

# Anisotropic Optical Absorption Properties of Single-Walled Carbon Nanotubes

Y. Murakami, E. Einarsson, T. Edamura, S. Maruyama

Department of Mechanical Engineering, The University of Tokyo

7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan

Anisotropic optical absorption properties of single-walled carbon nanotubes (SWNTs) are determined from the measurements of a recently developed vertically aligned SWNT film grown on an optically polished quartz substrate. In addition to the inter-subband region below 3 eV, we present for the first time the remarkable polarization dependence of absorption peaks at 4.5 eV and 5.25 eV. Furthermore, the important relevance of these absorption peaks of SWNTs to the optical properties of graphite is revealed. Finally, a method for determining a nematic order parameter for an aligned SWNT film by separating the collinear absorption peak at 4.5 eV from other transition dipoles is introduced, followed by determination of optical absorption cross-section of the SWNTs.

The vertically aligned SWNT film was grown on both sides of a quartz substrate supporting Co catalyst [1], using the alcohol CCVD method [2]. The film consists only of SWNTs that are sufficiently clean, i.e. contain virtually no amorphous carbon and no multi-walled carbon nanotubes, as confirmed by resonant Raman scattering ( $G/D$  ratio  $> 25$ ) [1] and high-resolution transmission electron microscopy (HR-TEM).

Figure 1 shows a cross-sectional FE-SEM image of the sample used in the measurements, which has a thickness of 2.1 mm per side. Figure 2a and 2b show polarized absorption spectra from the aligned SWNT film for s- and p-polarized light, respectively, normalized by the  $\cos^{-1}\theta$  increment of the light path length. The angle  $\theta$  was changed from  $0^\circ$  to  $45^\circ$  in increments of  $7.5^\circ$ . Most noticeable is the polarization dependence of the peaks at 4.5 and 5.25 eV, whose origins and characteristics toward light polarization have been investigated in detail and to be presented in the symposium.

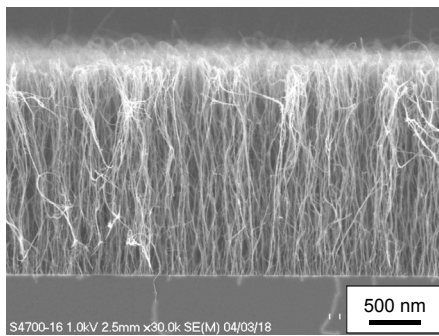


Fig. 1. FE-SEM micrograph of the vertically aligned SWNT film used in the measurements directly grown on a quartz substrate.

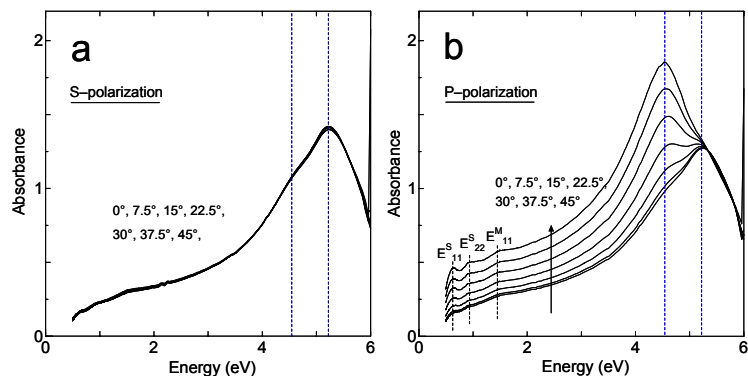


Fig. 2. Absorption spectra of the vertically aligned SWNT film. The angle of incidence was varied from normal incidence (bottom spectrum) to  $45^\circ$  (topmost spectrum) at a step of  $7.5^\circ$ . Polarizations are (a) 's' and (b) 'p' toward the substrate plane.

## References

- [1] Y. Murakami, S. Chiashi, Y. Miyauchi, M. Hu, M. Ogura, T. Okubo and S. Maruyama, *Chem. Phys. Lett.* **385** (2004) 298.
- [2] S. Maruyama, R. Kojima, Y. Miyauchi, S. Chiashi and M. Kohno, *Chem. Phys. Lett.* **360** (2002) 229.