Overview of Poster Session D

Tony F. Heinz
Department of Physics
Columbia University
New York, NY  USA

tony.heinz@columbia.edu

http://heinz.phys.columbia.edu
My Concept of Overview

Short clear description of each poster and its relation to the others

NT Conference Charter (§4.3)
“2 minutes/2 viewgraph summary”
My Concept of Overview
Poster Session D: Topics Listed

- Raman Characterization of Nanotubes
- Other Characterization of Nanotubes
- Atomic Structure of Carbon Nanotubes
- General Studies of Carbon Nanostructures
- Non-Carbon Nanotubes

72 Posters – § 4.4 of NT Charter
Overview

- Non-Carbon Nanotubes (10)

- Characterization of Nanotubes
  - Raman (20)
  - Other Characterization (13)

- Defects in Carbon Nanotubes (11)

- General Studies of Carbon Nanostructures (17)
Non-Carbon Nanostructures: Nanotubes and Nanowires

**Nitrides**
- BN
- BCN

**Oxides**
- $\text{Al}_x\text{O}_y$
- ZnO
- $\text{SiO}_x$

Noncentrosymmetric:
- Piezoelectricity
- Linear EO effect
- Large band gap
BN and BCN Nanotubes

- D36 Nunes et al. (T)
- D38 Huang et al. (E)
- D39 Lourie (E)
- D40 Yap et al. (E)

E = Experiment
T = Theory

- Electronic structure and stability BCN nanostructures
- Chemical peeling, branching of BN nanotubes in DMSO
- Refractive properties of BN nanotubes in high E fields
- Low-temperature growth of BN nanotubes
D-40: Low Temperature Growth of Pure Boron Nitride Nanotubes at 600 °C (Yap et al.)

RF plasma-enhanced laser deposition process

- Phase-selective growth
- Impurity free
- Vertically aligned at desired locations

4.9 eV
Oxide Nanostructures

Electronic, optoelectronic prop., catalysis, ...

- D41 Yap et al. (E)
- D42 Seifert et al. (T)
- D44 Chang et al. (T)
- D45 Uchino et al. (E)

- Direct growth of ZnO nanotubes w/o catalysts
- Structure and properties of Al oxide based nanotubes
- Structure and properties of aluminate tubes and bundles
- Growth of SiO$_x$ on Ge nanodots
Novel Nanostructures

- D37 Kurita et al. (T)  
  Energetics of ordered ice in CNTs

*Unique environment*  
*to study water-water interactions*

- D68 Seifert et al. (T)  
  Properties of diamond-based nanowires by DFTB

Comparison of:  
Nanowires (*diamond sp*³ carbon, not layer forming)  
Nanotubes (*graphitic sp*² carbon, layer forming)
Characterization Posters

- Raman characterization
- Other characterization approaches
Raman Characterization of CNTs

- Non-contact method suitable for various environmental conditions
- Suitable for ensembles, but can work at single nanotube level

  *Complements fluorescence and Rayleigh (elastic) scattering*

- Provides information on phonon structure:
  - Nanotube diameter through radial breathing mode (RBM)
  - Defects through D mode
  - Metallic/semiconducting character through Raman lineshapes
  - Nanotube alignment through polarization dependence

- Provides information on electronic structure (Jorio talk earlier today):
  - Raman excitation spectroscopy (for both M/S nanotubes)
Raman Characterization of Carbon Nanostructures

- **Understanding features of Raman spectroscopy**
  - Vibrational frequencies and response to temperature, strain, …
  - Electron/phonon coupling and transition strengths
  - Electronic level structure (Raman excitation spectroscopy)

  *in various structures: SWCNT, DWCNT, graphene, nanographite, …*

- **Applications of Raman spectroscopy to diverse problems**
Raman Spectroscopy (I)

- D01 Sauvajol et al. (E)
  - Raman spectra of (n,m) identified individual SWCNTs
- D57 Poncharal et al. (E)
  - Study of individual (n,m) labelled SWCNT
- D06 Saito et al. (T)
  - Chirality, energy dependence of 1st and 2nd order res. Raman
  - (also oral paper)
- D08 Sato et al. (T)
  - Two-phonon Raman intensity of SWCNTs and graphite
- D09 Lin et al. (E)
  - Temperature-dep. Raman of suspended SWCNTs
- D10 Ferrari et al. (E)
  - The Raman fingerprint of graphene
  - (also oral paper)
- D11 Telg et al. (E)
  - First optical transition in CNTs: resonant Raman study
Raman Spectroscopy

