Overview of Poster Session D

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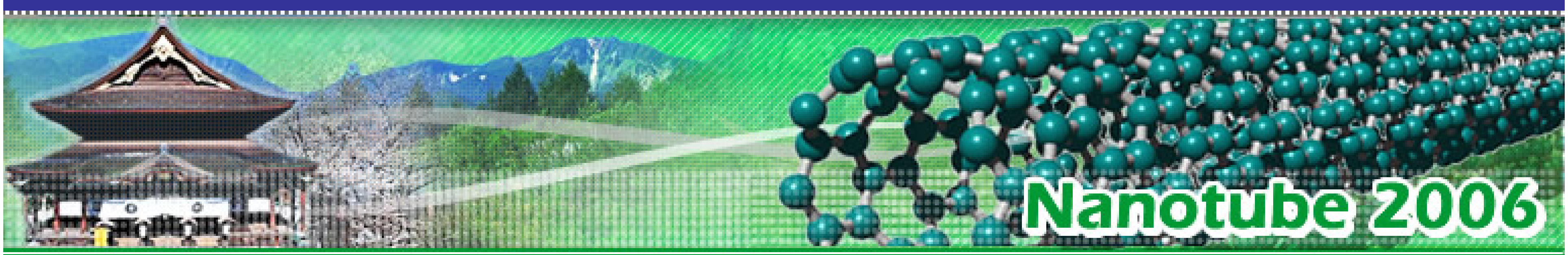


My Concept of Overview

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

NT Conference Charter (§4.3)
"2 minutes/2 viewgraph summary"

NT06

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

Al_xO_y
ZnO
SiO_x

Noncentrosymmetric:
- Piezoelectricity
- Linear EO effect

Large band gap

BN and BCN Nanotubes

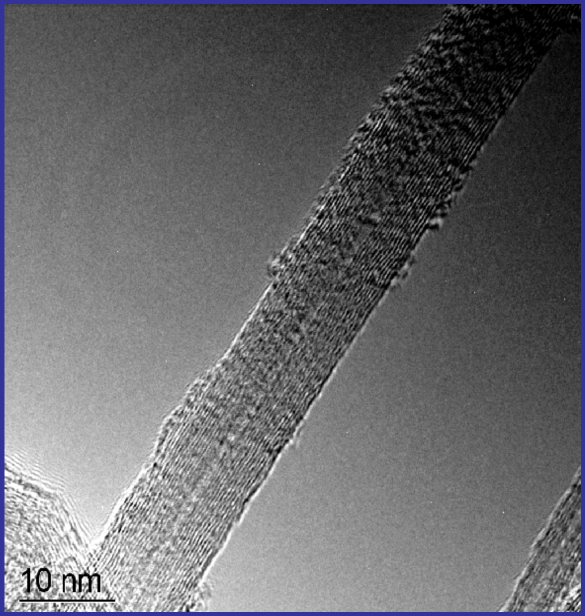
- D36 Nunes et al. (T)
- D38 Huang et al. (E)
- D39 Lourie (E)
- D40 Yap et al. (E)

