Nanotechnology:
Think Small and Look into the Future….

Gregory N. Parsons

Professor, Department of Chemical and Biomolecular Engineering,
Director, NC State Nanotechnology Initiative
North Carolina State University, Raleigh NC

Sanford Rotary Club
March 17, 2009

UNIVERSITY of NORTH CAROLINA
Office of the President

NONWOVENS COOPERATIVE
RESEARCH CENTER

NSF Science & Technology Center
NSF STC
Environmentally Responsible Solvents and Processes

Outline

- Definition
- History → Future
- Illustrations:
  - Single Crystal Silicon
  - Diamond, Carbon Nanotubes, Graphene
- Nano at NC State – New understanding to improve:
  - Environment
  - Safety and Security
  - Health and Bio-systems
  - Electronic Nanomaterials
  - Renewable Energy

  } Engineering
  Physical and Math Science
  Agriculture and Life Sciences
  Textiles
  Veterinary Medicine
- New Directions….

Definition

Nanotechnology:

- The application of quantum theory and other nanoscale phenomena to fundamentally control the properties and behavior of matter.
- Very small pieces of a material look and act differently than large pieces of the same material. Nanotechnology works to utilize the unique properties of very small systems.
- Nanotechnology will "benefit every industrial sector and health care field, … and help the environment through more efficient use of resources and better pollution control"*

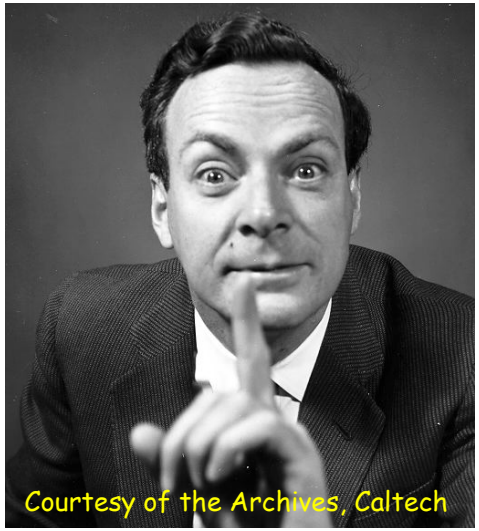
* Mihail Roco, *Scientific American*, August (2006) p 39

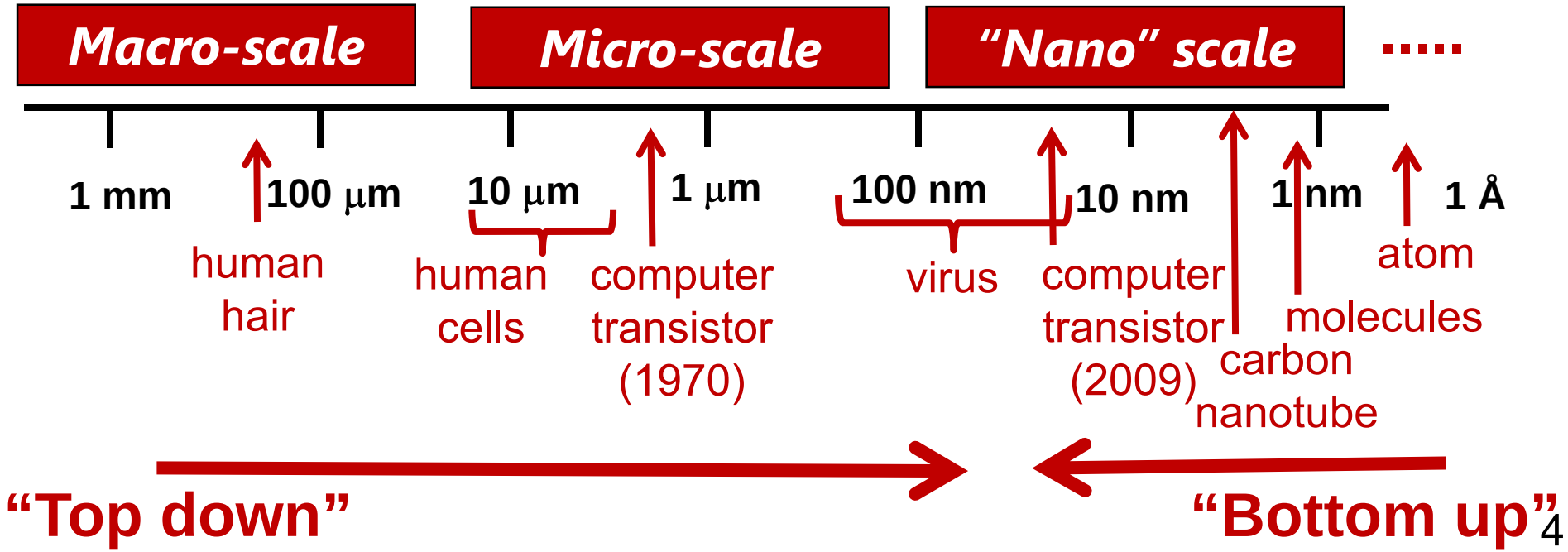
History of Nanotechnology

"There is plenty of room at the bottom"

1959, Richard Feynman, Nobel Laureate, Caltech

"The principles of physics, as far as I can see, do not speak against the possibility of maneuvering things atom by atom……





Future Nanotechnology

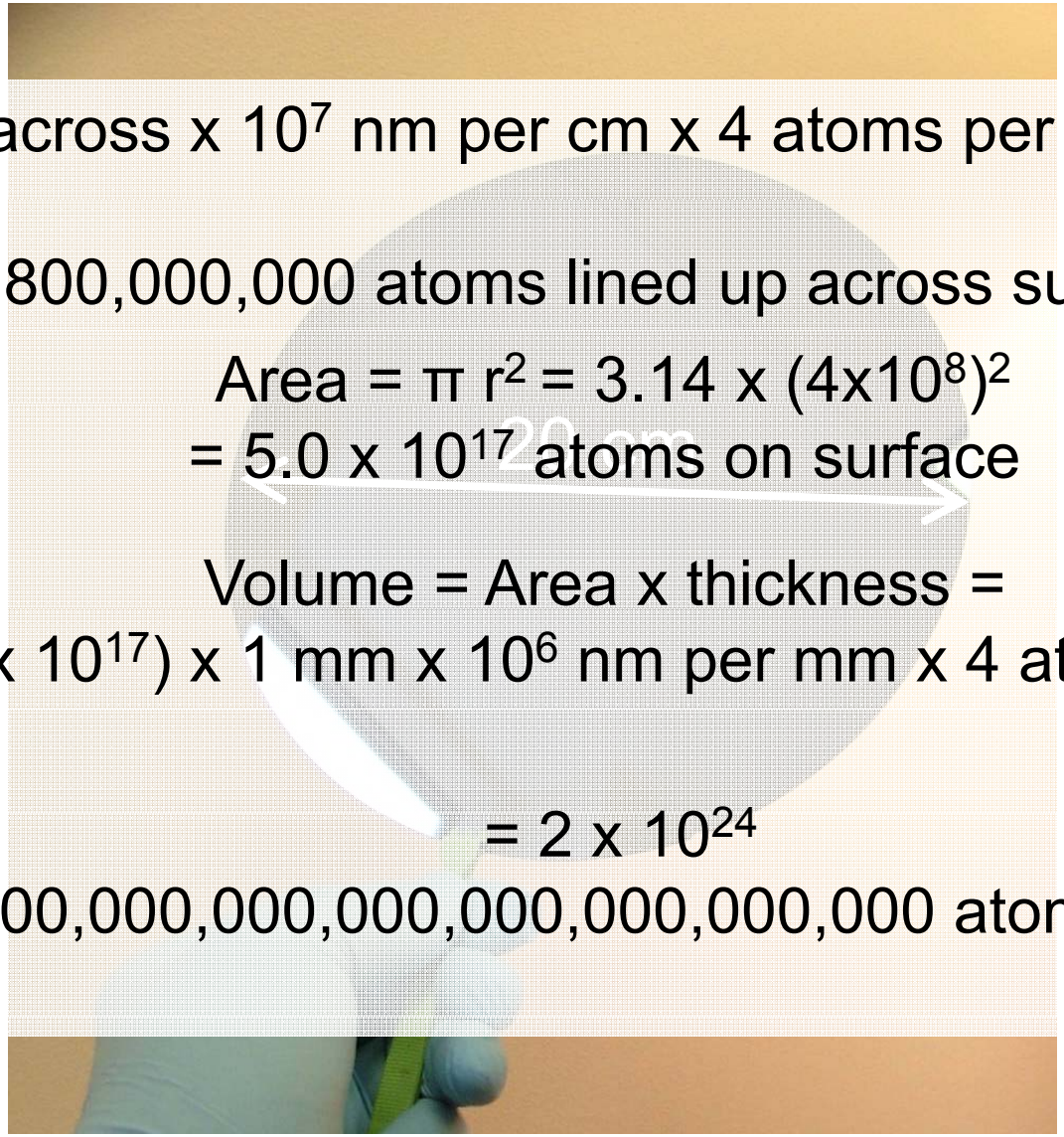
Three Questions (one easy, two harder):

