Outline

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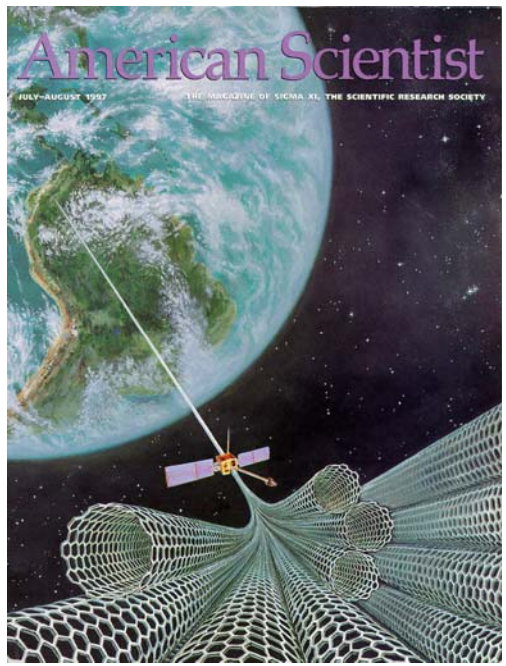
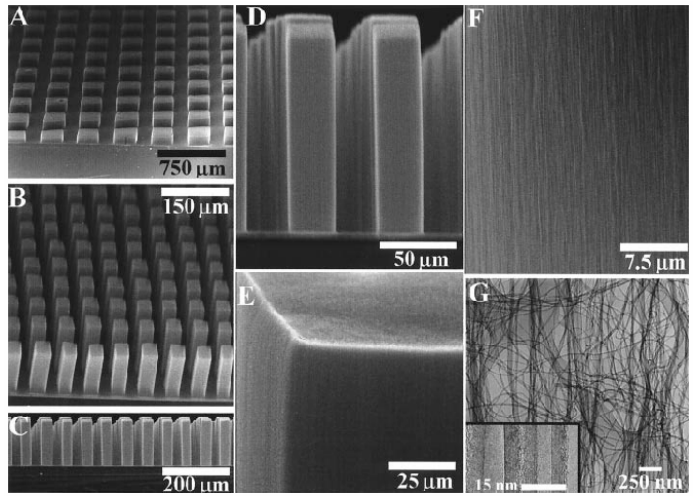
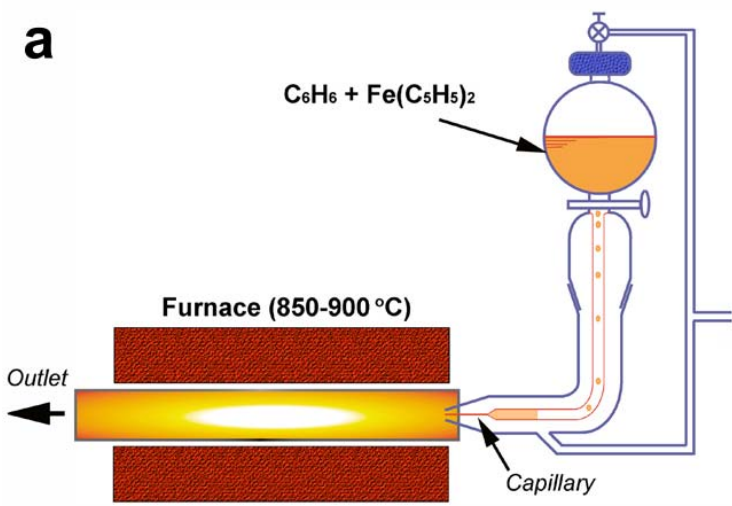
- **What we learned at NT06**
- **Achievements and Trends**
- **Challenges & Future Work**



