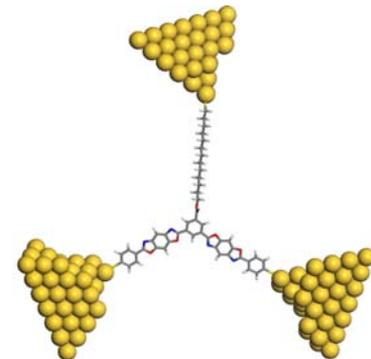
## Transport in ordered molecular arrays.

Vision: the monolayer FET

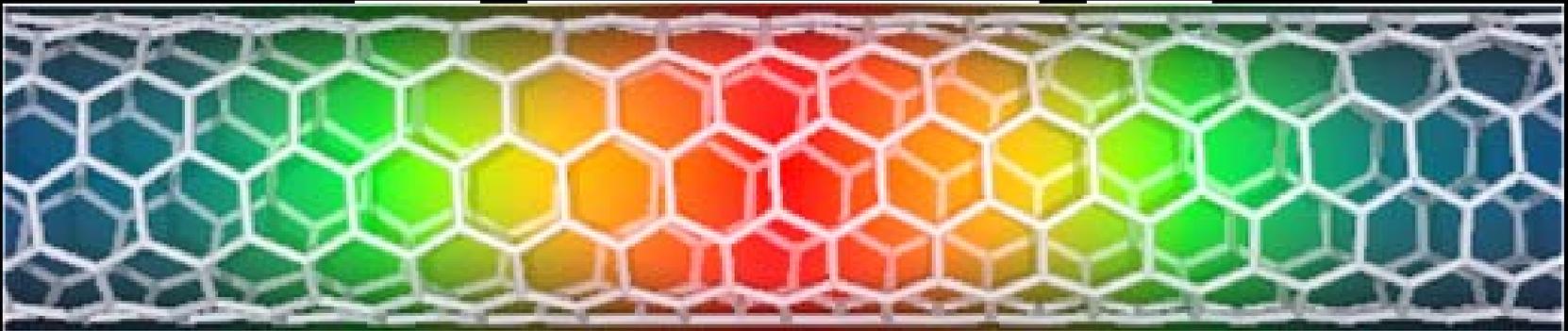


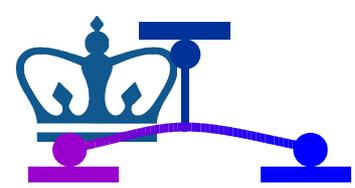
## Transport in single molecules.

Vision: single molecule FET

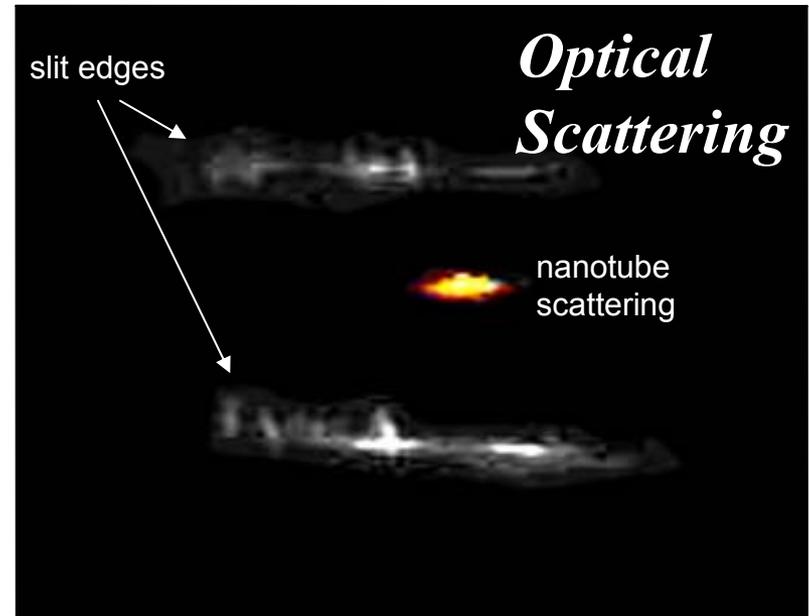
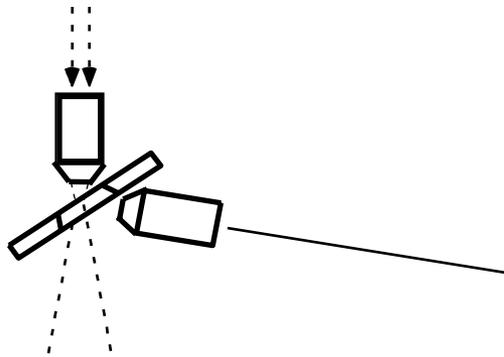
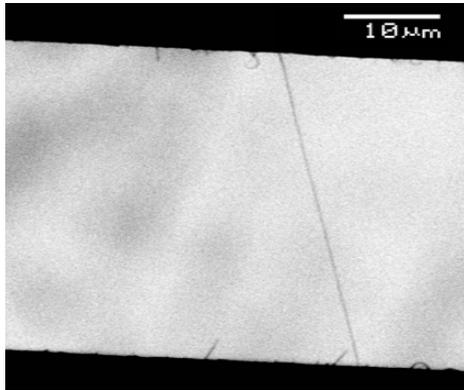