1. What technologies are around today that were not widely available 10 – 15 years ago?

2. What technologies will we have in 10 – 15 years that we don't have now?

3. What new knowledge is needed to realize these advances?

Silicon Electronics Technology



20 cm across x 10^7 nm per cm x 4 atoms per nanometer

= 800,000,000 atoms lined up across surface

Area = $\pi r^2 = 3.14 \times (4 \times 10^8)^2$

= 5.0×10^{17} atoms on surface

Volume = Area x thickness =

= $(5.0 \times 10^{17}) \times 1$ mm x 10^6 nm per mm x 4 atoms per nm

= 2×10^{24}

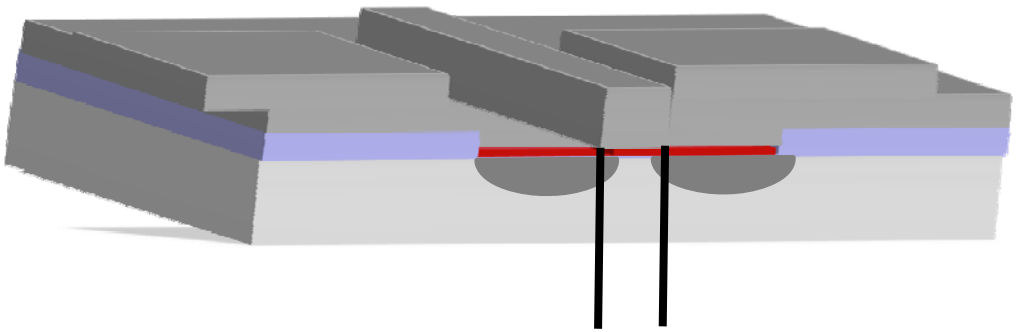
= 2,000,000,000,000,000,000,000,000 atoms in wafer

Silicon Electronics Technology

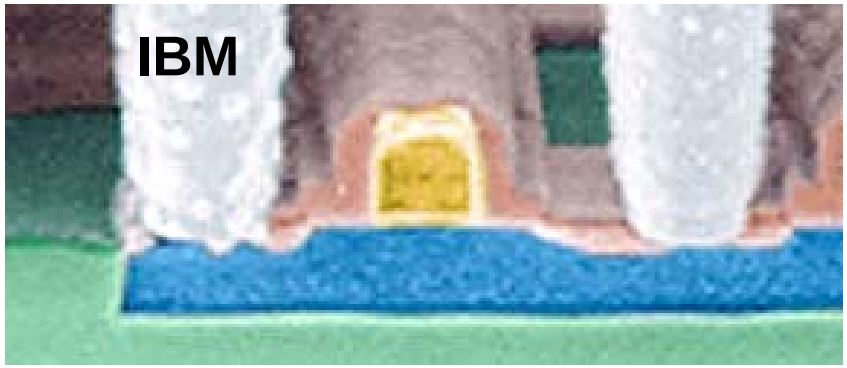
Silicon Electronics Technology

"Top down"

Bulk semiconductor crystal
Field oxidation
Area definition
Hi-k thin film deposition
Gate metal deposition
Gate metal patterning
Gate dielectric etch
Source/drain implant
Contact metal deposition/patterning