Synthesis: CVD and Non-CVD Techniques

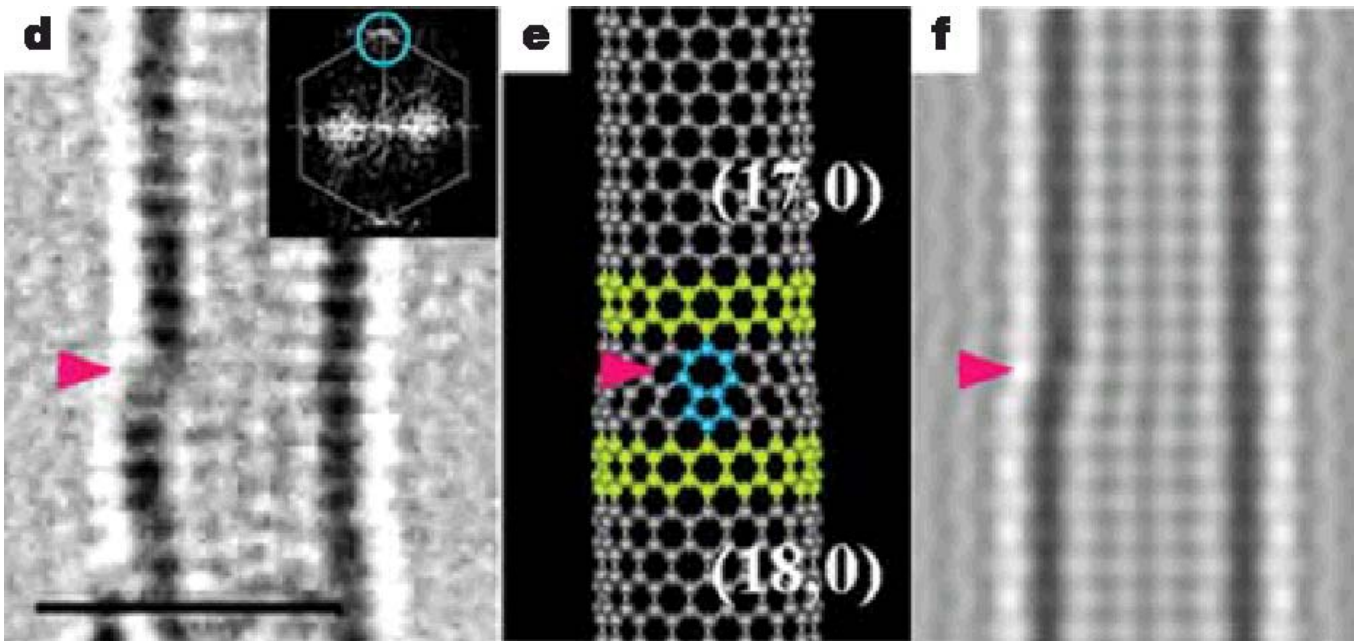
- **CVD method is still developing fast**
  - **Bulk Production** and Scalable Process (companies developing).
  - **Supergrowth has improved**
  - **Alcohol** based CVD becoming popular
  - **Continuous spinning** of Nanotube Fibers
- <u>Very few posters on Non-CVD</u> (Arc, Magnetron Sputtering, Chemical, Laser, Ball-Milling)
- Still need to control chirality (n,m), and understand growth mechanism





