NT05: Sixth International Conference on the
Science and Application of Nanotubes
Göteborg, Sweden
June 26 - July 1, 2005
http://nanotube.msu.edu/nt05/

CR Mildred Dresselhaus Friday, July 1

Concluding Remarks

Comment: pdf file of this talk can be loaded on the web site

- **Conference Overview**
- **What we learned at NT05**
- **Achievements and Trends**
- **Challenges & Future Work**

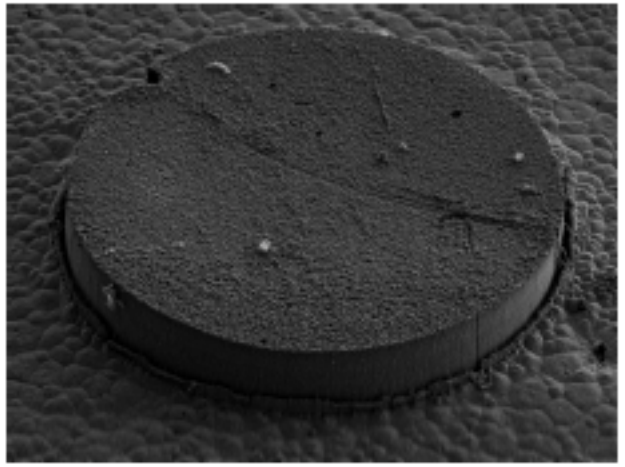
NT05 Conference Overview

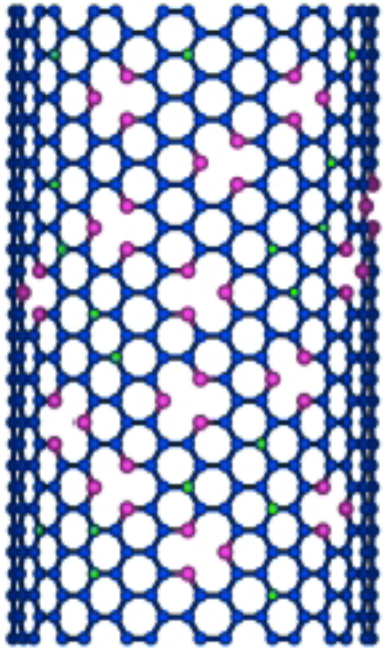
- *CVD Synthesis of Carbon Nanotubes* (81)
- Non-CVD Synthesis of Nanotubes (17)
- Formation and Characterization of Unusual Nanostructures (14)
- Raman Characterization of Nanotubes (12)
- Other Characterization of Nanotubes (18)
- Nanotube Dispersion and Purification (9)
- *Chemical Modification of Nanotubes* (29)
- Non-Carbon Nanotubes (12)
- *Nanotube-Based Composites* (26)
- Morphology and Application of Modified Nanotubes (13)
- Photo-Induced Reactions in Nanotubes (1)
- Thermal and Mechanical Properties of Nanotubes (16)
- Atomic Structure of Carbon Nanotubes (10)
- *Transport in Nanotubes* (37)
- Field Electron Emission (14)
- *Optical Properties and Optoelectronics* (24)
- Transport in Complex Nanostructures (4)
- Electron-Phonon Coupling in Complex Nanostructures (2)
- Nanotube-Based Transistors (10)
- Magneto-Transport and Magnetism (5)
- General Studies of Carbon Nanostructures (31)

(402 contributed abstracts received in total)

CVD and Non-CVD Techniques

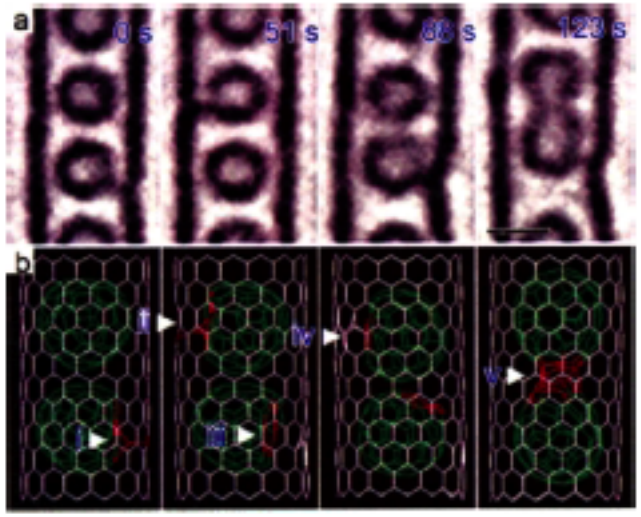
- CVD method is developing fast
  - **Bulk Production** and Scalable Process (companies developing).
  - **Alcohol** based CVD is powerful
  - **Continuous spinning** of Nanotube Fibers
  - **More active & controlled effort on DWNTs**
  - Starting Effort on **triple-walled NTs**
  - **Alignment** of nanotube arrays MWNTs (multi-layers)
  - **Supergrowth** Mechanism with H_2O (SWNTs)
  - **Doped Nanotubes**
- Plasma-enhanced CVD → Now making SWNTs
- No chirality Control yet!! But beginning!!
- More emphasis on **Small Diameter Tubes**
- Non-CVD (Arc, Magnetron Sputtering, Chemical, Laser, Ball-Milling)