**The Columbia**  
**University**  
**Nanocenter**





# Optical Spectroscopy of Single Nanotubes



Tony  
Heinz



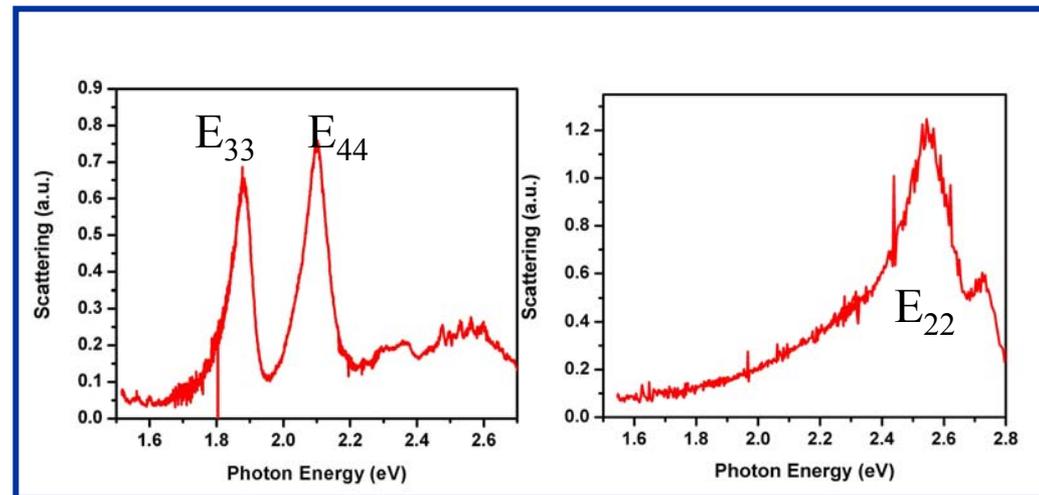
Feng  
Wang



Louis  
Brus



Stephen  
O'Brien

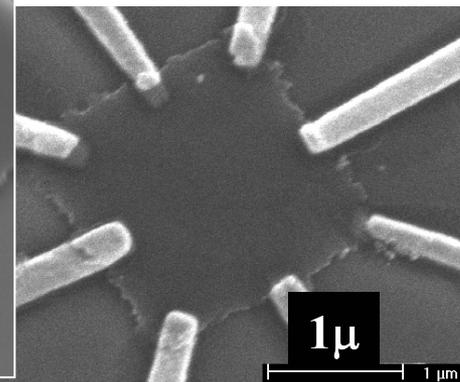
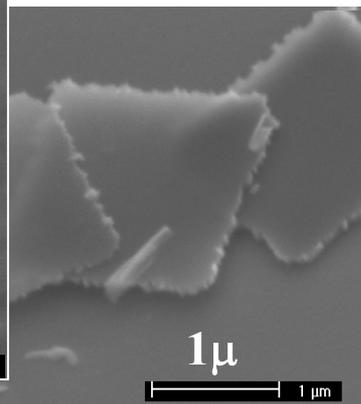
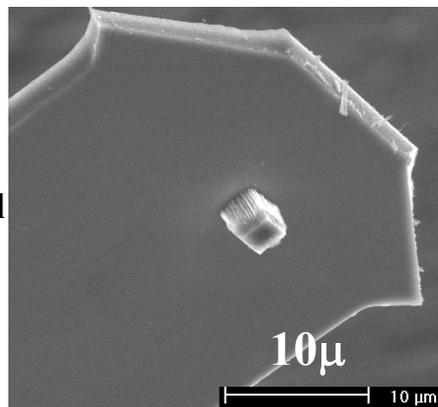
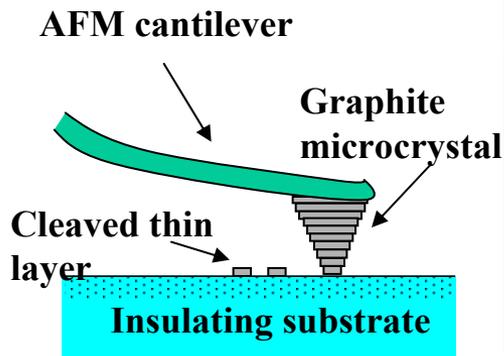




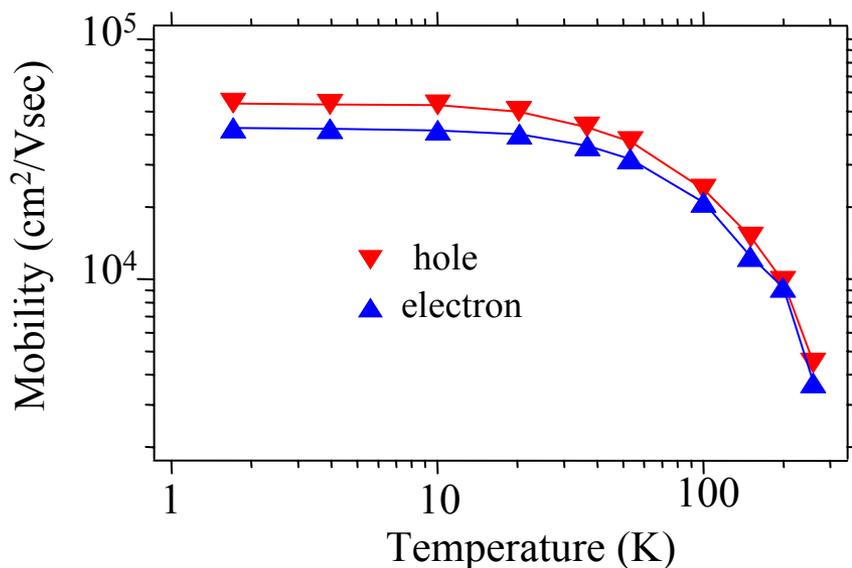
# Seeking a truly two dimensional molecular conductor.



## Nanopencil



Philip Kim  
Josh Small  
Yuanbo Zhang  
Alex Henderson  
Nada Petrovic  
Elizabeth Gabor



12 nm Graphite Crystal:

Mobility at 1.7K  
~ 50,000 cm²/Vs  
at 300K  
~ 3000 cm²/Vs



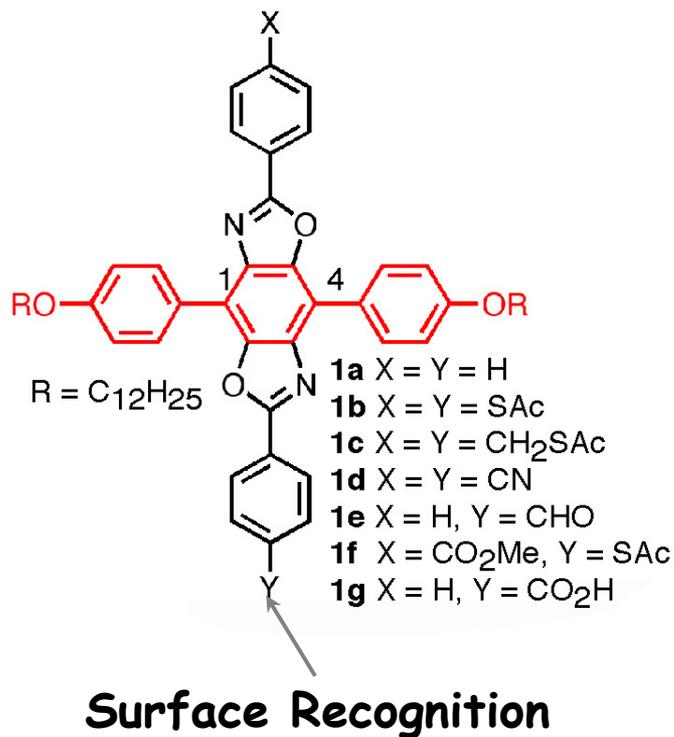
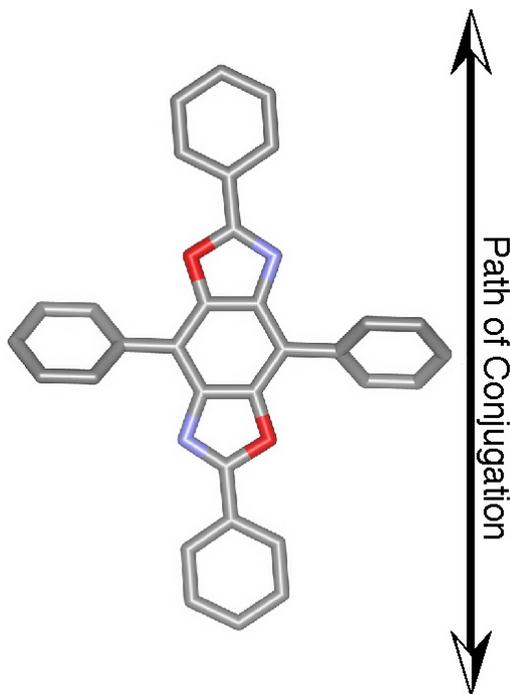
# New chemistry for understanding molecular conductance.