- 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

E = Experiment

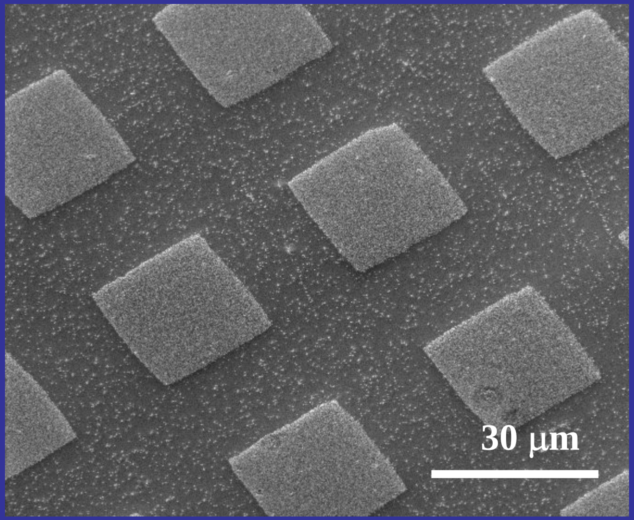
T = Theory

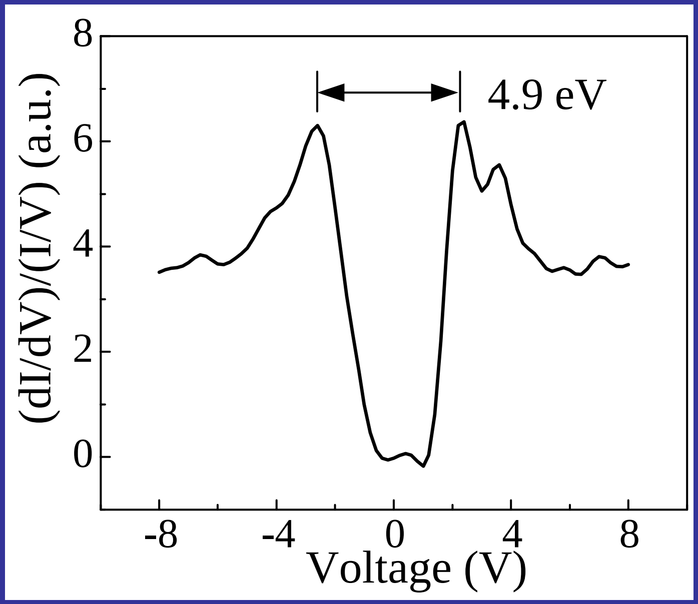
D-40: Low Temperature Growth of Pure Boron Nitride Nanotubes at 600 ℃ (Yap et al.)



RF plasma-enhanced laser deposition process

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





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**

<u>Comparison of:</u>

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

- <u>Provides information on phonon structure:</u>

  - Nanotube diameter through radial breathing mode (RBM)
  - Defects through D mode
  - Metallic/semiconducting character through Raman lineshapes
  - Nanotube alignment through polarization dependence

- <u>Provides information on electronic structure (Jorio talk earlier today):</u>

  - Raman excitation spectroscopy (for both M/S nanotubes)

Raman Characterization of Carbon Nanostructures

- <u>Understanding features of Raman spectroscopy</u>

  - 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, …

- <u>Applications of Raman spectroscopy to diverse problems</u>

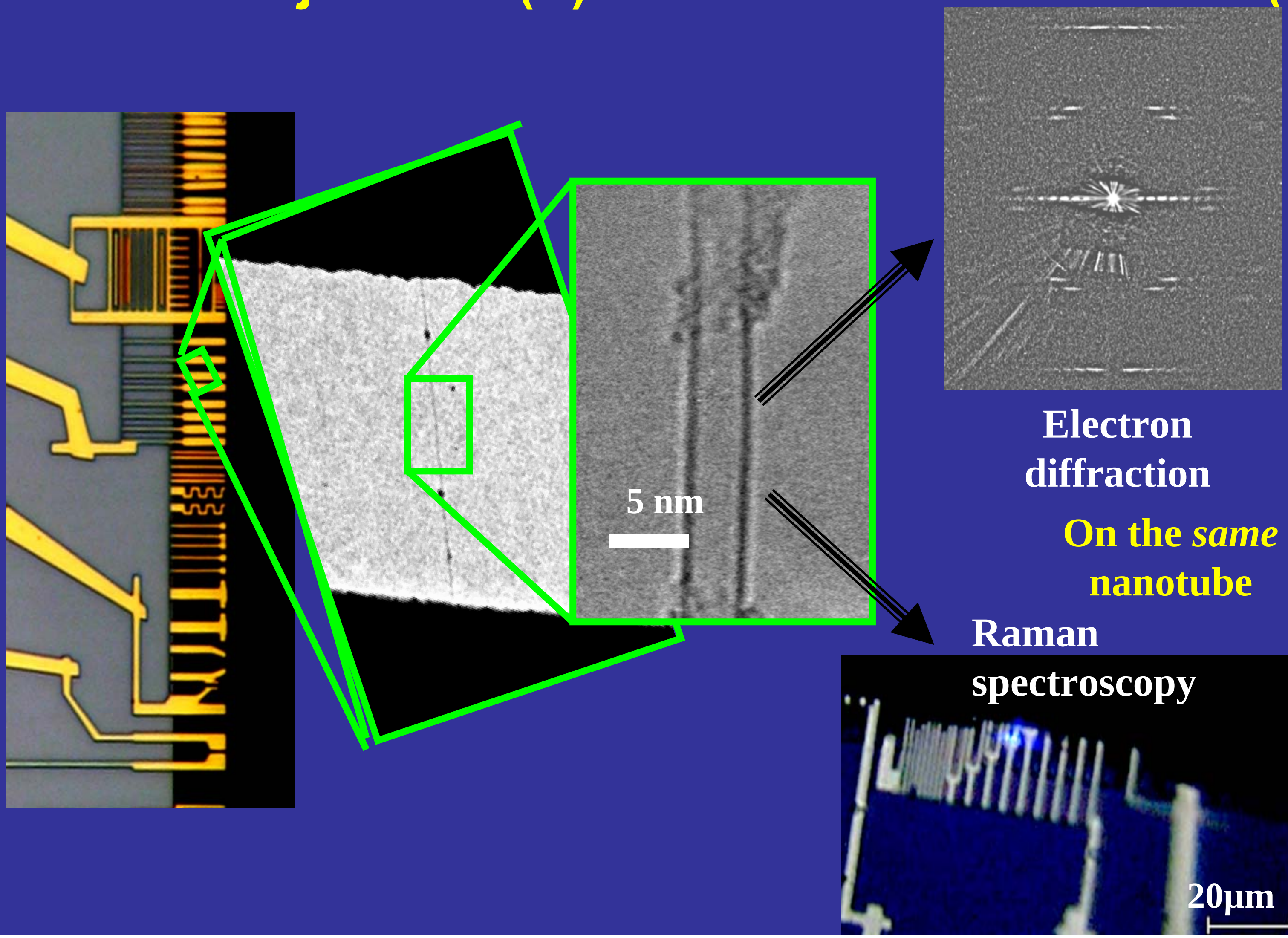
Raman Spectroscopy (I)