• Combine Raman with HRTEM

D01 Sauvajol et al. (E) and D57 Poncharal et al. (E)
Raman Spectroscopy (II)

- D13 Araujo et al. (E)
- D16 Cardenas et al. (E)
- D17 Ferrari et al. (T)
- D59 Niwase (E)
- D61 Cacado et al. (E) (also oral)
- D04 Haroz et al. (E)

- Anomalous scaling and a new ratio problem in SWCNTs
- Dispersive Raman features of solubilised SWCNTs
- Non-adiabatic effects in Raman spectra of nanotubes
- Vacancy concentration & Raman intensity in graphite
- Raman spectroscopy in nanographite
- Real-time observation of lattice vibrations in SWCTs
Raman Spectroscopy

- New approach to Raman spectroscopy with impulsive excitation by fs laser

D04 Haroz et al.
Raman Applications

- D02 Miyazawa et al. (E)
  - Raman analysis of fullerene nanotubes and nanowiskers
- D03 Kawamoto et al. (E)
  - Relative humidity sensitivity of DNA-SWCNT hybrids
- D05 Uchida et al. (E)
  - Raman study of laser-induced defects in SWCNTs
- D07 Kobayashi et al. (E)
  - Environmental eff. In PL/Raman from suspended SWCNTs
- D12 J. Kim et al. (E)
  - Raman study of poly(3-methylthiophene) nanotubes
- D14 Y. Kim et al. (E)
  - Raman study of Li insertion into DWCNT Bucky paper
- D15 Seong et al. (E)
  - Raman of SWCNTs on patterned substrates
Characterization

• √ Raman characterization

• Other characterization approaches
  STM
  HRTEM
  XPS/UPS
  EELS
  RF/microwave
  Fluorescent marker

[Also important, but not featured in these posters: IR, UV-vis, photoluminescence, …]
Other Characterization: HRTEM

Advances in real space and diffractive imaging of nanotubes and metallic inclusions. Oral presentations by Nakayama, Suenaga

- D19  Jiang et al. (T)  • Advances in analysis of TEM diffraction data for SWCNT
- D20  Jiang et al. (T)  • Robust Bessel-function method for (n,m) determination
- D21 Houlle et al. (E)  • 3D TEM observation of metallic nanoparticles in CNTs
- D33 Hirahara et al. (E)  • Direct observation of six-membered rings by HRTEM
- D46 Higashi et al. (E)  • In-situ monitoring of Fe nanoparticles in a-c walls
Other Characterization: STM

Real-space analysis of structure with electronic spectroscopy by STS at single tube level

- D24 Clair et al. (E) Low-T STM of SWCNTs on metal surfaces
- D48 Fukui et al. (E) Direct observation of superstructure of DWCNTs by STM

Electronic interactions:
- Nanotube substrate
- Nanotube/nanotube
Other Characterization: RF/Microwave

*High-frequency response*

*Non-contact electrical measurements*

- D18 Zhao et al. (E)
- D71 Eriksson et al. (E)

- Complex permittivity of MWNTs filled with metallic Ag
- High-frequency properties of CNTS NEMS
Opportunities in Characterization

(1) *Extensive combination of different methodologies*

- D34 Arepalli et al. (E) (given as oral)
- Carbon nanotube material quality assessment

(2) *Combination of different characterization tools at single nanotube level*

Example: Raman / HRTEM (D01 and D57)

Single nanotube optics, HRTEM, STM with thermal transport / electrical transport / mechanical properties …
What’s missing?