## Cruciform $\pi$ -systems

### Bis-benzoxazoles

- Flat
- Oxidatively stable
- High tensile strength
- Rock stable



Colin Nuckolls



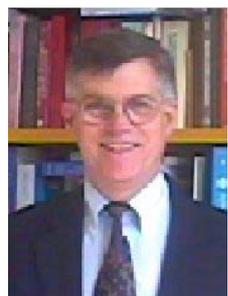
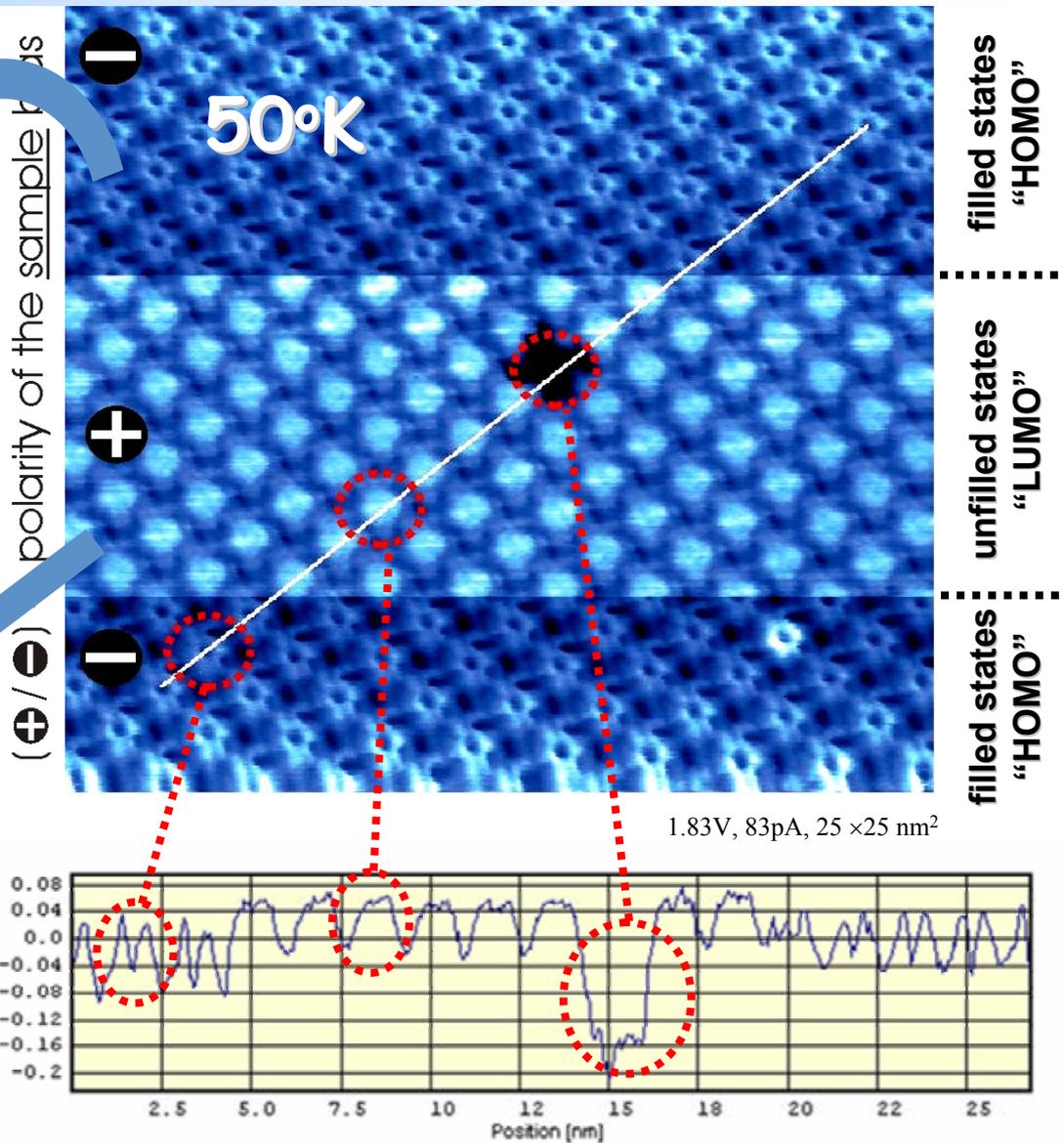
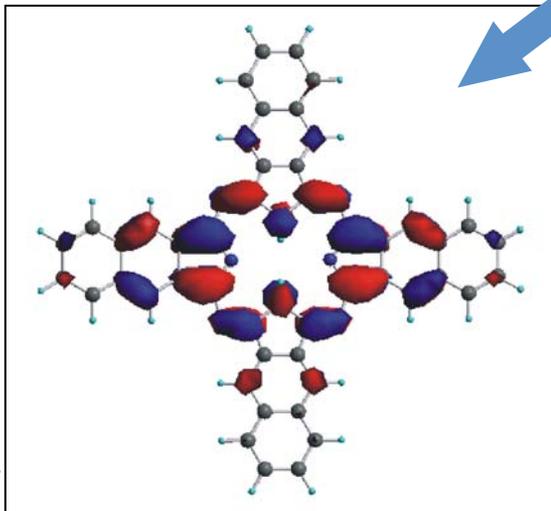
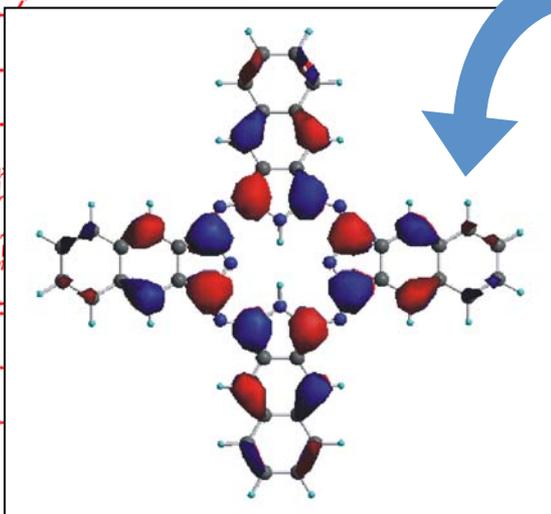
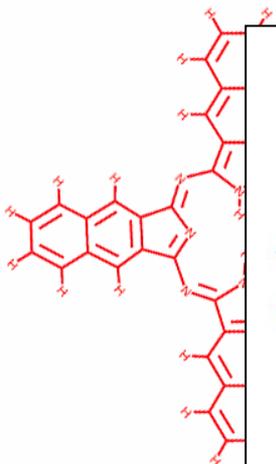
Ken Sugo  
Jen Klare  
George Tulevski



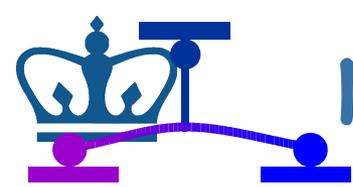
# Structure and conductance in ordered arrays (cont..).