- 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) (also oral paper) — • Chirality, energy dependence of 1st and 2nd order res. Raman
- 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) (also oral paper) — • The Raman fingerprint of graphene
- 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)



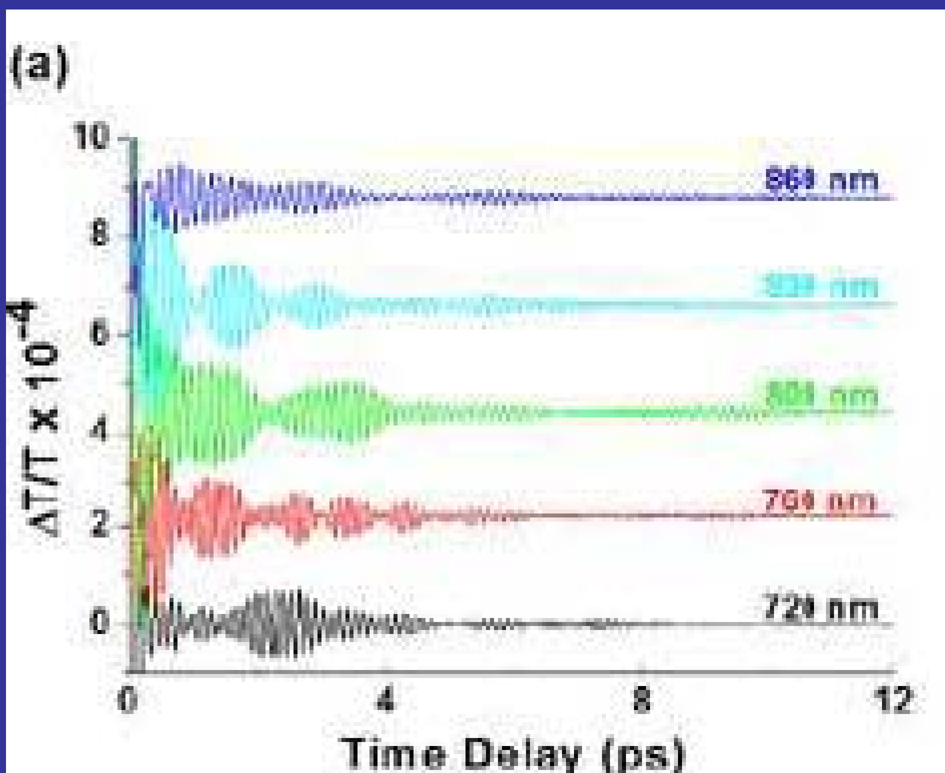
Raman Spectroscopy (II)