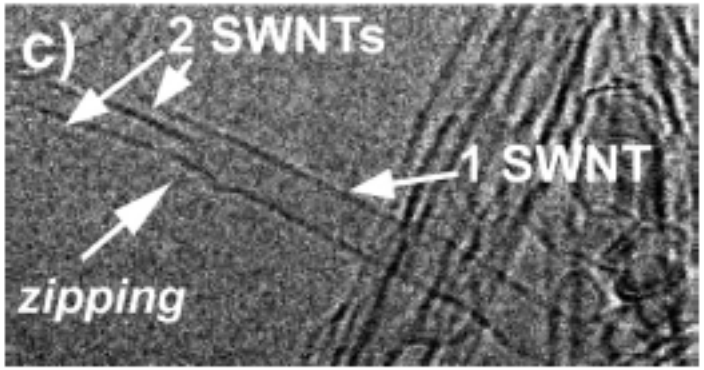




Characterization

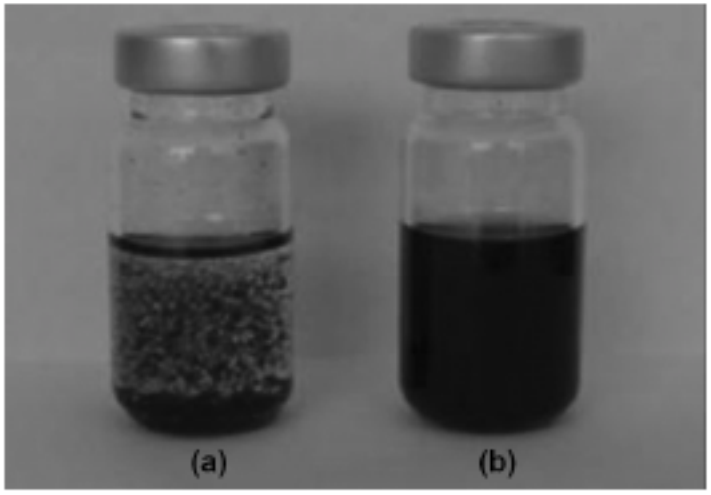
- HRTEM is improving (useful and powerful)
  - **Defects (individual atoms, vacancies)**
  - **Chirality (n,m) by imaging and ED**
  - **In-situ experiments (growth, kinetics)**
- Catalyst-NT Membranes under HRTEM →growth process
- MD simulations of NT growth
- Raman Spectroscopy
- STM and STS
- Photo-luminescence
- Magnetic Force Microscopy Developing Fast