## naphthalocyanine



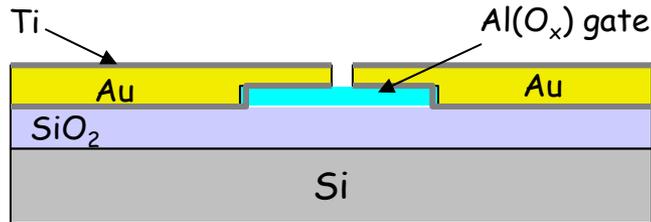
George Flynn,  
Chemistry



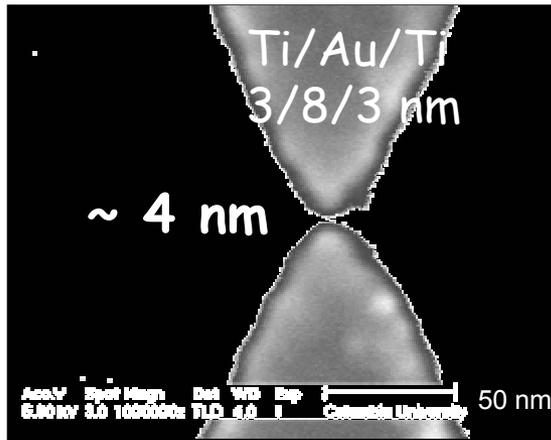
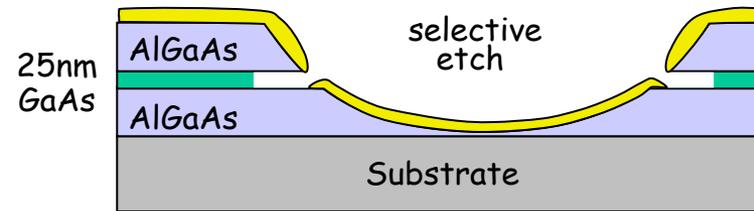
# Nanoscale device fabrication



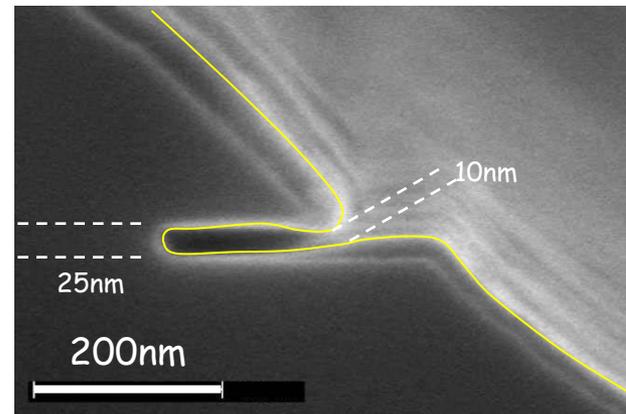
e-beam writing:



MBE



Shalom Wind



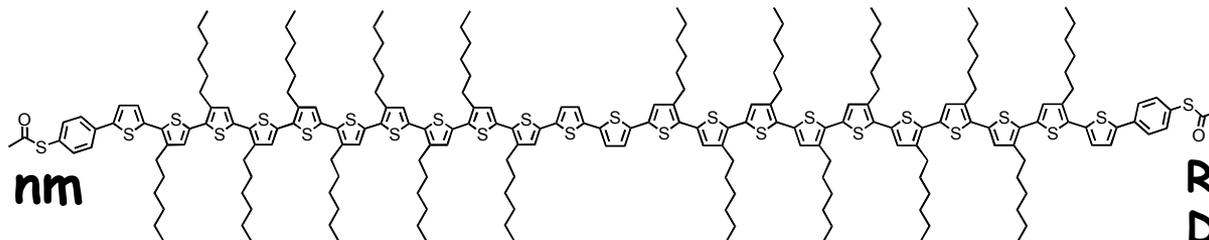
~20nm Si<sub>3</sub>N<sub>4</sub> layer (cvd)



Jochen Ulrich

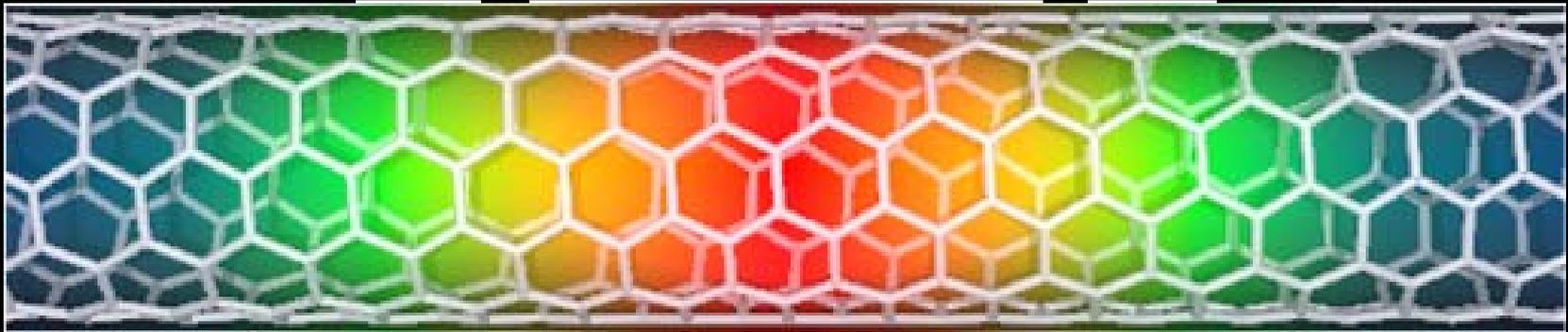
Process:  
100 keV e-beam lithography  
PMMA bilayer resist

length: 9.6 nm



Ronald Breslow  
Dennis Bong

**Education in**  
**nanocenters:**  
**example, Columbia**  
**Nanocenter**



# Educational and Outreach Consortium.

- Metro-NY base
- Diverse student population
- Strong science and engineering



Linda Doerrler,  
Chemistry,  
Barnard College



Daniel Akins,  
Chemistry,  
CUNY

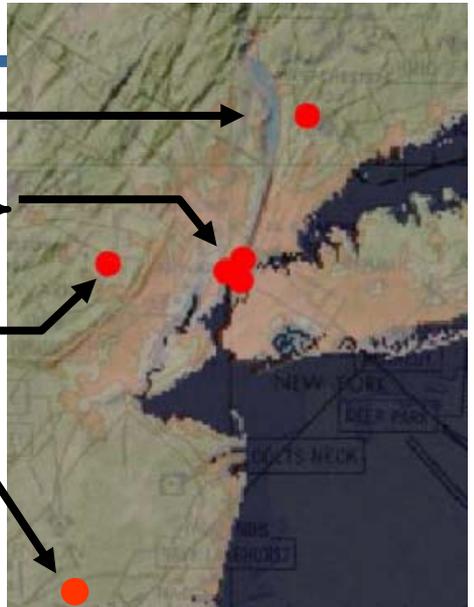
Strategic  
elements of  
program:

- Engagement
- Growth
- Transition



Robert Krchnavek,  
Electrical Eng.,  
Rowan University

- IBM
- Columbia University
- Barnard College
- CUNY
- Lucent
- Rowan University



# Engagement: Drawing from and broadening the pool of talented students.



SHAKE HANDS WITH SCIENCE!