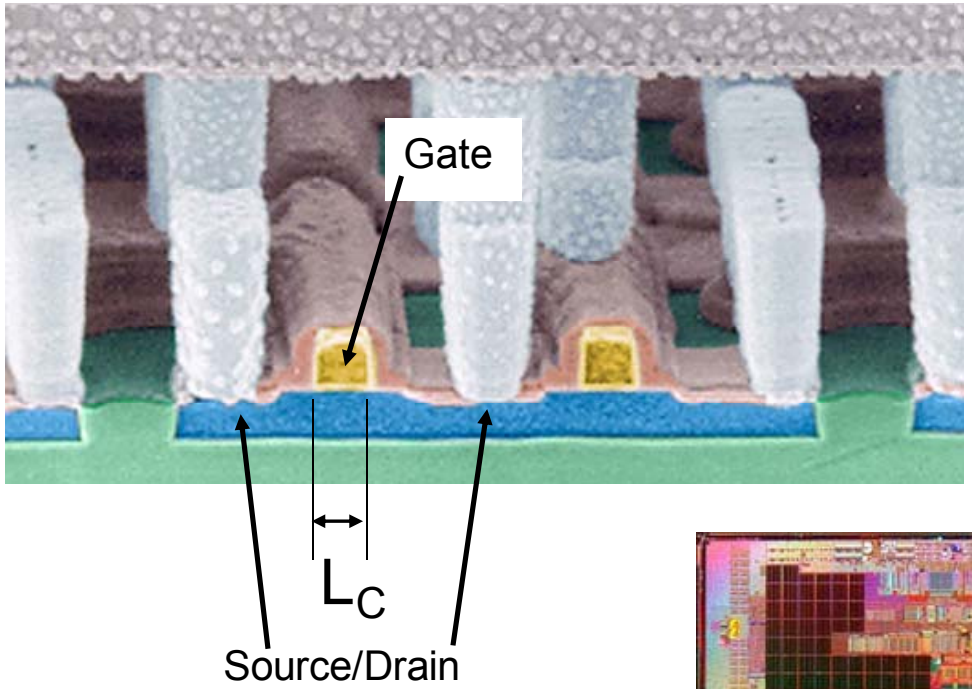
50 nm



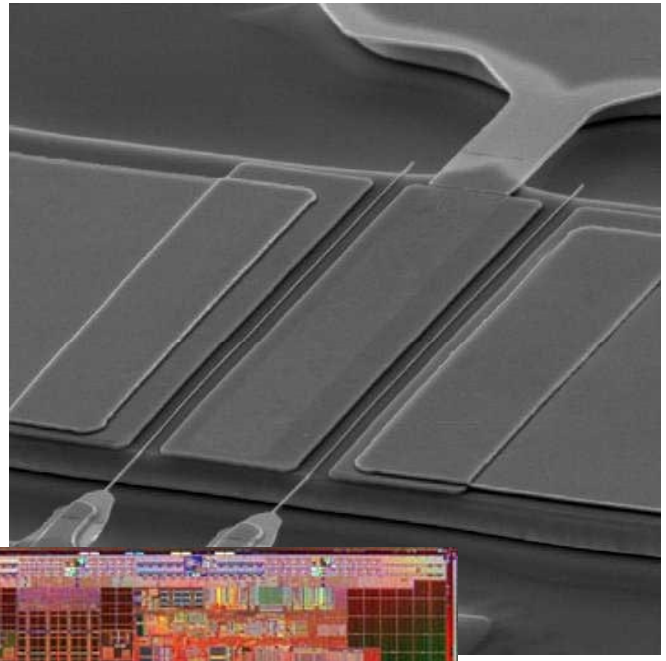
Transistor

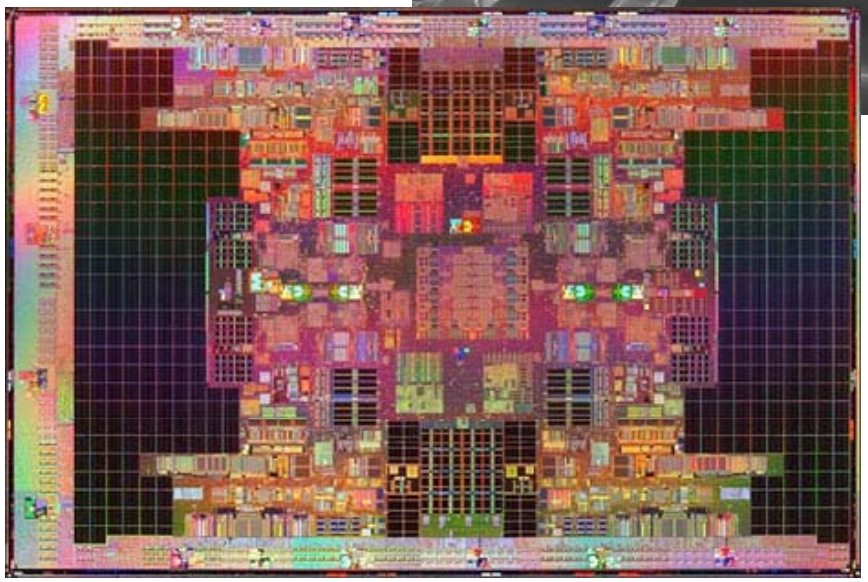
Silicon Electronics Technology

IBM



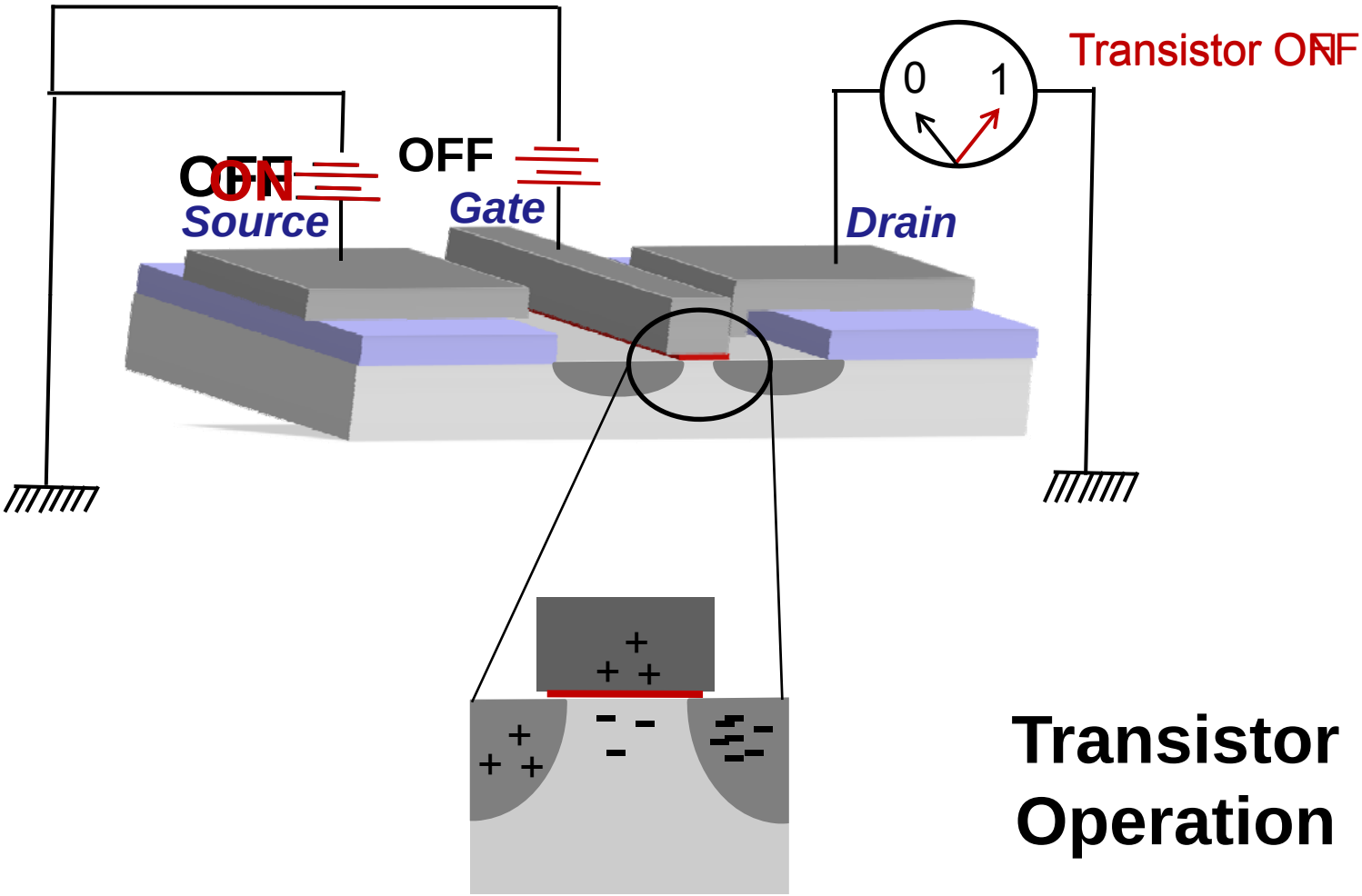
Intel InSb Transistor





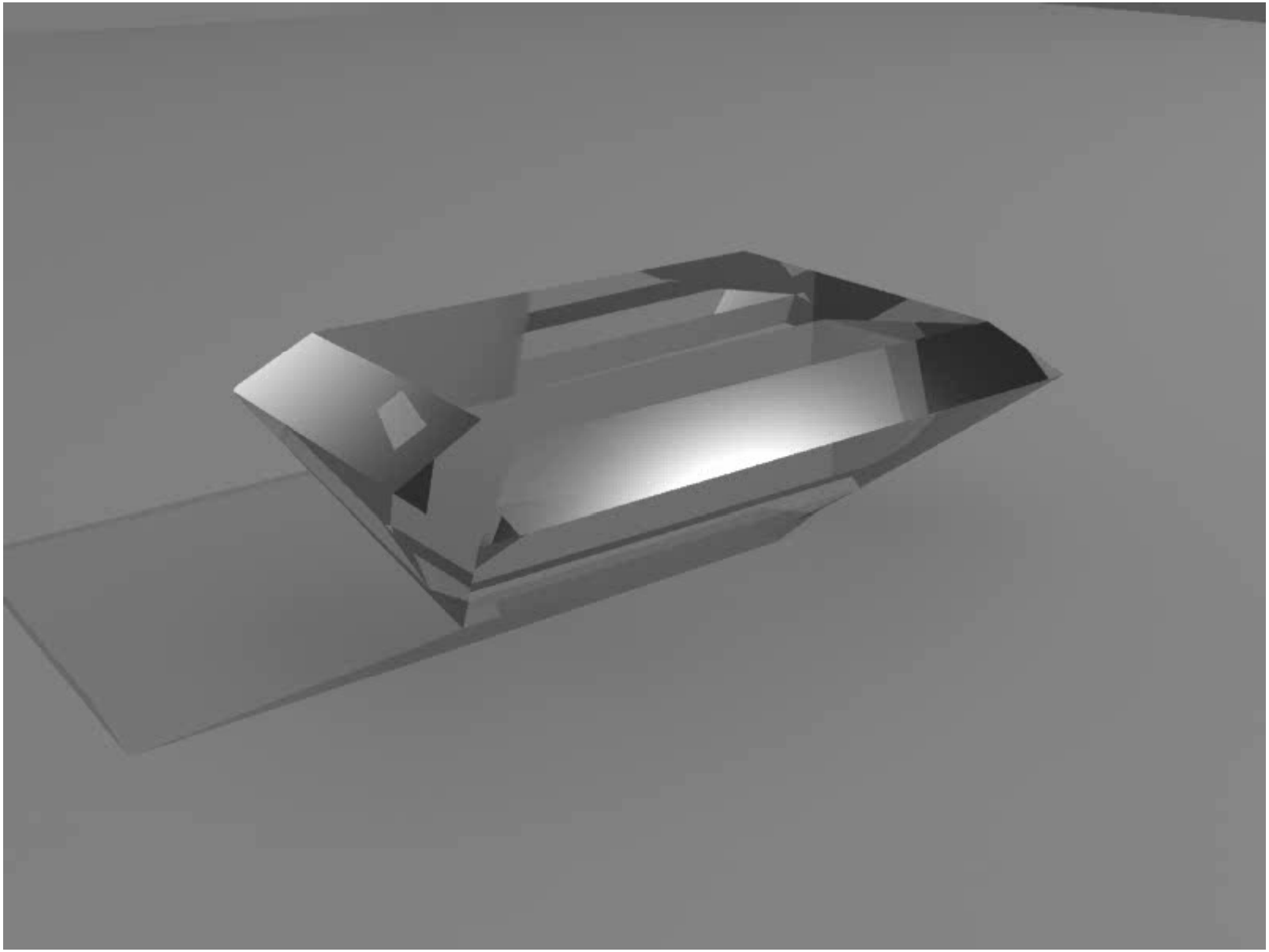
Intel Itanium Chip
2 Billion Transistors