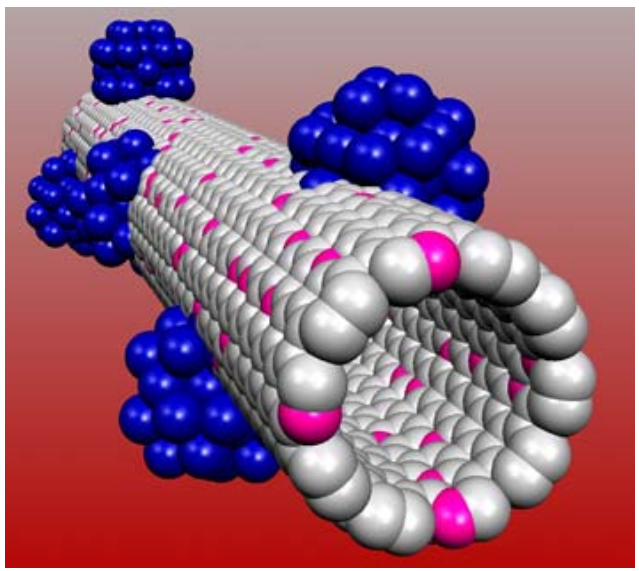
Characterization

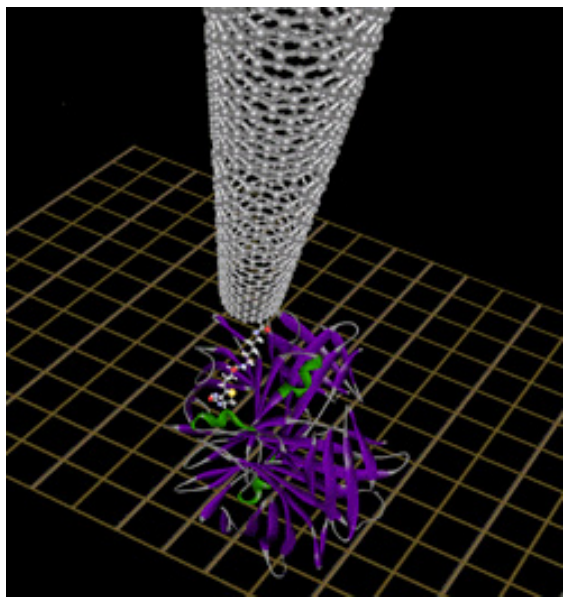
- HRTEM has improved (Aberration corrector now available; low voltages and HRTEM)
  - **Defects (individual atoms, vacancies)**
  - **Chirality (n,m) by imaging and Electron Diffraction**
  - **Need more in-situ experiments (growth, kinetics)**



Chemistry of Nanotubes

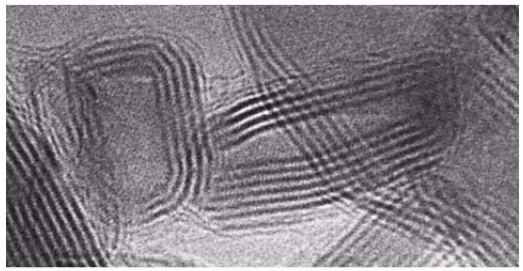
- More about Functionalization & Dispersion Methods
- More Applications' Oriented Papers
- Much More Bio Applications (Sensors and Biosensors)
- Doped Nanotubes
- Patterned growth of SWNTs on sapphire step surfaces
- Much more on DNA-wrapped tubes

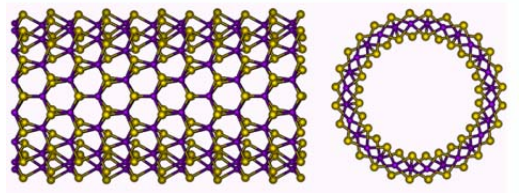




Non-Carbon Nanotubes, Nanowires & Related Materials

- Very few Papers on BN Nanotubes.
- A few works on MoS_2 and WS_2 tubes



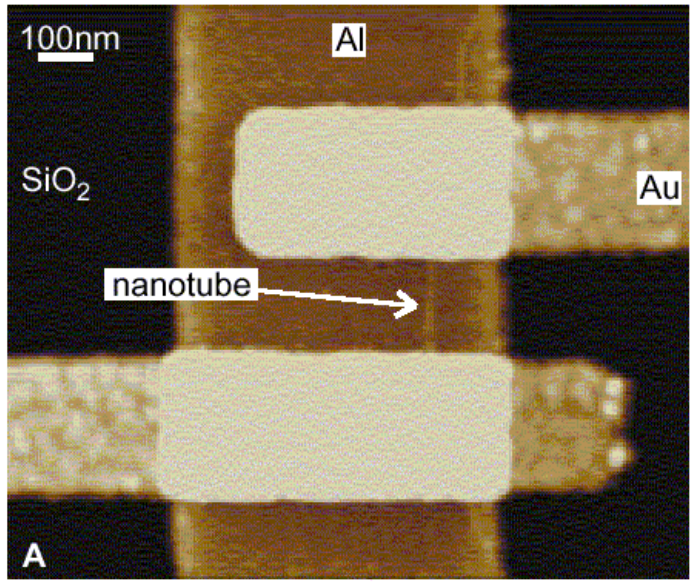


Composites and Modified Tubes

- Large number of contributions on Polymer Composites
- We still need to set standards for Nanotubes and applications. (Scientists Should be involved!)
- More papers on Transparent films.

