NanoTx'07

October 3rd, 2007

Coming Challenges in Electronics

Walt Trybula, Ph.D.

IEEE Fellow & SPIE Fellow

Director, Nanomaterials Application Center
at Texas State University-San Marcos, Texas

Director, The Trybula Foundation, Inc.

www.nanotxstate.org www.tryb.org

Walt's Point of View

- **Researcher, Scientist, and Technology Futurist**
  - Over 25 years in leading-edge technology
  - Director, Nanomaterials Application Center at Texas State University-San Marcos
  - Senior Fellow, SEMATECH, the first semiconductor consortium
    - International Technology Roadmap for Semiconductors Committees
      - Lithography
      - Modeling and Simulation – US Chair – 2005 to Present
    - Led Industry Immersion Lithography effort
  - Twelve years at GE; nine on Corporate Staff
    - Technology evaluation
    - Business viability
  - Extensive experience driving emerging technologies

Objective of Presentation

- Provide “food for thought” examples of some challenges that will be facing electronics
- Highlight some of the challenges that will occur as technology continues to shrink the dimensions
- Show the importance of having the entire technology solution

Format Employed for Examples

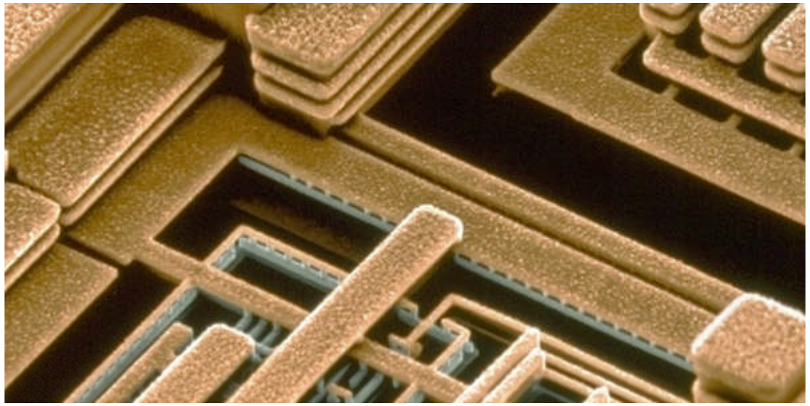
Topic:
A picture or description is employed to indicate the device or structure being described

Issues:
A short listing of some of the issues that are inhibiting the application of the specific example and will typically include an indication of the sizes involved

Potential Solutions:
This list contains actions that must be continued/started to develop the specific example to either a concept feasibility state or a production worthy state

Benefits:
This list indicates some of the advantages of developing products that will employ the device or structure described

Semiconductor Conductivity



Issues:

- Line widths of less than **50nm** may have conductivity issues due to grain boundaries and crystal orientations
- Resultant impact on device performance and yield

Potential Solutions:

- Revert to Aluminum conductors with an associated loss in properties
- Enhanced uniformity of copper with lower actual conductivity
- Develop new processes and equipment

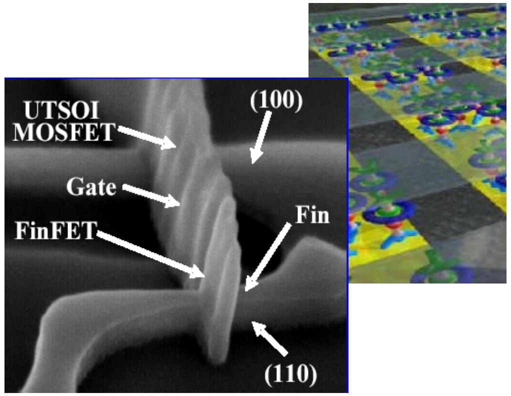
Benefits:

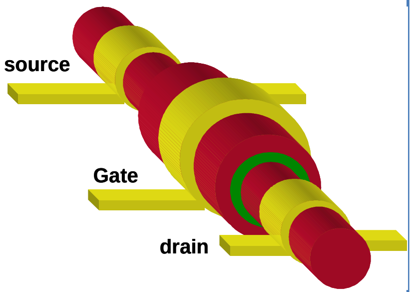
- Improved performance
- Higher yields and lower costs
- Improved designs and functionality

Transistor Evolution

Future: 15 years

Non-classical CMOS





Beyond CMOS

Issues:

- Sizes under **20nm**
- Manufacturing capability
- Developing theoretical understanding
- Experimental data
- Radical change from experience

Potential Solutions:

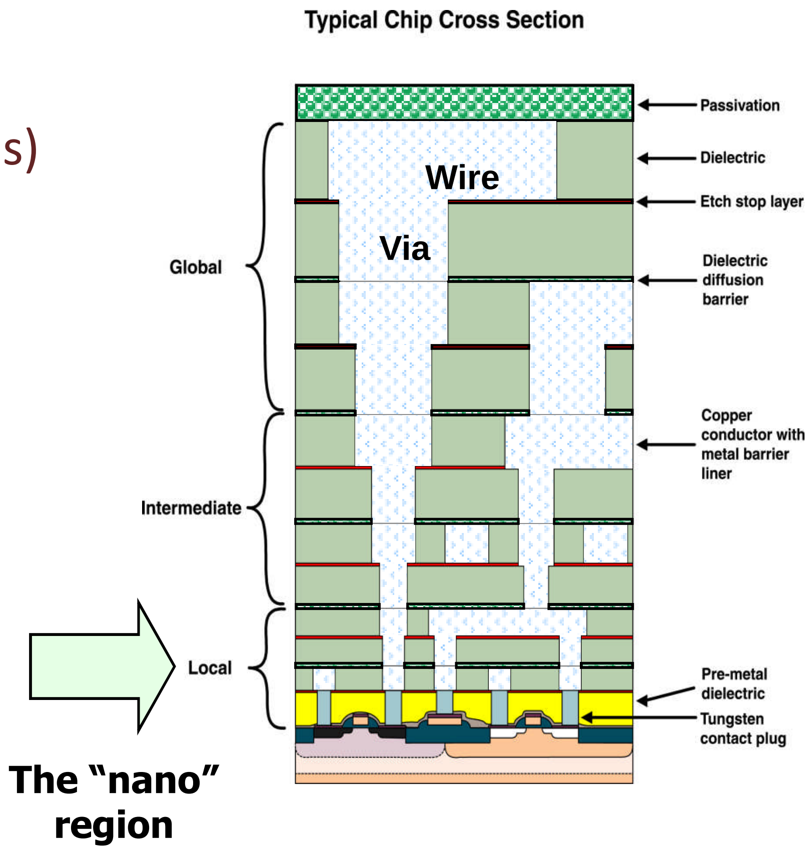
- Continued research and development
- Develop understanding of operational characteristics
- Industry/academia involvement in materials and functionality evaluations

Benefits:

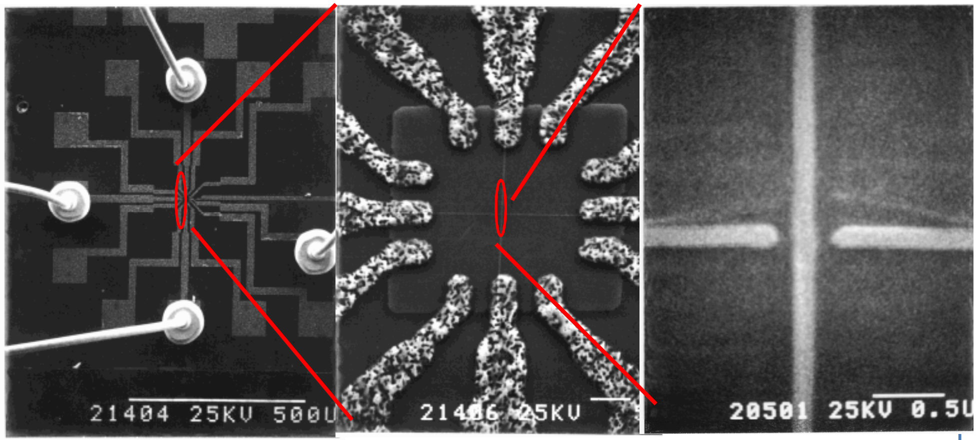
- Continue on with existing devices
- Extension of Moore's Law
- Existing infrastructure continues to support the industry

What is the Infrastructure?