Silicon Electronics Technology

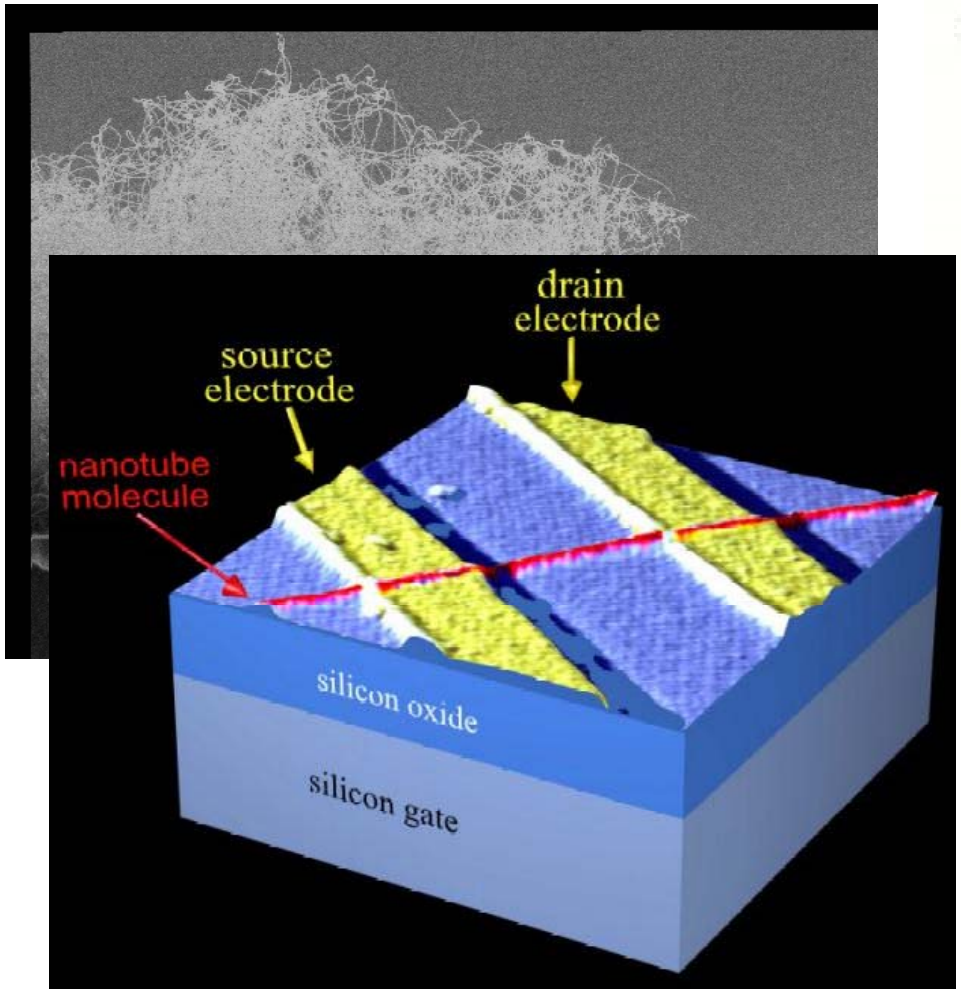


Transistor Operation

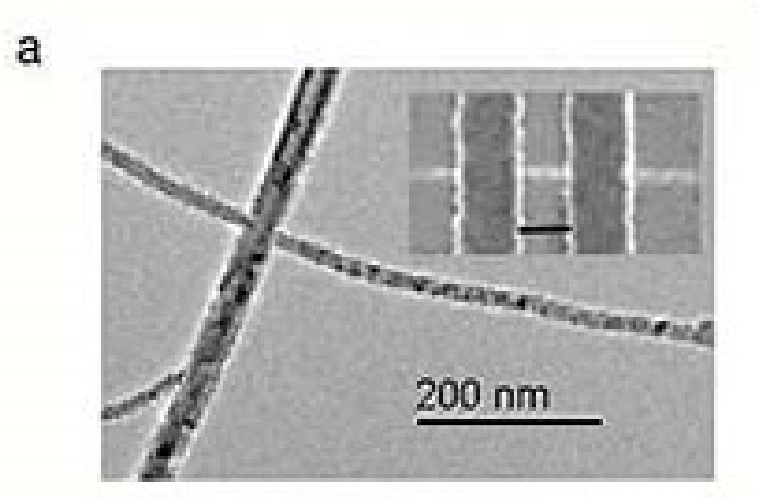
Diamond → Carbon Nanotubes



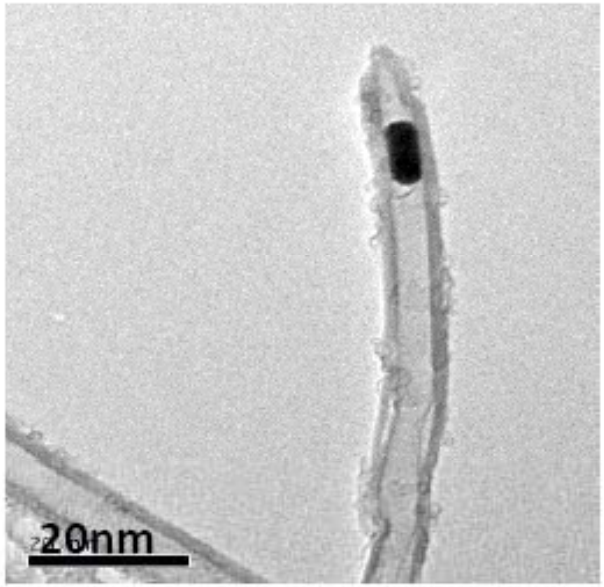
Carbon Nanotubes and CNT Transistors



Nature, May 1998



SPIE, March 2008



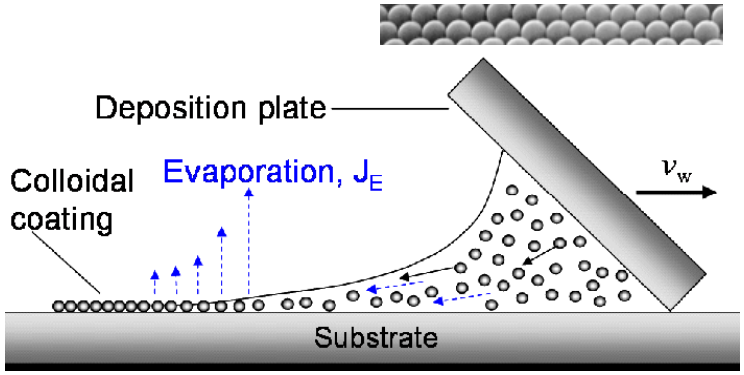
Small Science Leads to Big Future at NC State

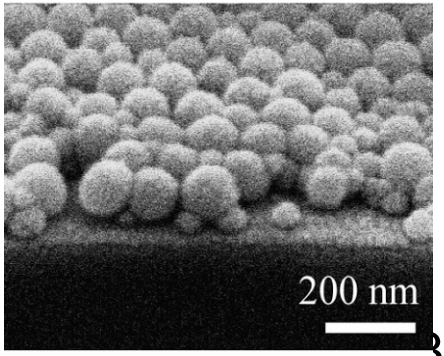
E-field assemblies from gold nanoparticles and live cells

New Jobs, New Companies, and the Nanotechnology Economy

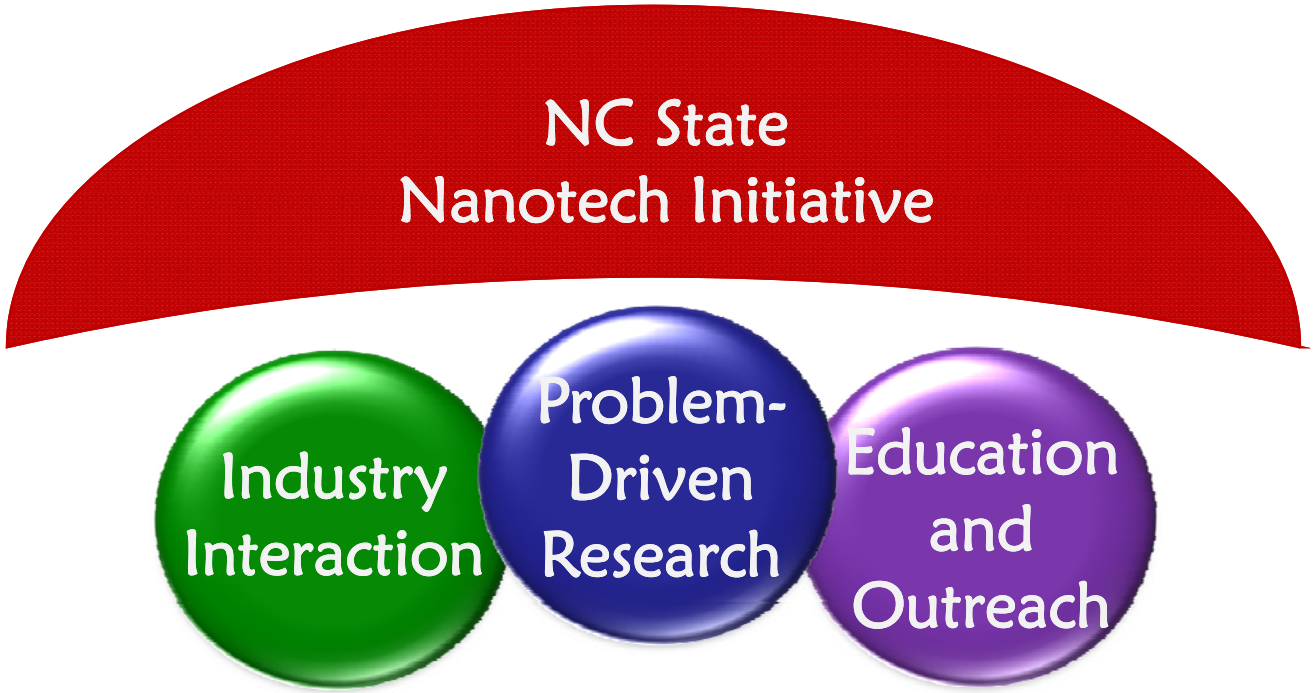
The Global Race for Nanotechnology Leadership:

North Carolina Can Rise to the Challenge



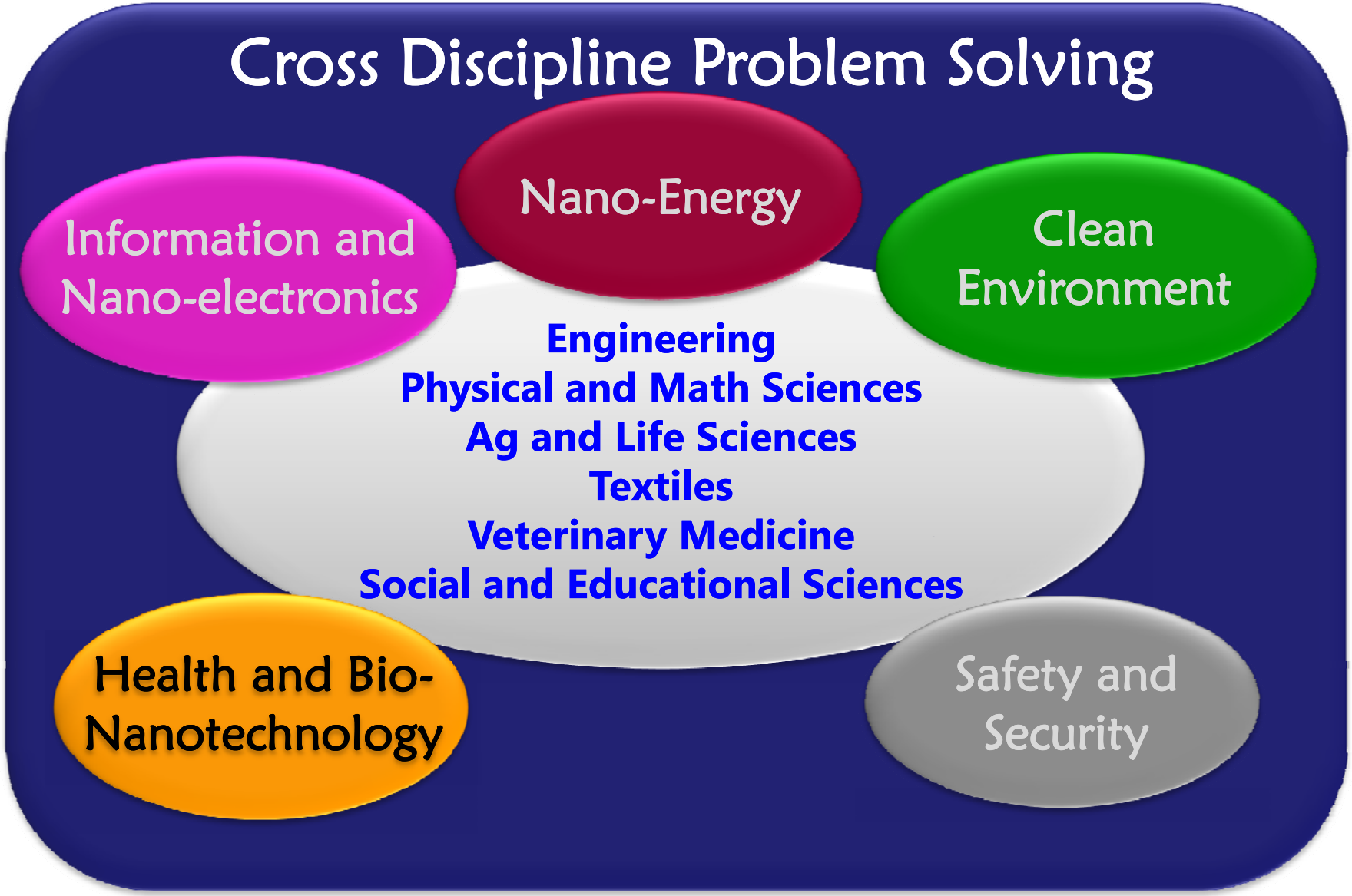


NC State Nano-Initiative



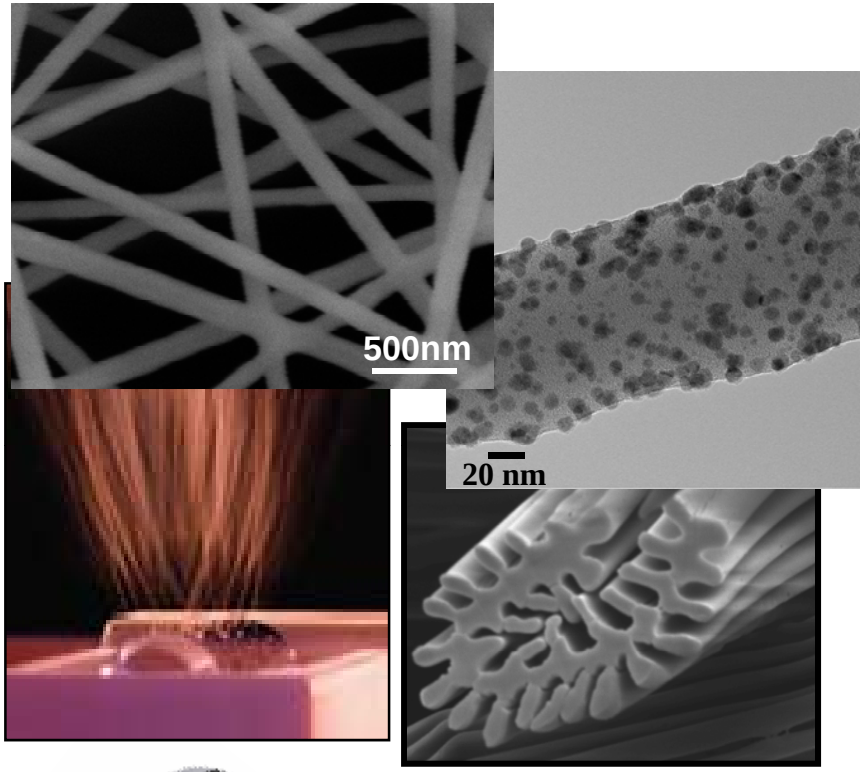
Mission: To address fundamental understanding of nanomaterials and nanoscale processing to solve problems and produce products of value to the people of North Carolina.

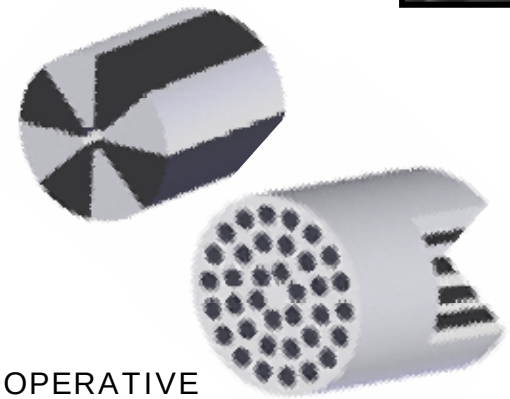
NC State Nano-Initiative

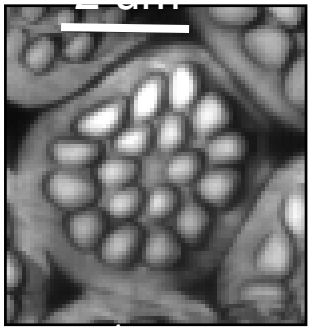


Nano for Environment

- Nanofiber Filtration: Clean Water and Air
  - Nanofibers for air, water filtration devices
  - Reduce energy consumption
  - “Smart Filters” – Integrated sensor devices
  - Electrospinning: 100 nm
  - Multicomponent Spunbond: 200 nm







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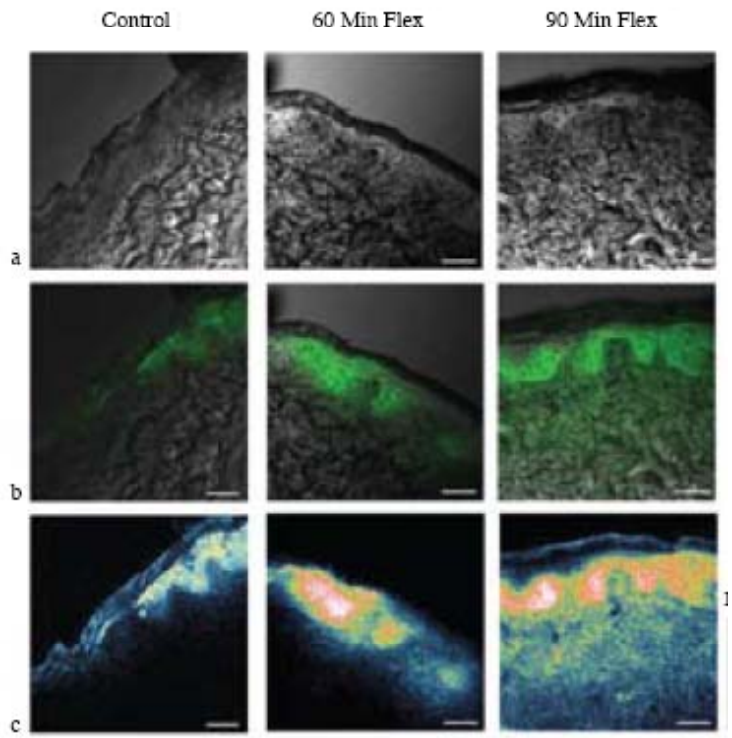
Nano for Environment

Future Worker Safety Concerns Prompt Study



Dr. Nancy Monteiro-Riviere and graduate student Leshuai Zhang run tests on skin cell cultures to measure the penetration of nanoparticles.

Dr. Nancy Monteiro-Riviere's research is much more than skin deep. That's the very reason her research needs to be done, she says. The College of Veterinary Medicine professor studies the effects of compounds—from drugs to chemicals to cosmetics—that come in contact with the skin. Her latest concern: nanoparticles.

Nano for Safety – Fibers and Textiles

- Protection
  - First Responders
  - Fire, Chemical, Particulates, etc.
- Purification
  - Hazardous vapor remediation
  - Nanoparticle capture
- Signal/Response
  - Chem/Bio sensors
  - Responsive systems
  - Agent delivery/release
- Biomedical Systems
  - Pathogen capture, destruction
  - Separations in pharmaceutical manufacturing