# NANO-DAY in NEW YORK

AN ALL-DAY, CITY-WIDE, SCIENCE AND ENGINEERING EXTRAVAGANZA DESIGNED TO INCREASE HIGH SCHOOL STUDENTS' AWARENESS OF NANOSCIENCE AND NANO-TECHNOLOGY AND THE IMPORTANT ROLE THESE DISCIPLINES WILL PLAY IN THE FUTURE OF OUR GLOBAL SOCIETY.

**A PRESENTATION OF THE COLUMBIA UNIVERSITY NANO-CENTER AND THE CITY COLLEGE OF NEW YORK**

**Saturday, April 17, 2004**  
8:30AM-1:00PM — Aaron Davis Hall  
1:00PM-3:30PM — The Great Hall  
The City College of New York • 135th St. & Convent Ave.  
In collaboration with Columbia University, The City College of New York, Barnard College, and Rowan University.

FOR MORE INFORMATION ABOUT NANO DAY IN NEW YORK, PLEASE CALL (212) 650-8240 AT THE CITY COLLEGE OF NEW YORK.  
COORDINATORS: B. Brown, CCNY and A. Levy, CU

**HIGHLIGHTS INCLUDE**

- Featured Speakers
  - Senator Hillary Clinton (Invited)
  - Bill Nye the Science Guy
  - Professor Daniel L. Akins
  - Professor Wendy Crone
  - Professor Horst Stormer
  - Nobel Laureate, Physics
- Exhibits and demonstrations on cutting-edge research being conducted at CU, CCNY, Barnard College, and Rowan University
- Tours of engineering and science laboratories
- A "Nano Raffle" (Top Prize: Laptop computer)

in association with NYSIPAR

# Engagement: Drawing from and broadening the pool of talented students.



Bill Nye, "The Science Guy" with students and staff.

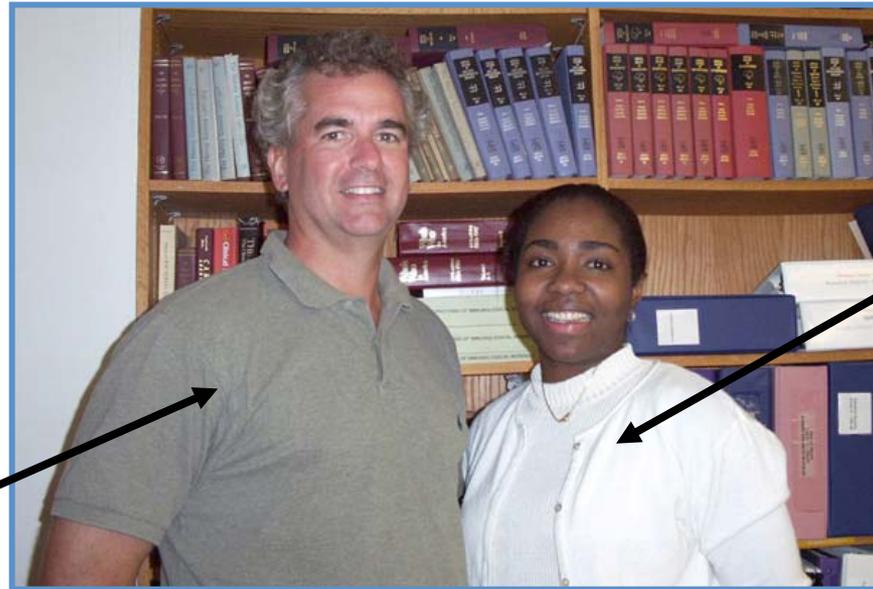
Professor Horst Stormer with Prof. Wendy Crone and students.



# Engagement: Drawing from and broadening the pool of talented students.

Summer programs: Middle School and High School teachers and students.

## RET: Research Experience for Teachers.



DeWitt Clinton  
High School,  
Working with  
Stephen O'Brien

Tom Byrne    Florence Dodier

Benjamin Cardoza  
High School,  
Working with Ron  
Breslow

# Engagement: Drawing from and broadening the pool of talented students.

General public: Video production.

**SMALL WONDERS**  
The Race to the Nanoscale

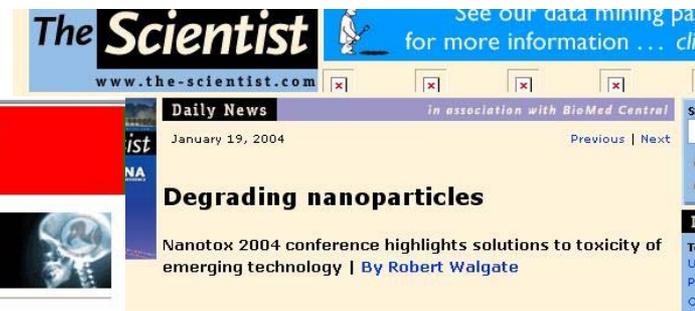
$10^{+6}$  meters       $10^0$  meters       $10^{-5}$  meters

A ONE HOUR DOCUMENTARY  
PROPOSED BY TATGE/LASSEUR PRODUCTIONS  
AND COLUMBIA UNIVERSITY

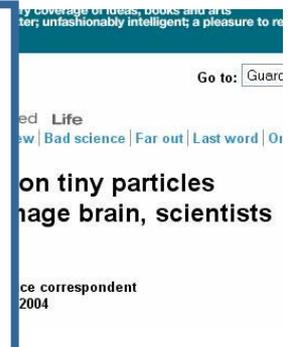
$10^{+5}$  meters       $10^{-2}$  meters       $10^{-6}$  meters

The image is a 3x3 grid of images illustrating the scale of the nanoscale. The top row shows a satellite view of a lake ( $10^{+6}$  meters), a close-up of a leaf ( $10^0$  meters), and a microscopic view of a cell ( $10^{-5}$  meters). The middle row shows a close-up of a leaf ( $10^{+5}$  meters), a close-up of a leaf vein ( $10^{-2}$  meters), and a microscopic view of a cell ( $10^{-6}$  meters). The bottom row shows a satellite view of a lake ( $10^{+5}$  meters), a close-up of a leaf vein ( $10^{-2}$  meters), and a microscopic view of a cell ( $10^{-6}$  meters). A central text box in the middle row reads: "A ONE HOUR DOCUMENTARY PROPOSED BY TATGE/LASSEUR PRODUCTIONS AND COLUMBIA UNIVERSITY". The title "SMALL WONDERS The Race to the Nanoscale" is centered in the top row.

# Growth: Involving students in all aspects of the program: Safety Program.



- Strong chemical and materials hygiene.
- HS&E educational program for all participants.
- Protection against inhalation and dermal exposure.
- Proper procedures for handling of potentially hazardous materials.
- Strict adherence to government and institutional regulations.
- Proper disposal of waste materials.
- Dissemination of information regarding potential hazards.
- Proper reporting of all reportable incidents.