- For Semiconductors – Lithography
  - Exposure tools (create images)
  - Mask (pattern for exposure tools)
  - Resist (Form images on wafer)
  - Metrology (measure/characterize images)
  - [each line above has a corresponding infrastructure]
- Mask Infrastructure Example
  - Pattern Generator
  - Mask Substrate Material
  - Inspection Tools
  - Repair Tools
    - Laser Repair
    - Focused Ion Beam (FIB) Repair
    - E-beam Repair



Quantum Dot Transistors



Issues:
- Primary designs require extremely low temperatures
- Possible room-temperature designs would require **10nm** features
- Material fabrication is not on silicon

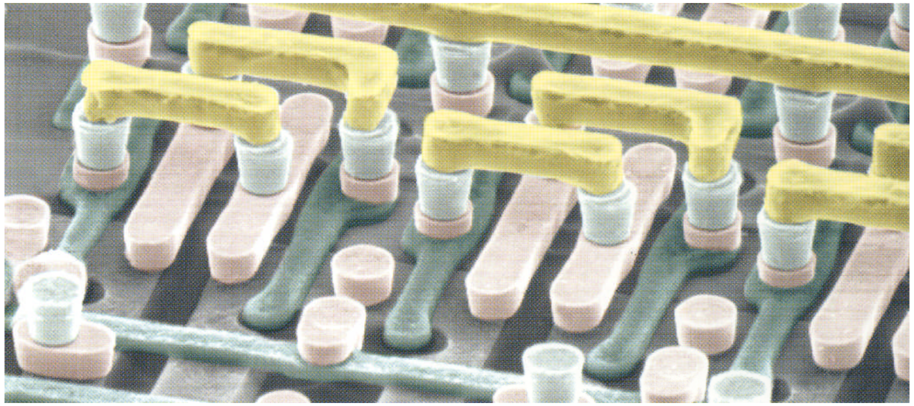
Potential Solutions:
- New material solutions
- Improved III-V compound semiconductors

Benefits:
- Reduce number of transistors per circuit function
- New opportunities for innovative designs
- Enhanced security

Gated quantum wire in GaAs/AlGaAs heterostructure 2DEG.