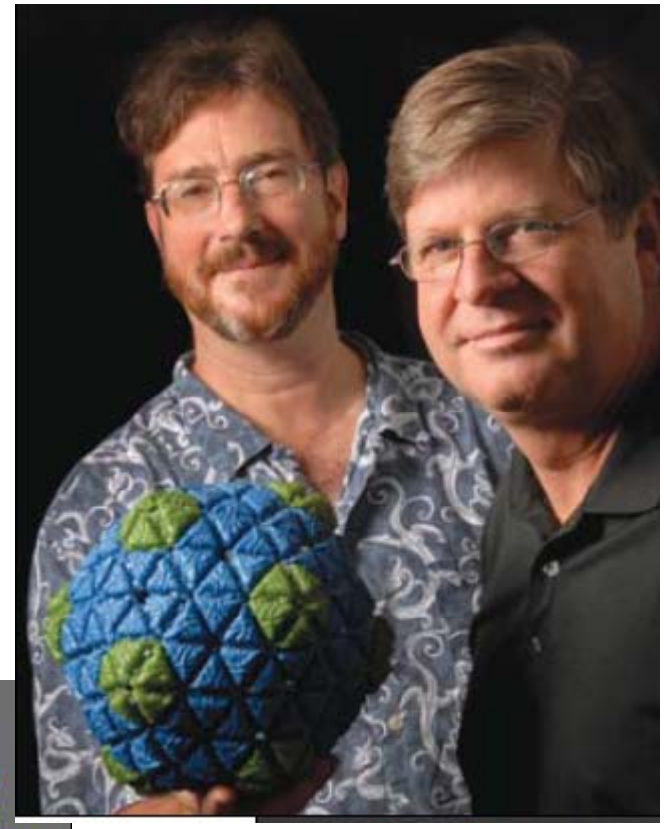
Health and Nano-Biotechnology

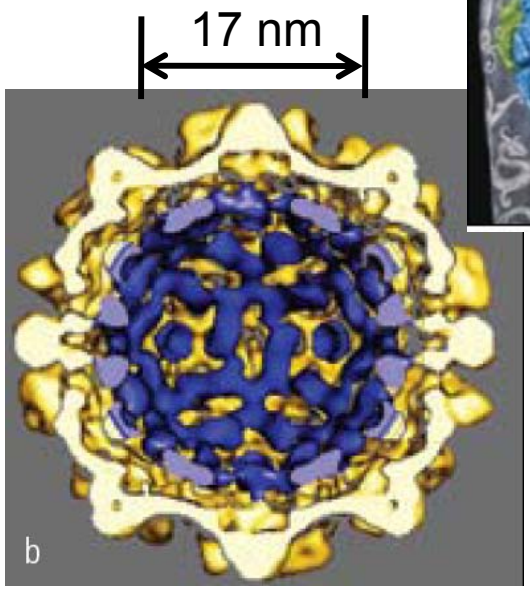
Sneaky Virus Packs Healthy Punch

Drs. Stefan Franzen and Steve Lommel are running a smuggling operation in their labs on Centennial Campus. They are sneaking a cache of disease-fighting weapons through the body's defenses and hope to destroy or reprogram targeted cells. Their secret weapon? A modified 38-nanometer plant virus.

"This system has the potential to fight a lot of diseases."

CALS, PAMS

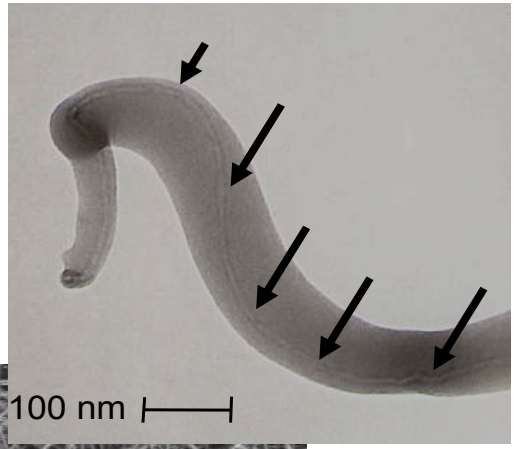




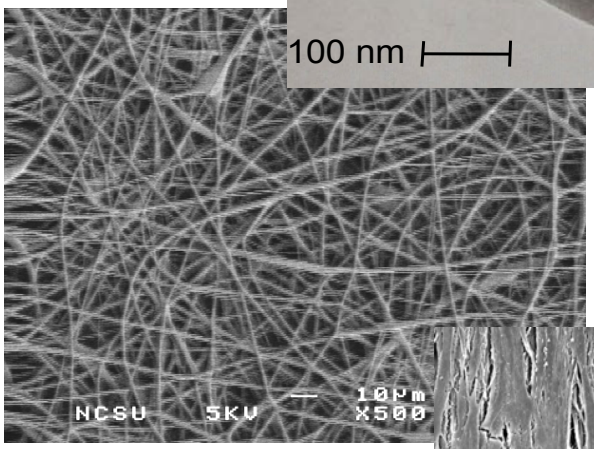
Red clover necrotic mosaic virus has an ordered inner core comprised of an RNA/protein complex

Carbon Nanotube-based Body Implants

Poly-lactic acid polymer hybridized with multi-wall carbon nanotubes enhances strength and performance for tissue engineering scaffolds

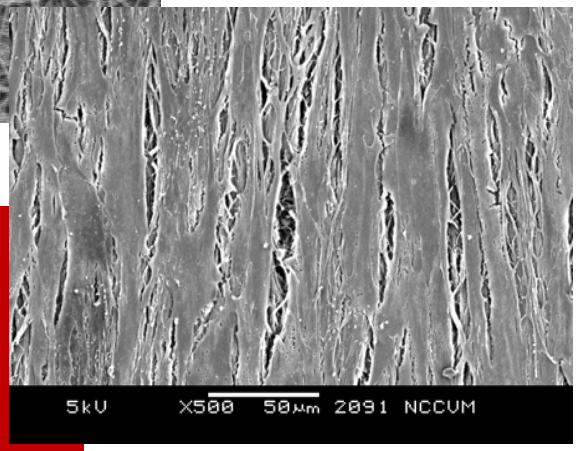


Hybrid Fibers



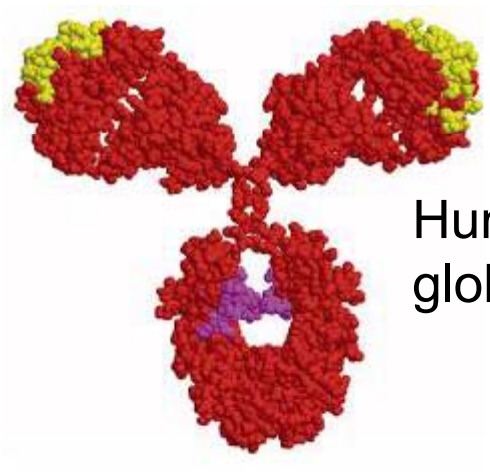
Mats

Cell growth



Cross Discipline:
Russ Gorga, Textiles
Laura Clarke, Physics
Elizabeth Loboa, Biomedical Engineering

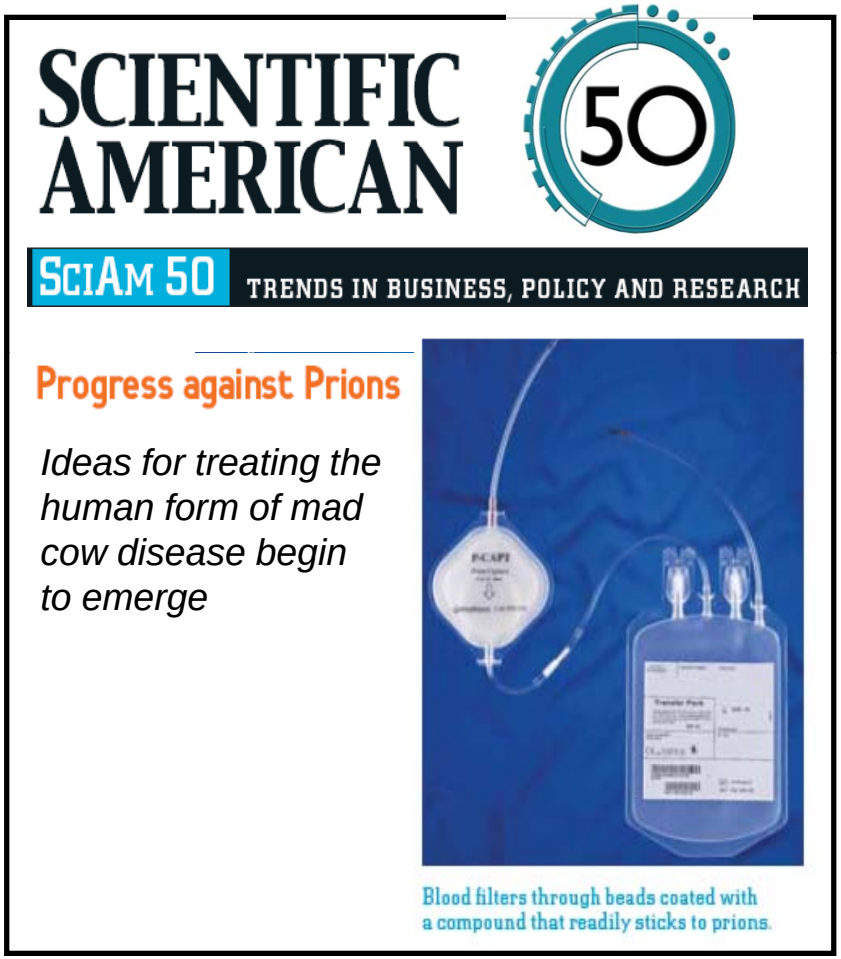
Blood Filtration Technology



Human Immuno-globulin G (hIgG)

- Nano-engineered filter device to capture antibodies or infectious proteins (such as prions)

Pathogen Removal and Detection Technologies, Inc. (PRDT)



SCIENTIFIC AMERICAN 50

SCIAM 50 TRENDS IN BUSINESS, POLICY AND RESEARCH

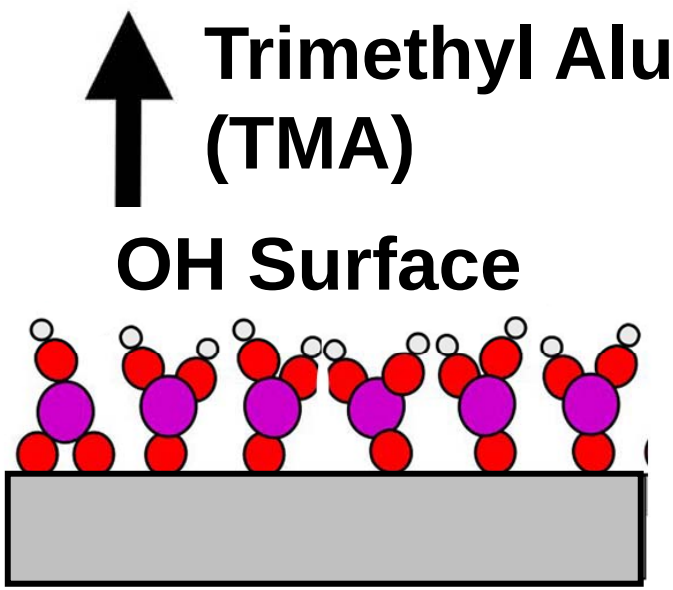
Progress against Prions

Ideas for treating the human form of mad cow disease begin to emerge

Blood filters through beads coated with a compound that readily sticks to prions.