# Education: International cooperation.

**Korea: Center for Superfunctional Materials**  
Prof. Kim S. Kwang, Director  
Department of Chemistry  
Pohang University of Science and Technology  
Pohang, Korea

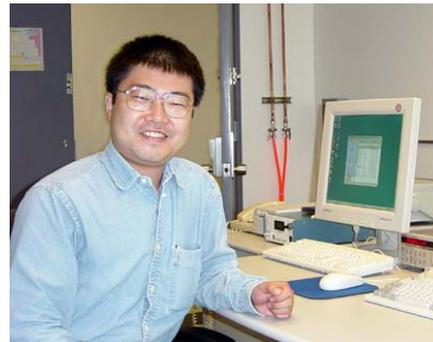
- Collaborative research
- Visiting scientists

**Prof. Kwang S. Kim**



**Dr. Byung Hee Hong**

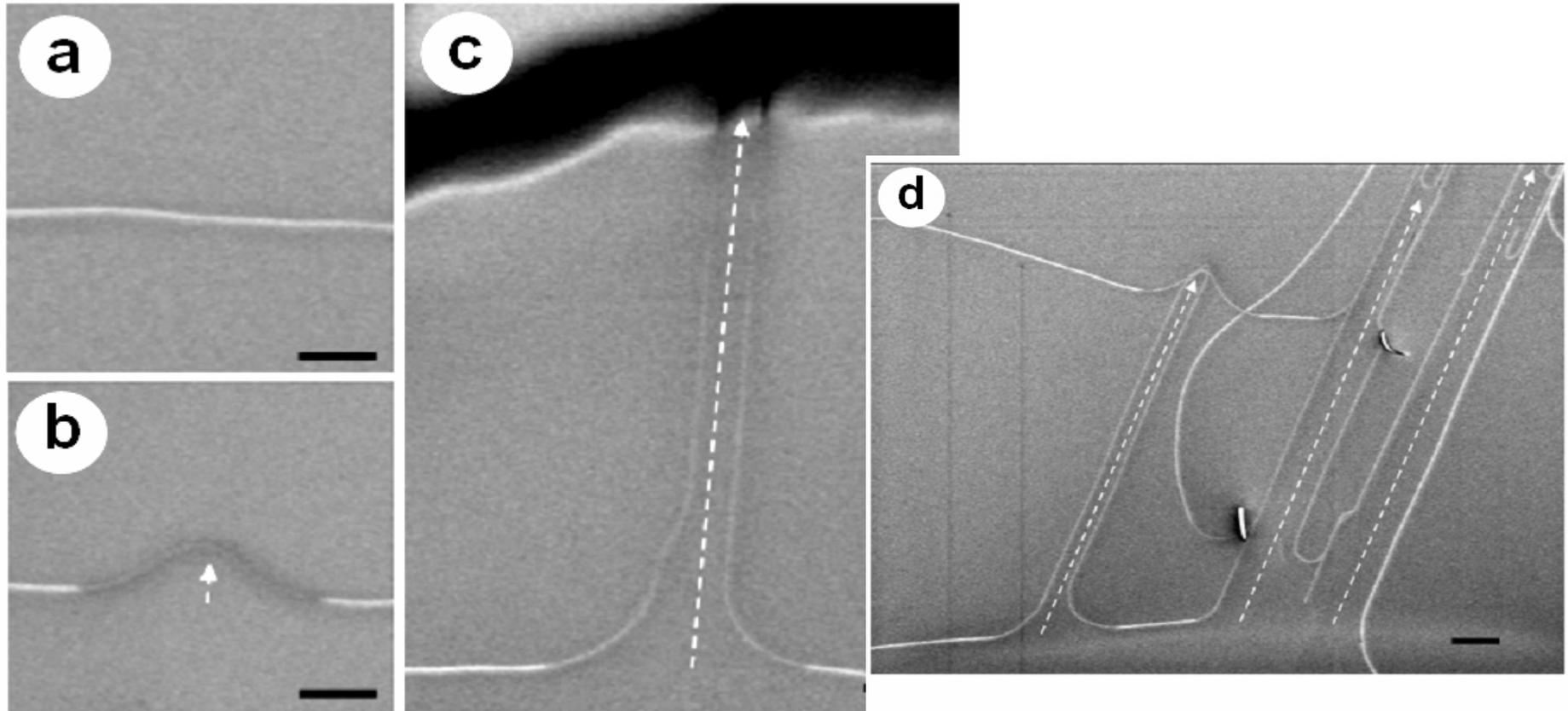
**Japan:**  
Prof. Takao Someya  
University of Tokyo.



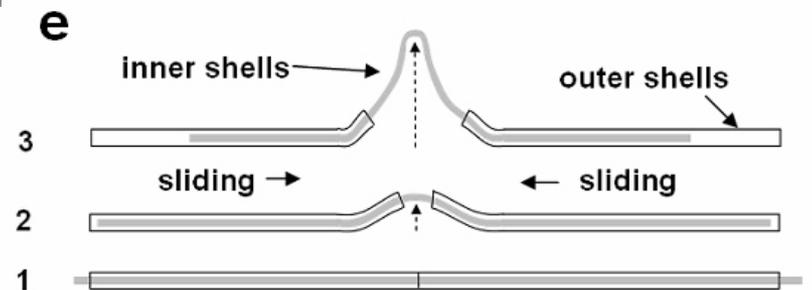
**Hong Kong:**  
Prof. Michael Loy  
Hong Kong University  
of Science and  
Technology.



# Columbia-Korea collaborative research: Extracting inner shells of long multi-wall carbon nanotubes.



Byung Hee Hong  
Philip Kim  
Kwang S. Kim



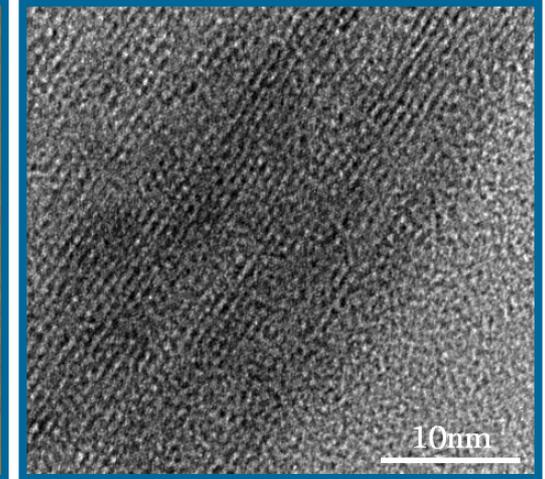
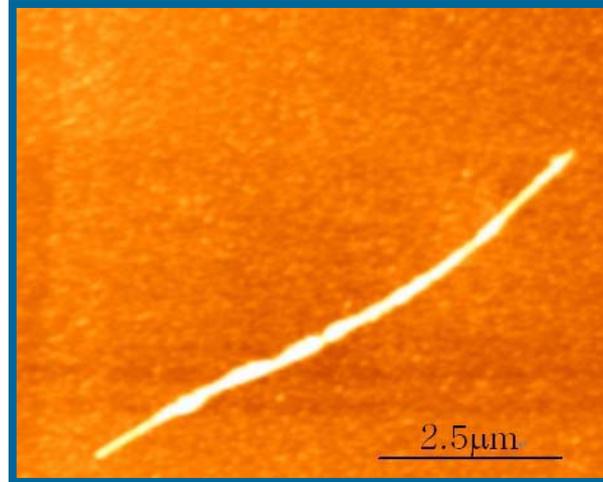
# Columbia-Korea collaborative research...continued.