Prof. Gregory Spencer – Texas State University

Novel Memory



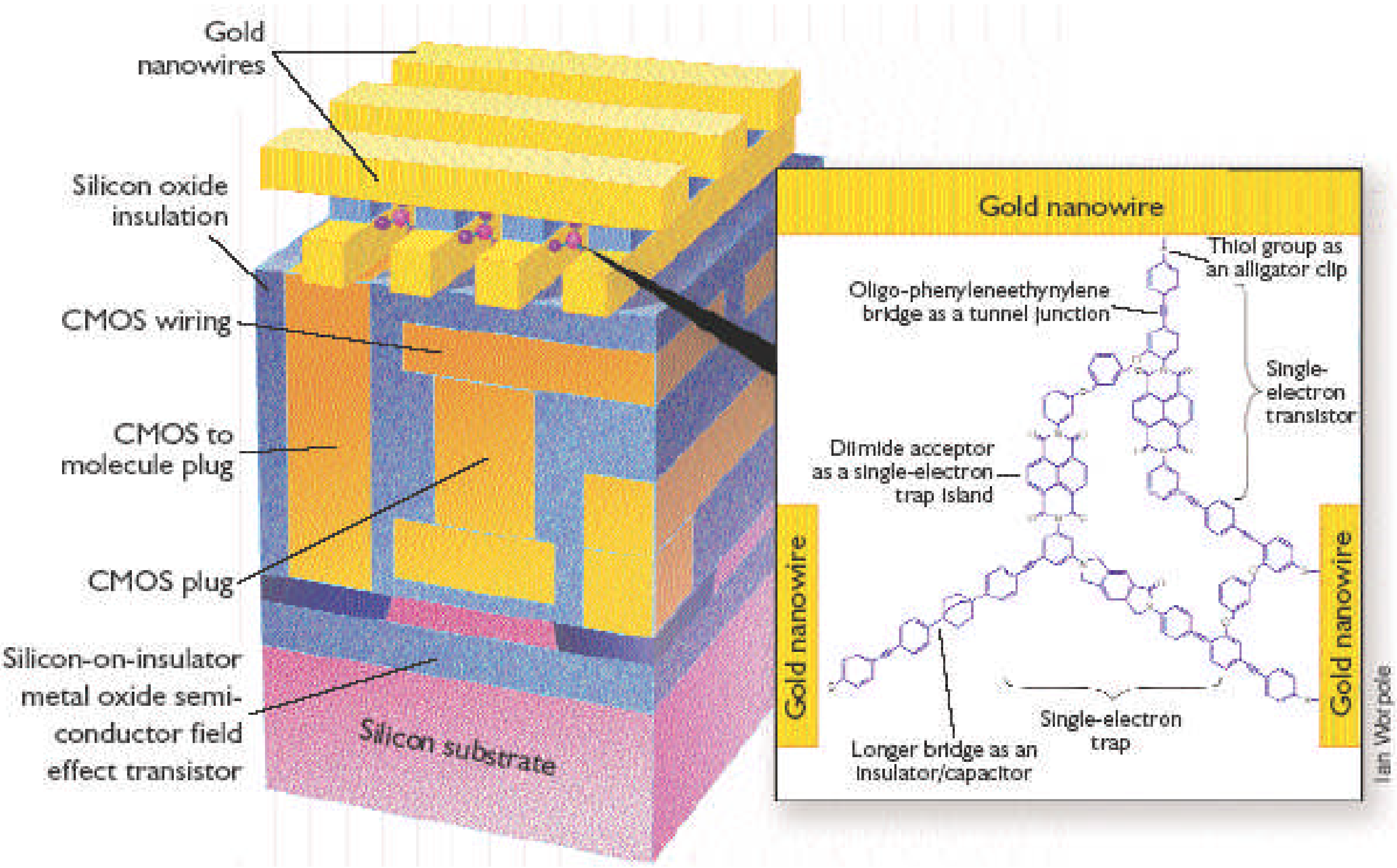
Issues:
- Existing memory density
- Spacings below **20nm**
- Interconnections
- Failure mechanisms
- Power requirements

Potential Solutions:
- Nanowire applications
- Innovative lithography below 32nm
- Self-assembly of interconnects
- Self-assembly of memory units
- Molecular storage

Benefits:
- Increased density of storage
- Dense solid state memory
- Improved switching times
- Faster computing with greater memory access

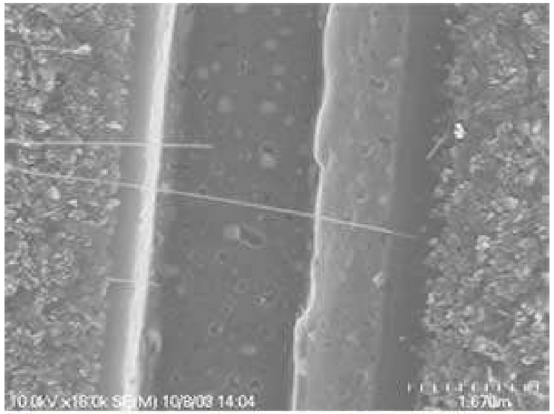
Picture courtesy of M. Meyyappan

Molecular Electronics



Konstantin Likharev, The Industrial Physicist, June/July 2003, p.20

Nanowires



Silicon nanowires are shown here growing horizontally over a "trench" on a silicon wafer. The silicon nanowires, which are about 17 nanometers in diameter -- about 3000 times smaller size than the size of a human hair -- are viewed with an electron microscope.