MacoPharma P-Capt™

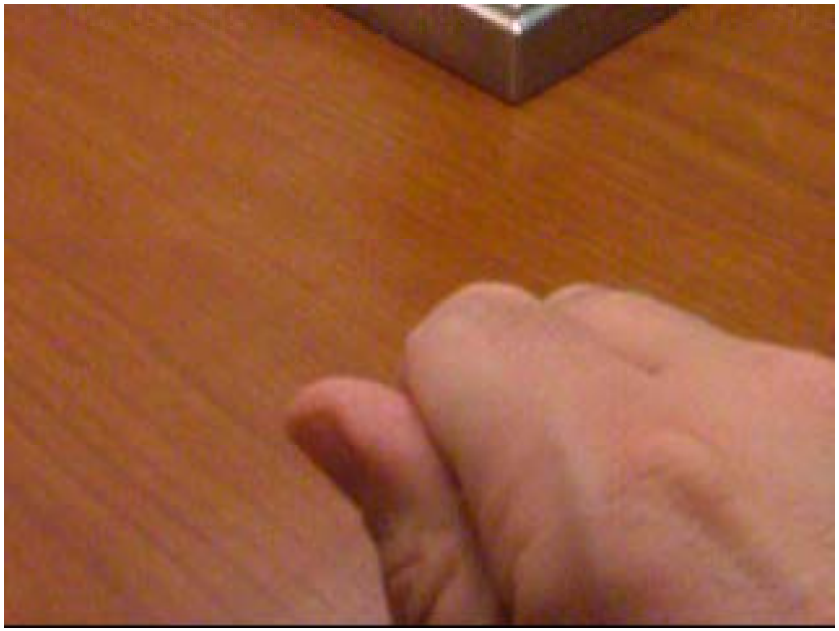
Atomic Layer Deposition



Sequential self-limiting reactions produce highly conformal coatings on 3D fiber networks

Nano-Textiles: Nanofiber Surface Modification

@ NC STATE



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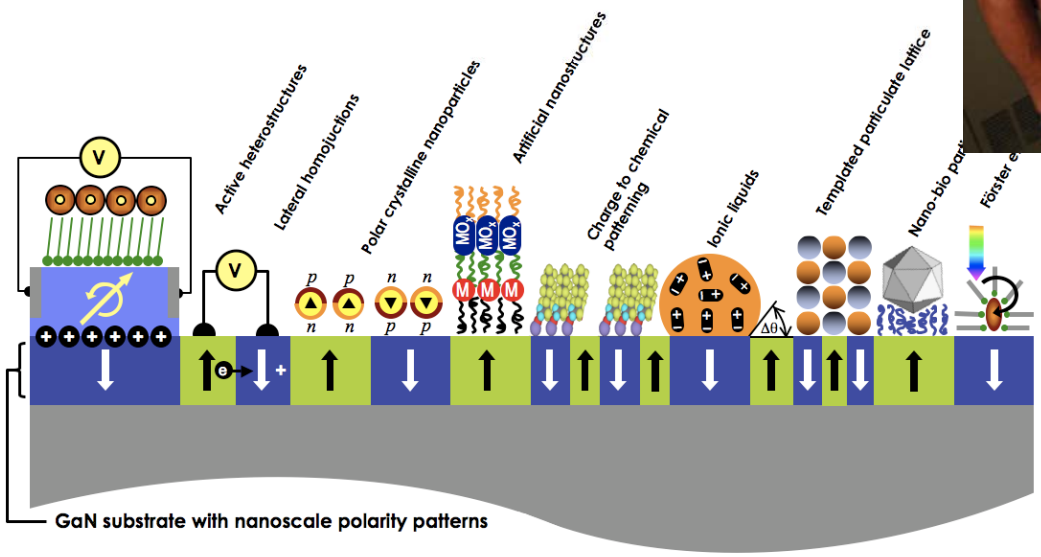
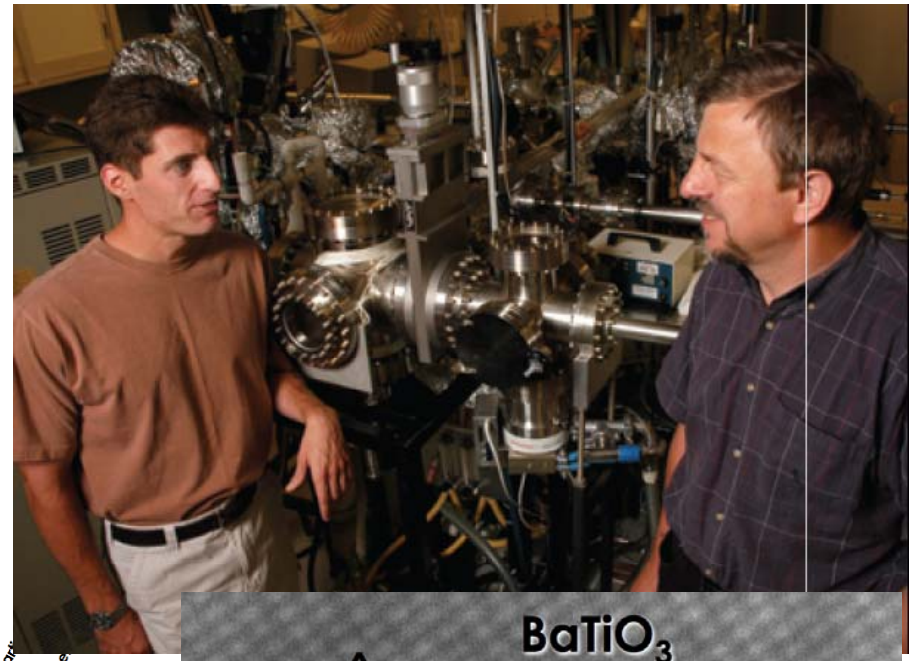
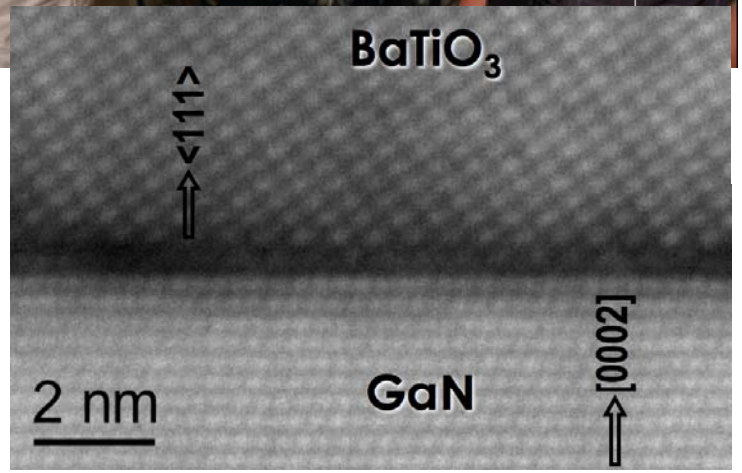
Atomic Stacking Yields Potential

NCSU researchers have achieved epitaxiallly integrated ferroelectric oxides on GaN, for applications including tunable polarity doping