*Improved probes of nanotube surface chemistry and structure, particularly at fractional monolayer coverages*

- Nanotube doping
- Nanotube electrical contacts
- Nanotube light emission
- Nanotube functionalization
- In-situ growth analysis and control
  ...
Other Characterization: Surface Chemistry, Composition

**XPS/UPS:**

- D22 Pichler at al. (E) • Properties of functionalized SWCNTs (also by EELS, etc.)
- D29 Tokura al. (E) • XPS study of vertically aligned CNT films

**Adsorbing Fluorescent Markers:**

- D66 Nishikiori at al. (E) • Characterization of surface structure of acid-treated nanofibers by fluorescent probe

*Other approaches exist, but this remains a critical area for future technique development*
Important Characterization/Analysis Theme in Posters: Atomic Defects in SWCNTs

**Tools:** Primarily electron microscopy
(sometimes with micromanipulation)
Theory/modeling

Excellent example of:
Analysis below the level of nanotube chirality
Importance of experiment/theory interaction for full understanding

[Invited papers by Y. Nakayama, K. Suenaga]
Atomic Defects in Nanotubes

**Issues:**
- Formation of defects
- Modification: separation, diffusion, ...
- Annealing behavior

**Properties:**
- Relative stabilities, pathways, barrier heights

Kotakoski et al. (D49)
Defects in Nanotubes (I)

- D49 Kotakoski et al. (T) • Kinetics of defects on CNT walls studied by Monte Carlo
- D50 Kawai et al. (T) • Diffusion barrier for mono-vacancy on CNT
- D51 Okada et al. (T) • Energetics & electronic struct. of line defects in CNTs
- D52 Berber et al. (T) • Atomic and electronic structure of divancies
- D53 Mori et al. (T) • Energetics of plastic bending of carbon nanotubes
- D54 Tien et al. (T) • Orientation dependence of vacancies in defective CNTs

*Modified electronic/magnetic properties from vacancies*
Defects in Nanotubes (II)

- D56 Bichara et al. (T)
- D58 Niwase et al. (T)
- D64 Choi et al. (T)
- D65 Krasheninnikov et al. (T)
- D72 Jeong et al. (T)

- Zeolite-grown SWCNTs are highly defective
- Defect engineering of graphene: radiation damage
- Stone-Wales barrier reduction in metallofullerenes
- Intrinsic and radiation-induced defects in CNTs
- Defect-derived localized states in semiconducting SWCNTs
Perspective: Defect Engineering

+ Defects can destroy desired properties of ideal crystals

+ Defects can also enhance properties of ideal crystals

- Modify and control electronic properties: Doping

- Modify and control mechanical properties:
  Hardening
  Nanostructure control (e.g., nanocoils)
General Carbon Nanotube Studies

- Synthesis and Post-Synthesis Processing
- CNT Interactions with their Environment
- Biological Applications and Safety
Synthesis and Post-Synthesis Processing

- D25 Song et al. (E)
- D47 Irle et al. (T)
- D55 Hassanien et al. (E)
- D62 Krash et al. (E)
- D67 Okaziki et al. (E)
- D69 Jeong et al. (E)
- D70 Ota et al. (E)

- Selective removal of metallic SWCNTs by microwave rad.
- DFTB method for calculations of growth, reaction, properties
- Selective etching of metallic SWCNTs with H plasma
- Fabrication of products containing metallic SWCNTs
- MWCNTs, graphitic- and C$_3$N$_4$- particles by dc arc discharge
- Alignment of carbon nanocoils by dielectrophoresis
- Preparation of twisted carbon nanotubes

Selection for S/M SWNCTs
Interactions of CNTs with their Environment

*SWCNTs strong interactions with their environment, modifying their electronic, phononic, and physical structure*

- D26 Lien et al. (T)
- D27 Petrov et al. (E)
- D28 Muramatsu et al. (E)
- D32 Krash et al. (T)
- D63 Jeong et al. (E)

- Electronic properties of a pair of narrow-gap SWCNTs
- Water-induced effects on electronic prop. of SWCNTs
- Pore structure and oxidation stability of DWCNTs
- Effects of external electric fields on finite SWCNTs
- Atomic and electronic structure of SWCNTs on Si(100) stepped surfaces
Biological Applications and Human Safety

Very significant emerging field (good and bad!) that is not highly represented at NT 06 – but to which we can definitely contribute

- D23 Haniu et al. (E)
  - Effect of subcutaneous implantation of CNTs in mice

- D30 Takeuchi et al. (E)
  - NaCl-catalyzed oxidation of MWCNTs

- D31 Grausova et al. (E)
  - CNTs a future material for bone tissue engineering

- D35 Hwang et al. (E)
  - Using magnetic carbon nanocapsules as support in synthesizing Cisplatin (anticancer drug)