## Bismuth semi-metallic nanowire synthesis.

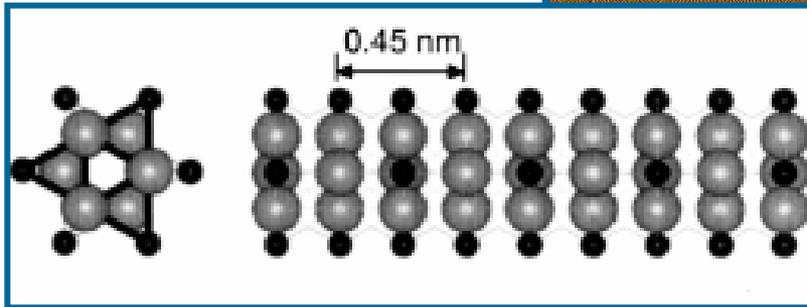
Ju Young Lee  
Kwang S. Kim  
Philip Kim



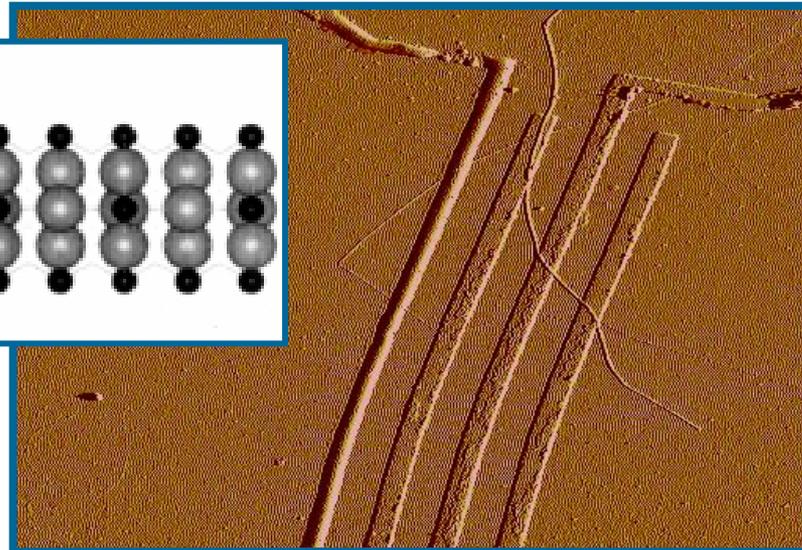
Ju Young Lee



## Molybdenum selenide nanowire: synthesis and transport.



Yeon Suk Hong  
Latha Venkataraman



Yeon Suk Hong

# Transition: Preparation for “life after the university experience in nanotechnology”.

## Short courses

- Graduate level
- No credit
- 1.5 days
- Open to all  
(priority to nsec students)
- Maximum of 25 students
- Minimum of 15 students

### Ethical conduct of research

- The ethos of the researcher
- Schematic of research process
- Discussion groups: case studies
- Federal codes: Misconduct in Science and Engineering
- Sample major case, facts and regulatory framework.

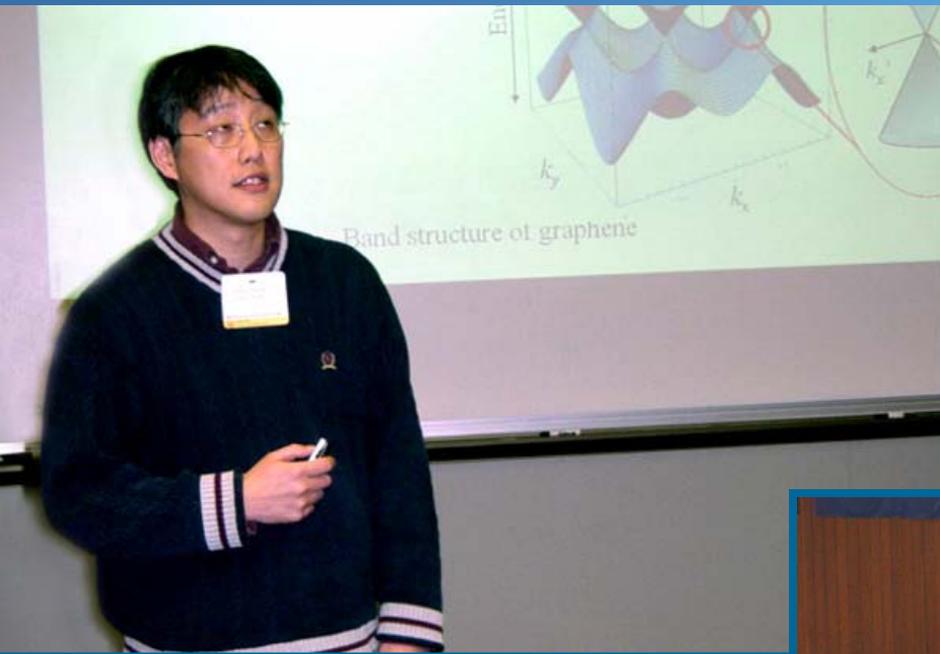
### Science Policy: Nanotechnology at the Science-Society Interface

- A comparison: Genetic Eng. And Nanotech.
- Current state of nanotechnology.
- Assessing nanotechnology
- Nanotechnology and public perception.
- Political science: the role of government.