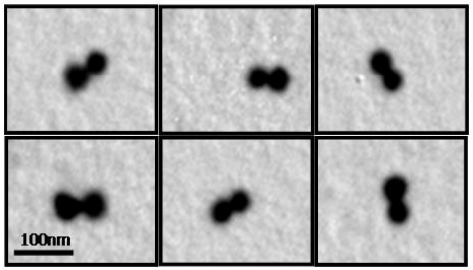


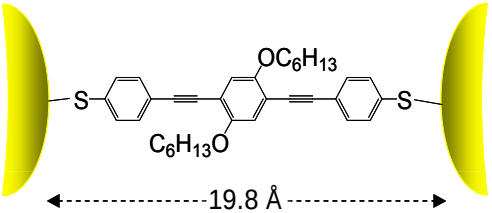
Electronic Nanomaterials

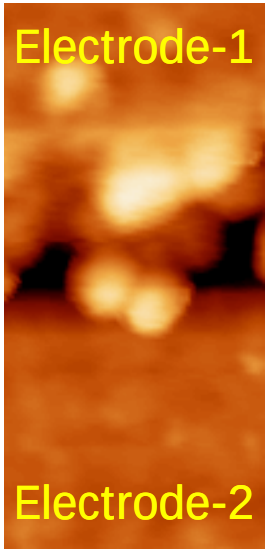
@ NC STATE

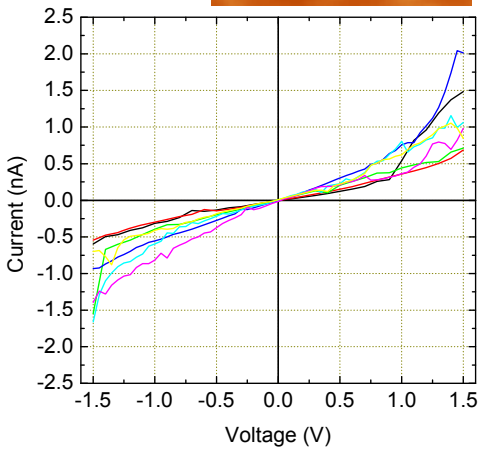
- New semiconducting materials
  - Faster computation
  - Polymer and organic semiconductors
    - Flexible displays;
    - Smaller size
    - Molecular electronics
- New metals, insulating materials
  - "High-k, metal gate" technology
  - Faster switching
- Quantum Computing
  - Whole new ways of information management

"Bottom Up"









Gorman, CH
Parsons ChE

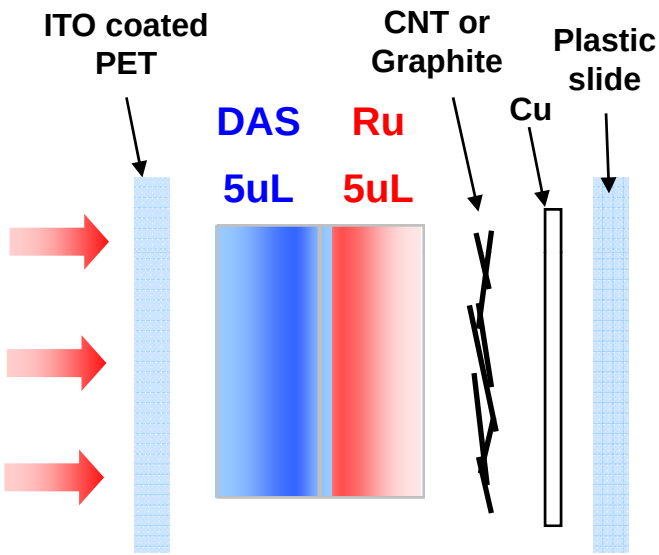
Renewable Energy Nanotechnology

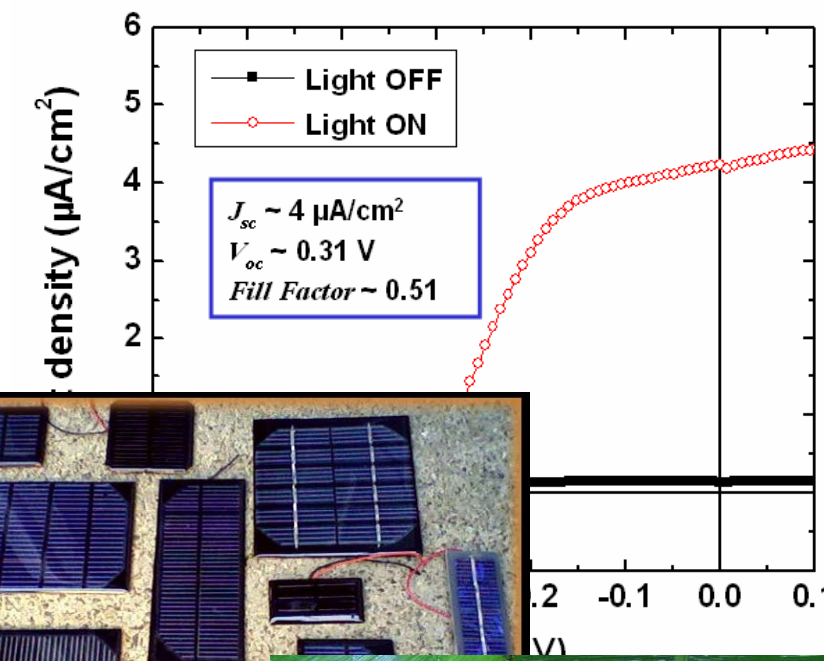
@ NC STATE

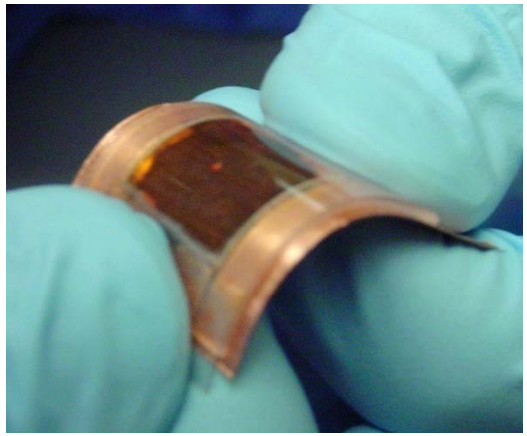
- The Future Renewable Electric Energy Delivery and Management (FREEDM) Systems Center
  - New grid compatible with renewable energy
- Nanostructures for Photovoltaics
  - Sunlight → Electricity
  - Follows natural photosynthesis
- NC State Nano-Energy Lab (2008)
  - Funding through US Department of Energy

Gel Photovoltaics

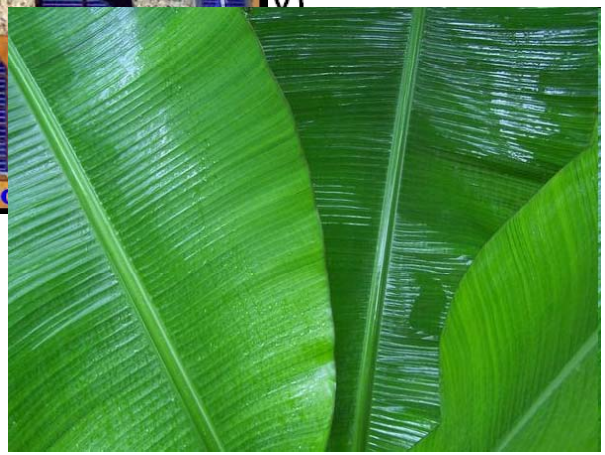
Potential for low cost, flexible, simple fabrication, robust and with low environmental footprint







Vision



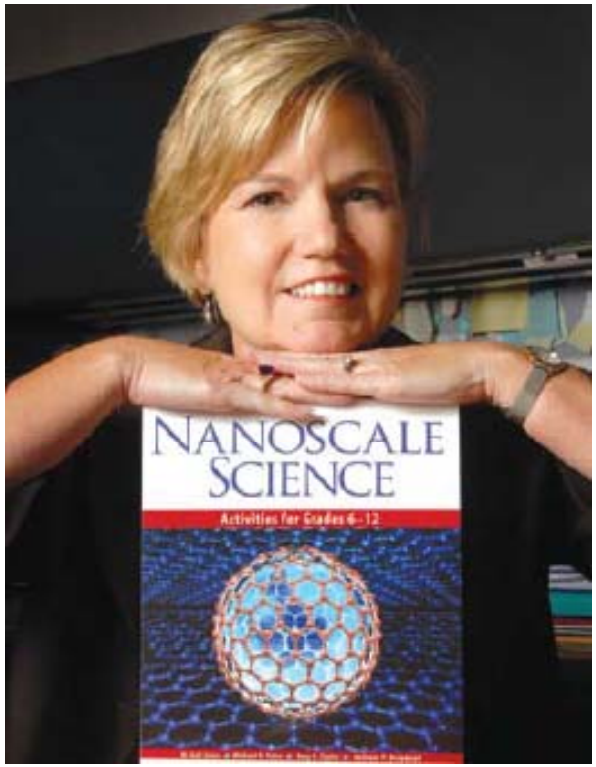
Velev Research Group

Social Nano-Science and Education

Informing the Public

Dr. Brent Faber says the media influences the way people view nanotechnology.

Moving nanotechnology from the realm of research to applied science requires education—in both the classroom and the boardroom. NC State faculty like Drs. Gail Jones and Lynda Aiman-Smith are working on both ends of that learning curve to ensure that the science behind nanotechnology becomes part of school curriculum and that the products that spring from nanotechnology become part of everyday life.



Future Nanotechnology

Three Questions (one easy, two harder):

1. What technologies are around today that were not widely available 10 – 15 years ago?

2. What technologies will we have in 10 – 15 years that we don't have now?

3. What new knowledge is needed to realize these advances?

End….

- Thank you for your interest…
- More information
  - *www.ncsu.edu/nano*
- NC State NanoDays: April 24, 2009
- Download these slides at:
  - *www.ncsu.edu/nano/news*

New technologies in next 10-15 years

- Satellite phones
- HDTV, Net TV
- Credit card phone
- “Batman” fabric wings
- Solar cars
- Super-strong “Spider-man” rope
- “Harry Potter” invisibility cloak
- New biomaterial fabrics and paper
- Prosthetics that are the same as natural
- Regenerative human organs
- Spooky interaction for communication
- Cure for cancer
- Catalysts for recycling
- Holographic display
- Transgenic crops
- Gene sequencing for plants and animals
- Fusion reactor
- Cure for baldness