<u>Issues:</u>

- Research applications with dimensions below **<u>20nm</u>**
- Manufacturing processes rely on fabrication in "forms"
- Large scale, ordered fabrication is not available

<u>Potential Solutions</u>

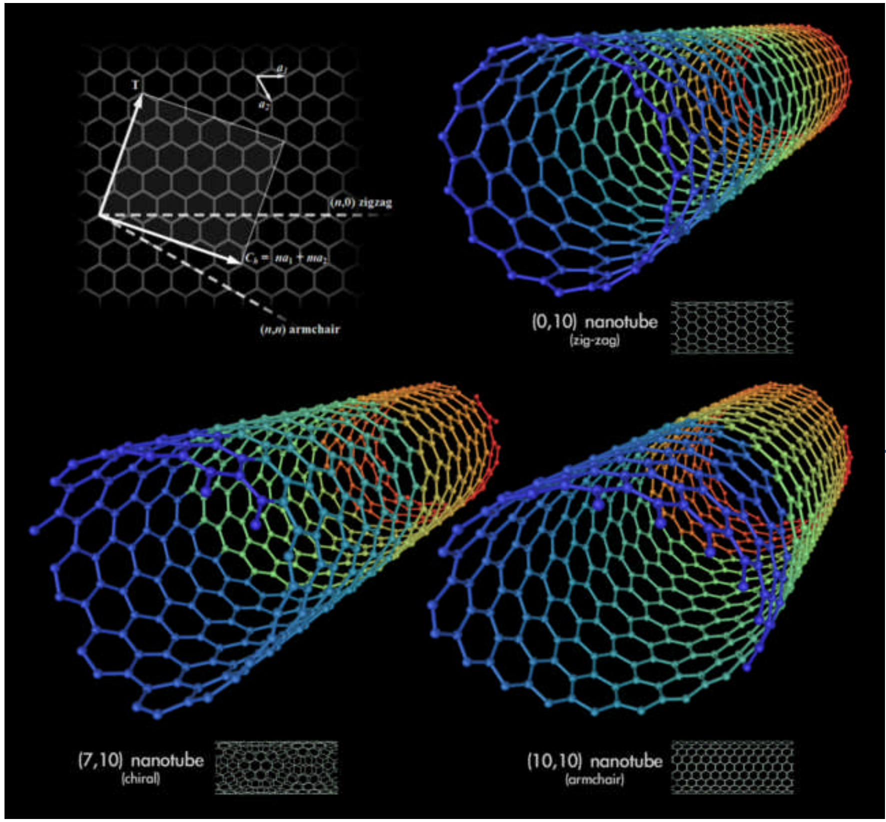
- Development of new processes based on ongoing research
- Additional efforts in related materials
- Improved processes/equipment

<u>Benefits:</u>

- Unique electrical and optical properties
- Building units for devices
- Wire diameter change results in band gap changes, which implies customizable effects

Ray Solanki, Oregon Science and Health University, Feb.23, 2004 issue Applied Physics Letter

Carbon Nano Tubes (CNT)



Issues:

- Production of Single Walled CNTs yield a mixture of types (dimensions to less than **1nm**)
  - Metallic
  - Semiconductive
- Separation of types is time consuming