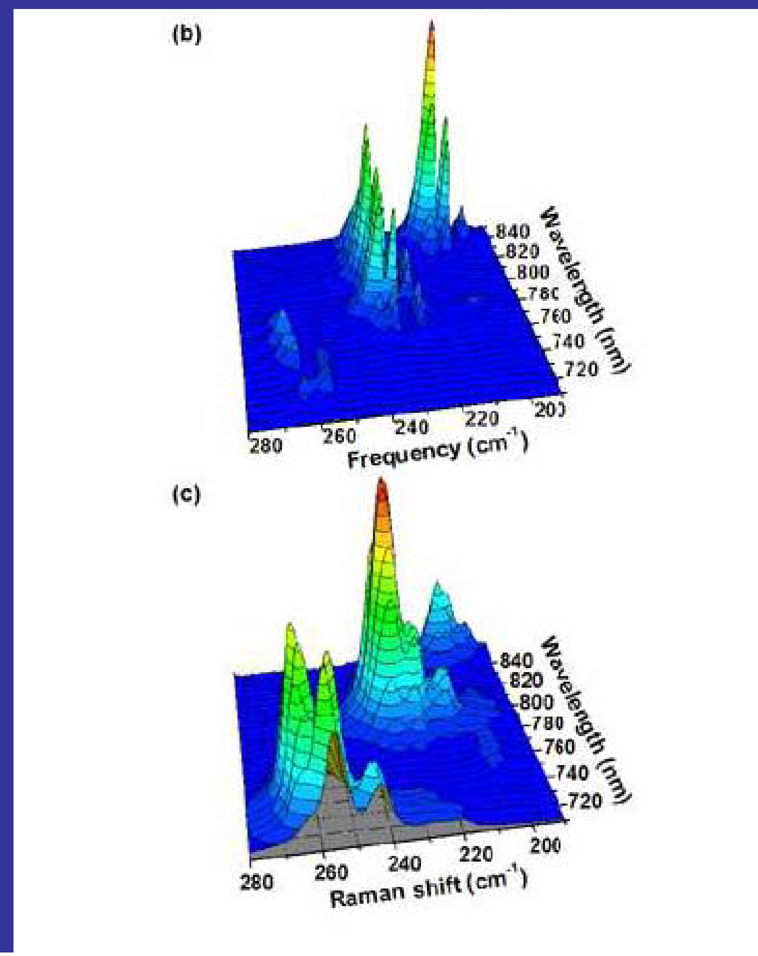
- **D13 Araujo et al. (E)** — Anomalous scaling and a new ratio problem in SWCNTs
- **D16 Cardenas et al. (E)** — Dispersive Raman features of solubilised SWCNTs
- **D17 Ferrari et al. (T)** — Non-adiabatic effects in Raman spectra of nanotubes
- **D59 Niwase (E)** — Vacancy concentration & Raman intensity in graphite
- **D61 Cacado et al. (E)** (also oral) — Raman spectroscopy in nanographite
- **D04 Haroz et al. (E)** — 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 nanopartices 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 super-structure 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)** — **• Complex permittivity of MWNTs filled with metallic Ag**
- **D71 Eriksson et al. (E)** — **• 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***

