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
- Very few posters on Non-CVD (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...

- Real 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