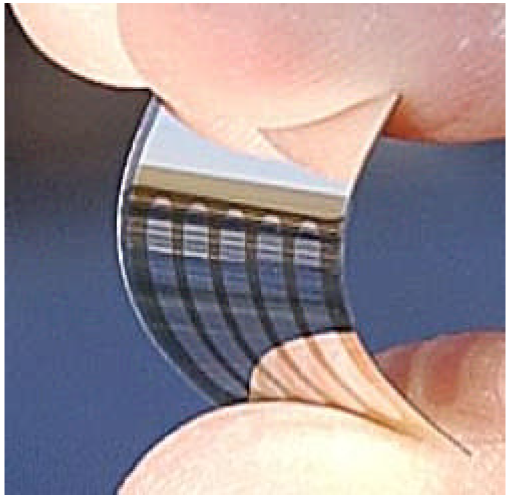
Benefits:

- Novel electronic devices
- High temperature applications
- Improved microscopy

Potential Solutions

- Continue development efforts

Solar Cells (Organic)



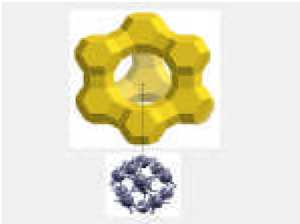
Issues:
- Efficiencies
- Material development
- Manufacturing processes

Potential Solutions
- Development of organic plastics with improved efficiency
- Development of adsorptive dyes
- Flexible conductors
- Enhanced property covering material

Benefits:
- Low cost energy
- Inexpensive to manufacture yielding to wide spread applications

Credit: Nicole Cappello and the Georgia Institute of Technology

New Material Properties



Issues:

- Unanticipated properties are being found in nano materials – **Example:**
  - **Thirteen atoms** of Silver have been shown theoretically to be magnetic
  - **Thirteen atoms** of Platinum have been experimentally shown to be magnetic

Potential Solutions:

- Quantify and classify the material properties in the range between bulk material properties and quantum phenomena
- Establish a program to employ theoretical projections to verify experimental data

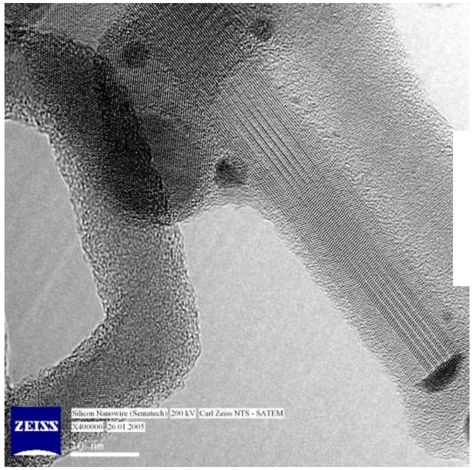
Benefits:

- Improve the time to develop nano based devices, due to eliminating the duplication of research efforts
- Creation of new products based on applying novel nano properties

Example: The creation of new memory devices that are 100x more dense than current technology

Silver properties reported May 30, 2006 in NanoTechWeb
Platinum experiments reported by University of Stuttgart

Metrology



Au dot structure
&
Nanowire Twinning

Issues:
- Imaging realm is at limits of resolution, in the **1nm** range
- Time per image is long >one hour
- Effective imaging applications require multiple images in minutes or less

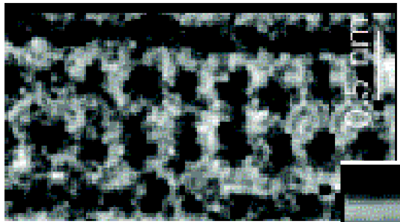
Potential Solutions:
- New solutions for metrology
- Enhancements to equipment
- New technologies

Benefits:
- Improved resolution of material properties
- Capability to employ in manufacturing processes
- If one can not measure something, it can not be manufactured

Aberration Corrected HR-TEM
Korgel Group Si Nanowire

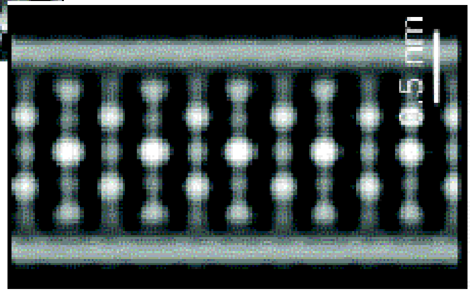
Metrology

Aberration Corrected TEM Imaging



Not corrected

Corrected



K & I in nanotube

Issues:
- Imaging is slow and computations are time consuming
- Unique structures can not be verified
- No validation results
- Dimensions extend to below **1nm**