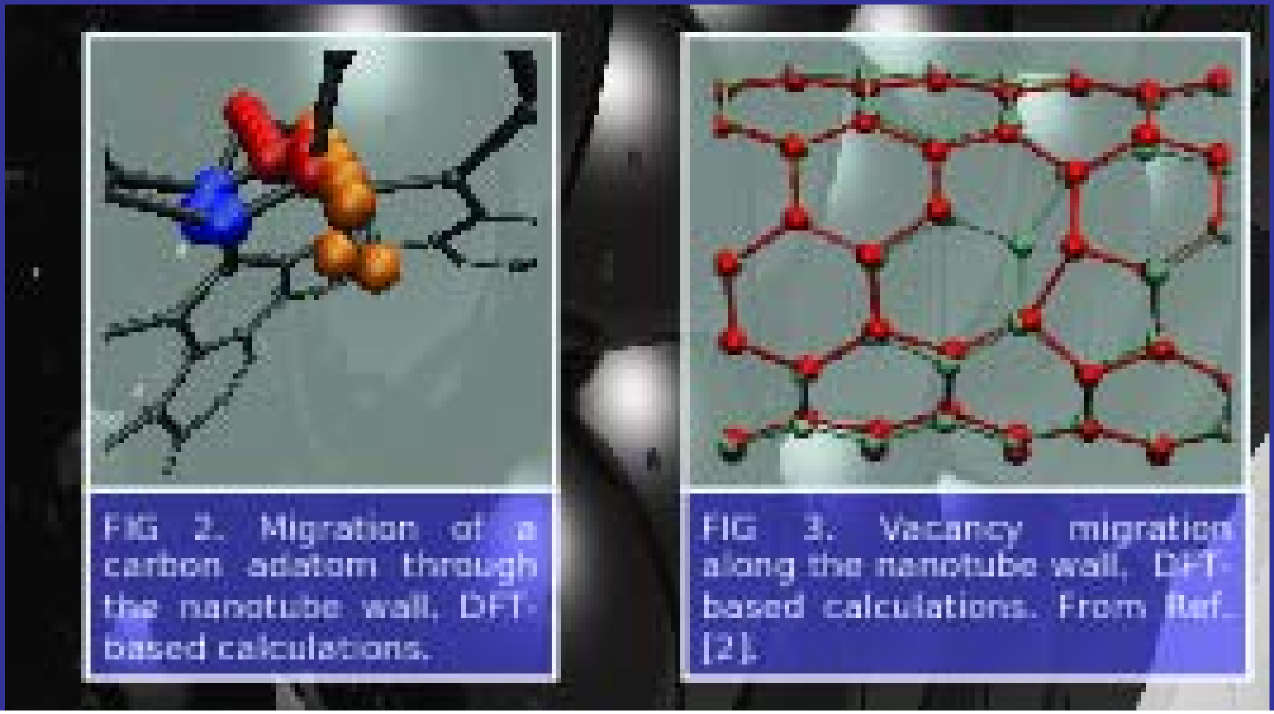


FIG 2. Migration of a carbon adatom through the nanotube wall. DFT-based calculations.

FIG 3. Vacancy migration along the nanotube wall. DFT-based calculations. From Ref. [2].

Kotakoski et al. (D49)

Defects in Nanotubes (I)

- D49 Kotakoski et al. (T)
- D50 Kawai et al. (T)
- D51 Okada et al. (T)
- D52 Berber et al. (T)
- D53 Mori et al. (T)
- D54 Tien et al. (T)

- Kinetics of defects on CNT walls studied by Monte Carlo
- Diffusion barrier for mono-vacancy on CNT
- Energetics & electronic struct. of line defects in CNTs
- Atomic and electronic structure of divancies
- Energetics of plastic bending of carbon nanotubes
- Orientation dependence of vacancies in defective CNTs

Modified electronic/magnetic properties from vacancies

Defects in Nanotubes (II)

- D56 Bichara et al. (T) — Zeolite-grown SWCNTs are highly defective
- D58 Niwase et al. (T) — Defect engineering of graphene: radiation damage
- D64 Choi et al. (T) — Stone-Wales barrier reduction in metallofullerenes
- D65 Krasheninnikov et al. (T) — Intrinsic and radiation-induced defects in CNTs
- D72 Jeong et al. (T) — 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) — • Selective removal of metallic SWCNTs by microwave rad.
- D47 Irle et al. (T) — • DFTB method for calculations of growth, reaction, properties
- D55 Hassanien et al. (E) — • Selective etching of metallic SWCNTs with H plasma
- D62 Krash et al. (E) — • Fabrication of products containing metallic SWCNTs
- D67 Okaziki et al. (E) — • MWCNTs, graphitic- and C_3N_4-particles by dc arc discharge
- D69 Jeong et al. (E) — • Alignment of carbon nanocoils by dielectrophoresis
- D70 Ota et al. (E) — • Preparation of twisted carbon nanotubes

Selection for S/M SWNCTs

Interactions of CNTs with their Environment

SWCTNs 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 representated at NT 06 – but to which we can definitely contribute

- **D23 Haniu et al. (E)**
- **D30 Takeuchi et al. (E)**
- **D31 Grausova et al. (E)**
- **D35 Hwang et al. (E)**

- **Effect of subcutaneous implantation of CNTs in mice**
- **NaCl-catalyzed oxidation of MWCNTs**
- **CNTs a future material for bone tissue engineering**
- **Using magnetic carbon nanocapsules as support in synthesizing Cisplatin (anticancer drug)**