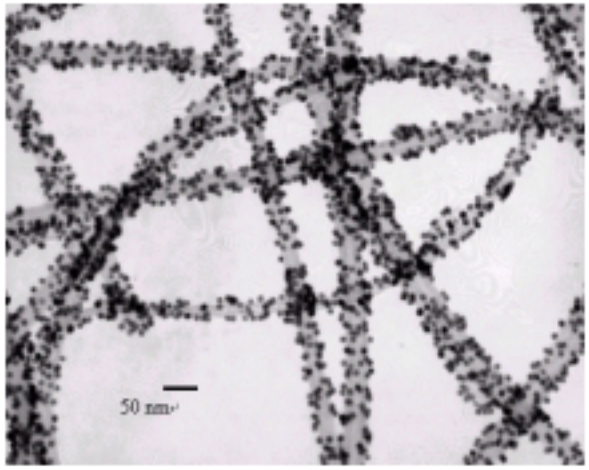




Chemistry of Nanotubes

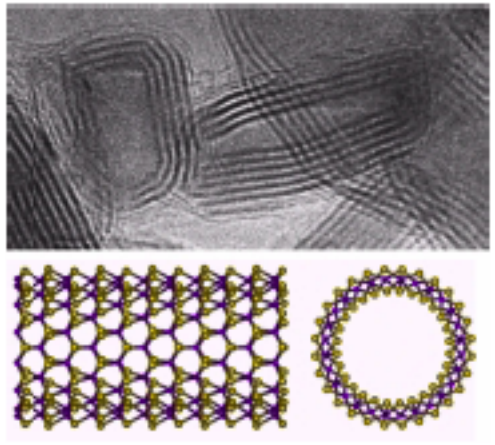
- Graphite and large diameter NTs are inert
- Introducing activity →Defects
- How to quantify and identify defects (Novel Electrochemical Methods)
- Functionalization & Dispersion Methods
- Separating, Cutting and positioning NTs.
- Doped Nanotubes
- Sensors and Biosensors
- Patterned growth of SWNTs on sapphire step surfaces
- DNA-wrapped tubes, Fluorination
- Removing amorphous carbon, and metal particles, adsorbates

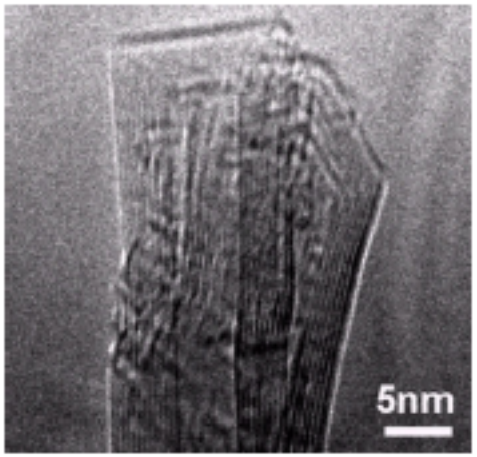




Non-Carbon Nanotubes, Nanowires & Related Materials

- BN, BCN Nanotubes
- Defects in BN tubes
- Nanotubes (layered Materials)
  - TiO_2, MoS_2, WS_2, CdS, etc.
- Need Calculations
- More Synthesis methods of layered nanotubes.
- More Property Measurements
- Nanowires of CdSe, ZnSe, ZnO, Si, BiSb, etc.
- *Future Trends: More Nano-Bio & Nano-graphite*





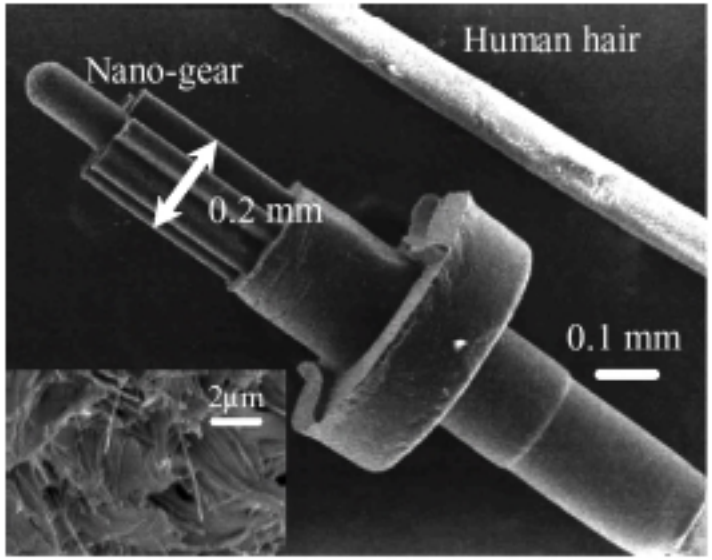
Composites and Modified Tubes

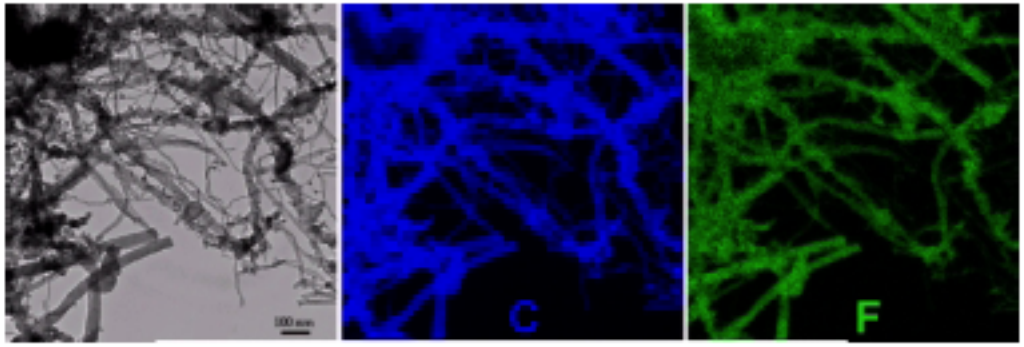
- Polymer Composites (we need standards)
- Conducting Polymers (transparent films)
- Electro-spinning of fibers
- In-situ polymerization from NT wall
- Novel Composites:

  Liquid Crystal,

  Ceramic-NT

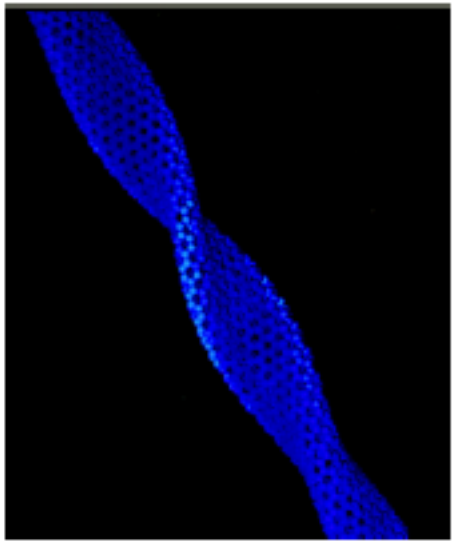
  Metal-NT

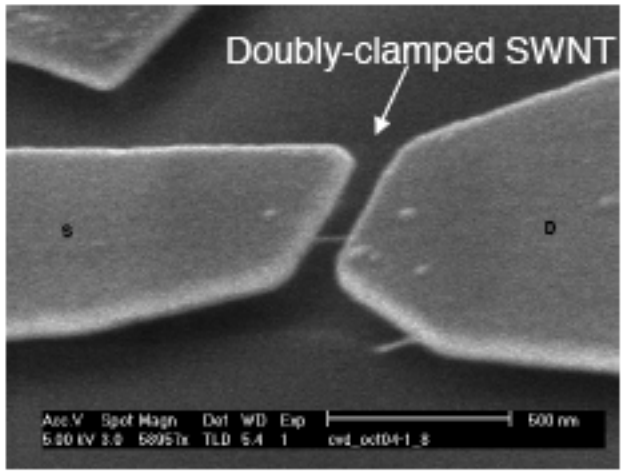




Mechanical and Structural Properties

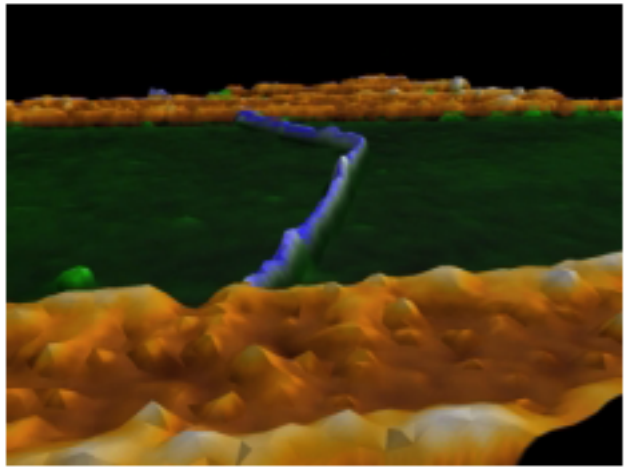
- Confinement effects of any filler within tubes (liquid, gas, solid)
- Current induced bends, repairing structural defects
- Generation & Disappearance of Stone-Wales type defects.
- Controlled point defects and their mobility
- Starting to do more NEMS with NTs
- Faceting MWNTs with Temperature
- Kohn Anomalies (Theory & Exp.)