Transport & Photophysics

- Transport is coming along well
- Ferromagnetic and Superconducting electrodes.
- Magneto Transport more developed (Spintronics of Nanotubes)
- Combining Transport with Raman, etc
- People looking at effects of defects in transport. More studies on defect control are needed.



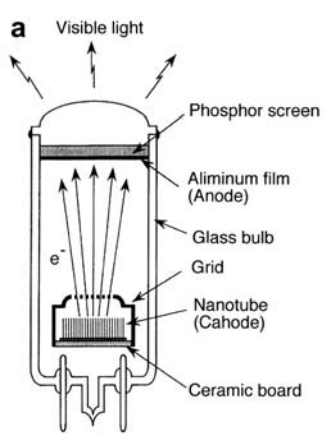
- Increased photoluminescence efficiency has been demonstrated (8%).

- Understanding of E_{11}^{S} excitonic states has advanced significantly (both experimentally and theoretically). Metallic exitonic states less understood

- New Techniques progressing well (NSOM, Rayleigh) but few groups are participating

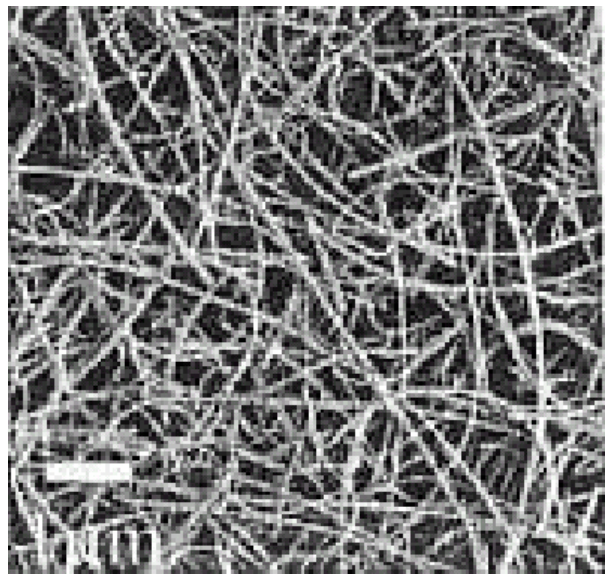
Applications

- Supercapacitors
- Polymer Composites
  High Thermal Conducting Plastics
  Transparent Conducting Films
  Li-ion batteries & Lead acid batteries
- Field Emission Devices & Displays
- Nanotube-based Transistors
- Biological Applications
  Micro-catheters, protein immobilizers, Drug Delivery, Cancer treatment, Sensors
- We still need more COMMERCIAL APPLICATIONS!
- Industry is getting more interested