### Scientific presentation and writing skills.

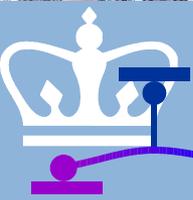


# Arden House Retreat - annually.



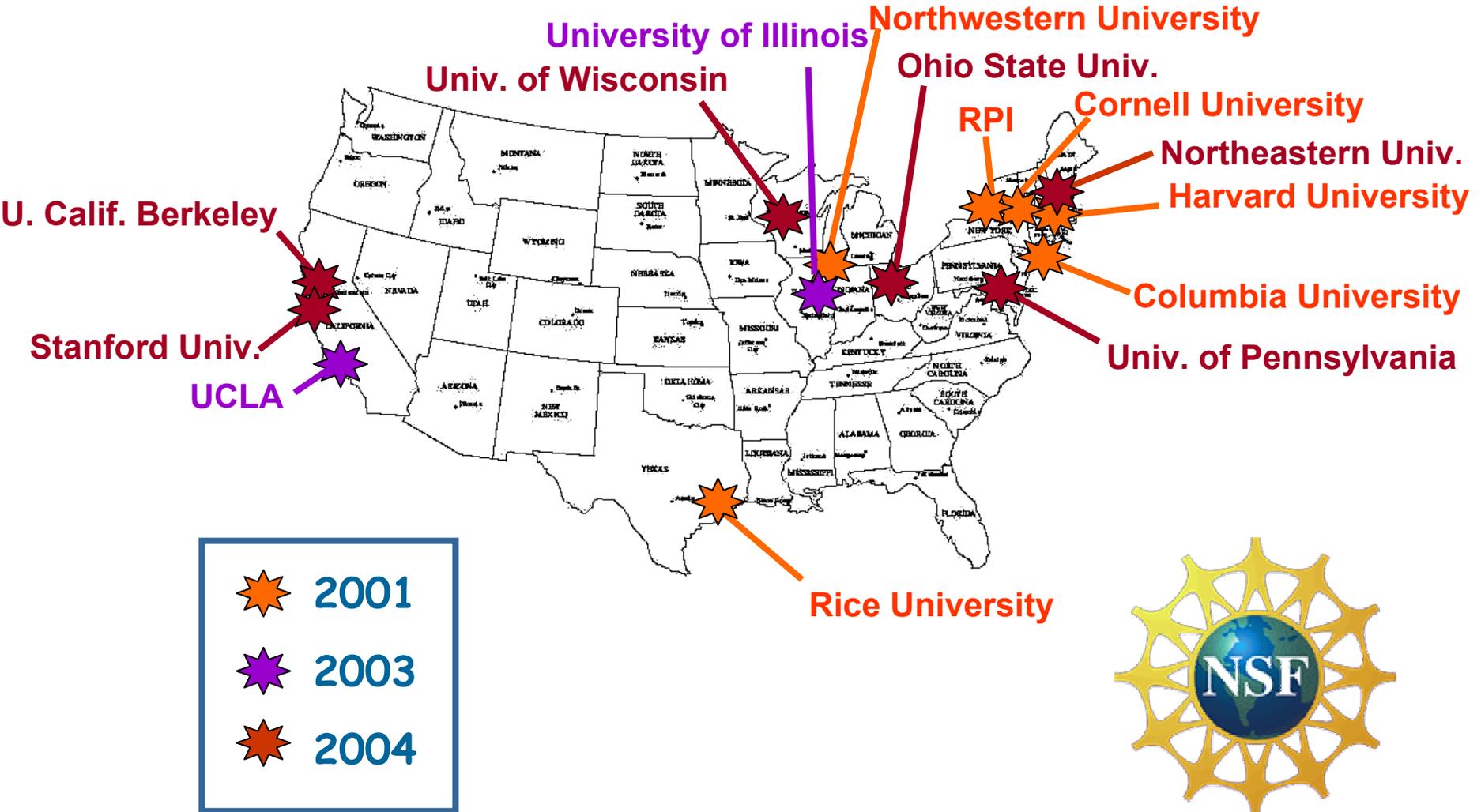
- 19 faculty members
- 3 research scientists
- 7 industrial collaborators
- 3 undergraduate students
- 40 graduate students and postdocs





# Extra Slides

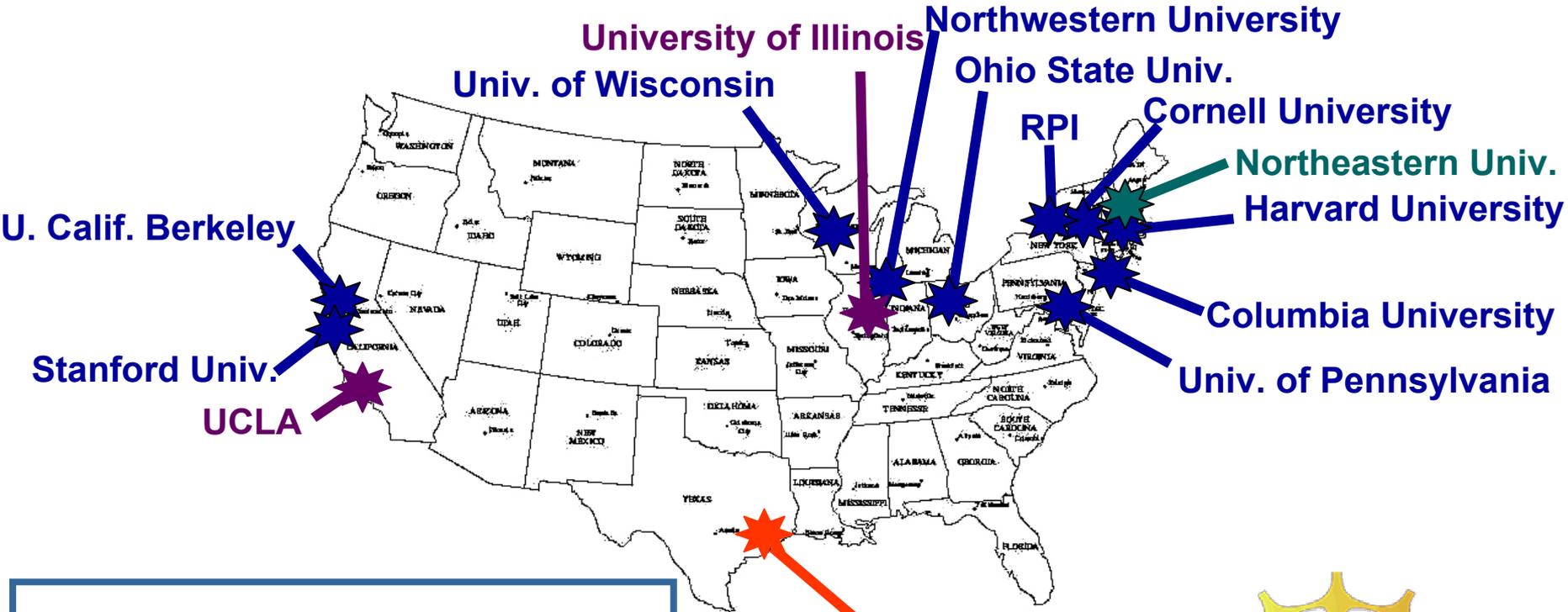
# Evolution of NSF NSEC's



	2001
	2003
	2004



# NSF NSEC's: Special programs



-  Science and engineering
-  + Environment/Biology
-  + Manufacturing
-  + Societal Impact



# US Infrastructure for Nanotechnology Research.

## Seven themes:

- Biotechnology,
- Nanostructures 'by design' and novel phenomena,
- Device and system architecture,
- Environmental Processes,
- Multiscale modeling,
- Nanoscale manufacturing;
- Societal implications and Improving human performance

**Nanoscale Science and Engineering Centers**

## NSF

- Individual research grants.
- NIRTs
- Research centers  
[MRSECs]  
Columbia for example  
[STCs]  
Cornell for example.

## **NSEC's**

- National nanotechnology infrastructure network  
Ex: Purdue - Computational nanotechnology
- Center for Learning and Teaching (NCLT).

## Other collaborating agencies

- ARO
- AFOSR
- DOE
- NIST

## National Institute of Health