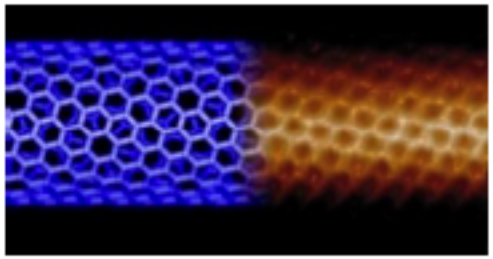
Transport in Nanotubes

- Devices from using long tubes provide better values for carrier scattering and mobility
- Firm evidence for phonon scattering effects in transport, and separation of acoustic and optical phonon contributions
- Measurements on suspended NTs (eliminate some extrinsic behaviors)
- Detailed understanding of SET and Kondo effects
- Combining Transport with Raman, etc
- Studies of Noise starting…
- *Still to come: Detailed understanding of Disorder & Defects in Transport*
- *Transport of DWNTs*



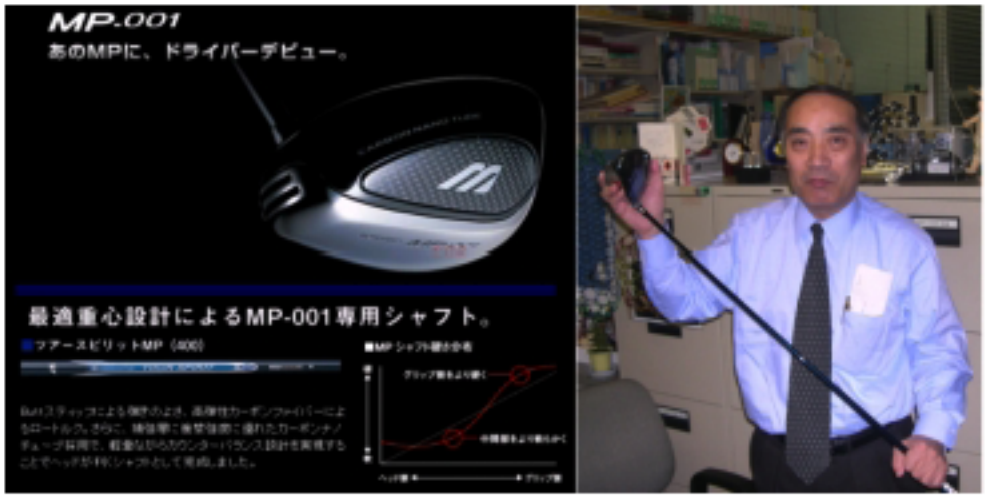
Photophysics

- Two-photon absorption experiments (Columbia & Berlin groups) demonstrated the need for excitons.
- Details of the exciton picture to describe the photophysics of SWNTs are emerging rapidly, including optically active and dark states.
- Correspondence principle between the usual Kataura plot and exciton model has been introduced.
- Femtosecond optics reveals lifetime of selected excited states, clarifying exciton picture.
- Coherent phonon generation in nanotubes has been demonstrated
- Rayleigh scattering for (n,m) determination



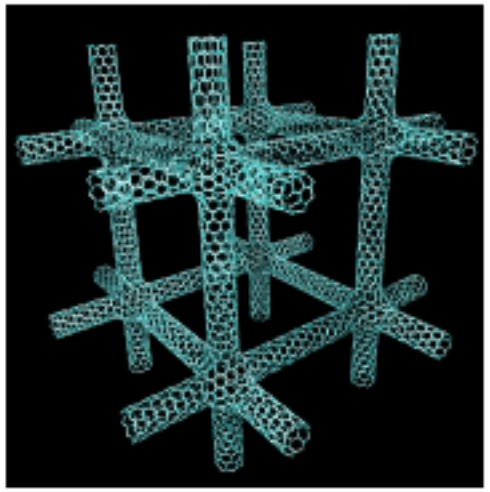
Applications

- Polymer Composites
  High Thermal Conducting Plastics
  Conducting Paints for automobiles
  Micro-gears
- Li-ion batteries & Lead acid batteries
- Field Emission Devices & Displays
- Nanotube-based Transistors
- Biological Applications
  Micro-catheters, protein immobilizers, Drug Delivery, Cancer treatment
- We need more COMMERCIAL APPLICATIONS