Potential Solutions
- Development and execution of validation plan
- Improved algorithms
- Improved equipment for rapid imaging

Benefits:
- Improved understanding of materials
- Ability to identify unique nano structures
- Ability to create and verify novel materials

Sloan, et al., MRS Bulletin, April 2004

Research Challenges

Nano technology brings on new challenges

- **Existing tools for investigations at the atomic level are expensive to acquire and maintain**
- **New research tools need to be developed to explore the nano realm**
- **Specialized facilities are required to maintain the cleanliness need for nano technology**
- **A new infrastructure might be required for the equipment yet-to-be-developed**

Education Challenges

Nano technology requires education and training in multiple fields for successful collaboration

- Combinations of chemistry, physics, engineering, biology, computer science, and many related disciplines are needed to fully understand the development of nano technology
- The development of the nano technology industry will require well educated technicians
- Scientific education needs to begin early in the learning process

Summary

- The advance of electronics will rely on the incorporation of shrinking feature sizes
- The next few years will witness the impact of changing material properties
- Advances in electronics must incorporate these unique material properties
- New tools will need to be developed to provide the ability to truly understand the novel phenomena that exists in the mesomaterial[1] region

[1]Mesomaterial region – the region of properties between bulk and atomistic

TEXAS STATE UNIVERSITY
SAN MARCOS
The rising STAR of Texas

NanoTx'07

October 3rd, 2007

Background Material

Walt Trybula, Ph.D.

IEEE Fellow & SPIE Fellow

Director, NANOMATERIALS APPLICATION CENTER
at Texas State University-San Marcos, Texas

Director, The Trybula Foundation, Inc.

www.nanotxstate.org www.tryb.org

ABOUT TEXAS STATE

- Texas State University-San Marcos is a **premier**, student-centered public university offering baccalaureate, masters and doctoral degrees to students on a traditional **residential** campus.

- **Founded**: 1899 as SWT State Normal School

- **President**: Dr. Denise M. Trauth

- **Campus area**: 427 acres in main campus *(including 4,322 acres of farm, ranch & recreational areas)*

110 Undergraduate majors

(7 academic colleges)

84 Masters programs

6 PhD programs

EE Program (Fall '07)

MSE Ph.D. Program ('09)

- Total student enrollment (27,503)
- Undergraduate (23,022)
- Hispanic/ Latino (5,025) (21%)

- 1110 Faculty
- 93% teach on the undergraduate level.

http://www.txstate.edu

Fall 2007

NANOMATERIALS APPLICATION CENTER

MISSION: The **NANOMATERIALS APPLICATION CENTER at Texas State University-San Marcos** coordinates, facilitates, disseminates information, and expedites nanoscience and nanoengineering developments to expedite the commercialization of innovation.

GOAL: Accelerate the development of high technology and the dissemination of these developments in order to expedite commercialization.

NANO-SAFETY

The NANOMATERIALS APPLICATION CENTER is addressing four key areas for developing a NANO-SAFETY collaborative effort that identifies the nanomaterial properties, the effect on humans and the environment, the means of handling the materials correctly, and the procedures that must be in place to minimize risk in applications. Discussions have been initiated with numerous organizations in order to address this critical issue.

Contact Information

Walt Trybula, Ph.D.

IEEE Fellow & SPIE Fellow

w.trybula@ieee.org

Director

Nanomaterials Application Center

Texas State University-San Marcos

w.trybula@txstate.edu

+1.512.245.6062

Director

The Trybula Foundation, Inc.

w.trybula@tryb.org

+1.512.695.4026