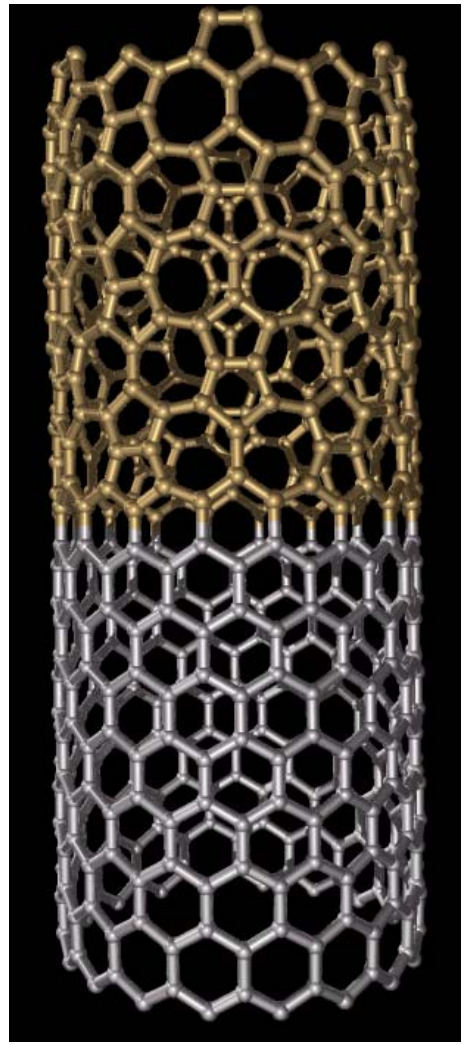
Overall Challenges

- **Standards**
  - On materials Characterization
  - Establish parameters for best samples, set minimum standards for applications, what accuracy is needed?
- **Health Effects**
  - Quantitative studies starting. More work is needed.
  - Effects on skin, lungs, etc.
  - Carcinogenic effects?



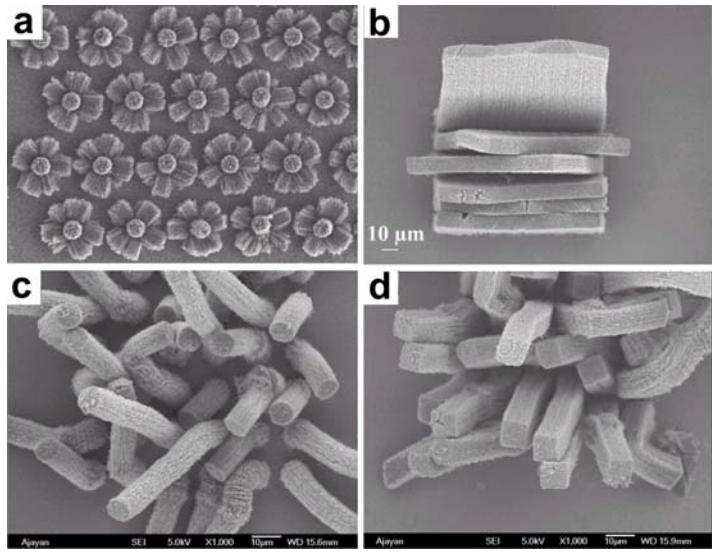
Theoretical Challenges

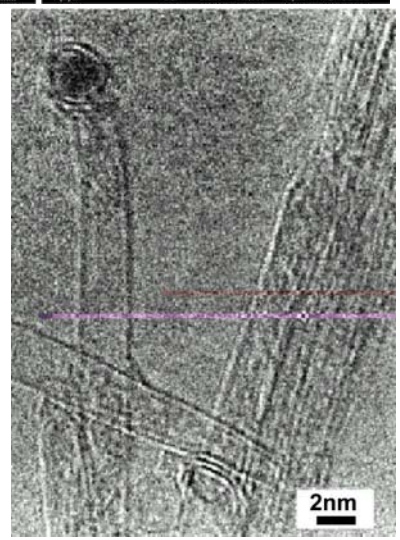
- Need more accurate Calculations for NT growth (large scale in space and time)
- Theory on Chemistry of NTs
  - Effect of Functionalization on electronic & transport properties
  - Different Doping Effects
- Quantum Transport and Spin transport in specifically functionalized nanotubes
- Assisting chemists in designing wet chemical synthesis of chirality controlled nanotubes
- Nanotube-based nanowires (Peapods and beyond, 1D magnets)
- Assist understanding nanotube-based room temperature superconductivity (wishful thinking!)



We need to work on…

- **<u>Real</u> control of nanotube growth (catalyst dimensions and chirality selectivity)**
- **Still need to Improve Characterization Techniques and develop New Ones**
- **In-situ experiments and**
  at the individual NT level
- **Thermal Transport on individual NTs**
- **Understand photoluminescence quantum yield and dark exciton states**
- **Nanotube Spintronics**
- **Graphene, Nanographite (unzipped Nanotubes) and C chains.**
- **Promote device concept innovation, and nanotube-based product development.**
- **Interaction of carbon nanotube research with related non-carbon nanotubes, nanowires and other nano-structures**





Future NTxx Conferences

- NT07 in Brazil (Ouro Preto)
- NT08 in France