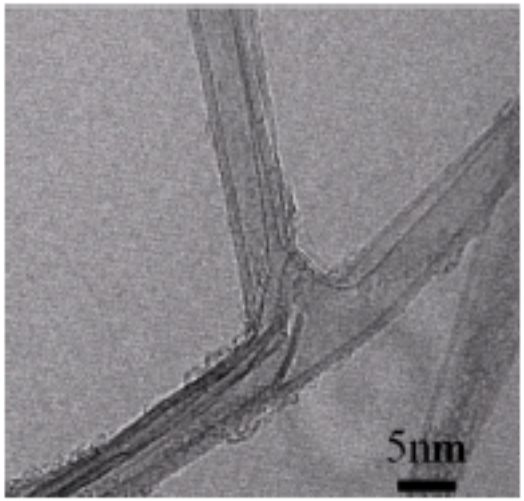
Overall Challenges

- **Standards**
  - On materials Characterization
  - How good are SWNTs, DWNTs, MWNTs?
    - Mean Diameter and distribution
    - Mean length and distribution
    - amorphous carbon content
    - Other materials content
    - Determine Metal/Semiconductor ratio
    - Determine (n.m) distribution
    - Identify Defect contents
    - Determine Functional groups
    - Estimate Doping
    - Bundles? Size of bundles?
  - How to BEST determine these parameters?
    - Combination of HRTEM, Raman, PL, TGA, SPM, etc.
  - Establish parameters for best qualities, set minimum standards for applications, what accuracy is needed?



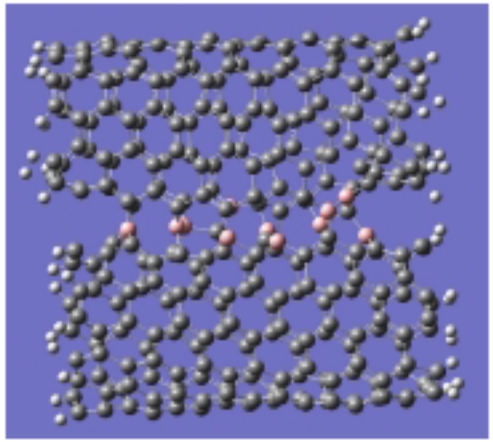
Overall Challenges

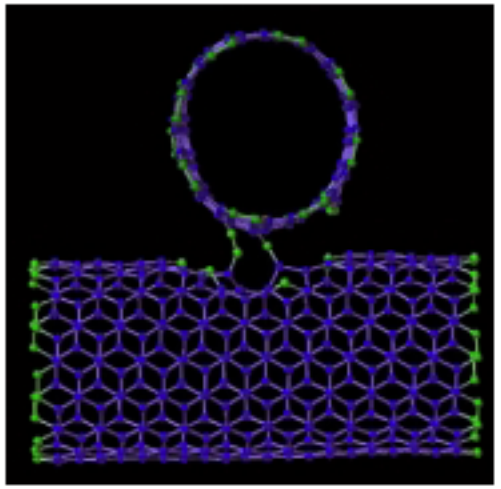
- **Health Effects**
  - Present status and knowledge
  - Best handling practices
  - Effects on skin, lungs, etc.
  - Carcinogenic effects?
  - What studies need to be done?
  - New special issue on Toxicity (Carbon Journal)



Theoretical Challenges

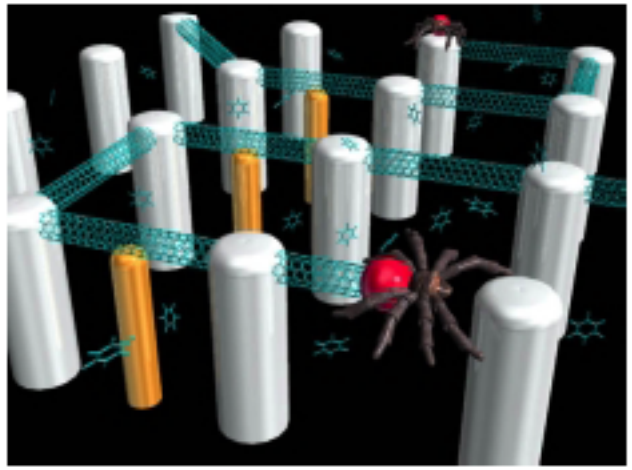
- Need accurate Calculations for NT growth (large scale in space and time)
- Theory on Chemistry of NTs
  - Effect of Functionalization on electronic & transport properties
  - Doping Effects
- Effect of Specific Defects on electronic properties & structural stability
- Electronic and Geometric Structure of DWNTs (treating incommensurability)
- Exciton Calculations for Photophysical Properties
- Predicting New Materials for Functionality & New Physics





We need to work on…

- **Real control of nanotube growth (catalyst dimensions and chirality selectivity)**
- **Improve Characterization** Techniques
- **In-situ experiments and at the individual NT level**
- **Easy NT manipulation**
- **Thermal Transport on individual NTs**
- **More experiments that are definitive of exciton phenomena including identification of dark states**
- **Applications**



Future NTxx Conferences

- NT06 in Japan
- NT07 in Brazil
- NT08 ??? – please post advert on Forum

Comment: GDR-I candidate for NT08 in a place to be decided