

# Polarized Raman Spectroscopy of Vertically Aligned Single-walled Carbon Nanotubes

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Recently, we have prepared up to 30  $\mu\text{m}$  thick vertically aligned single-walled carbon nanotube (VA-SWNT) films with high purity by the alcohol catalytic CVD method [1]. Previous polarized Raman spectroscopy studies [2] showed that the peak around 180  $\text{cm}^{-1}$  is very strong at 488 nm excitation for incident light polarized perpendicular to the tube growth direction, but diminishes for parallel polarization. Recent high-resolution Raman measurements revealed that this strong peak is composed of four separate sharp peaks and disappear when the VA-SWNT film is dispersed. Additionally, we found that the films are comprised primarily of small bundles, typically fewer than ten SWNTs [3], which inspired us to investigate the origin of the 180  $\text{cm}^{-1}$  peak.

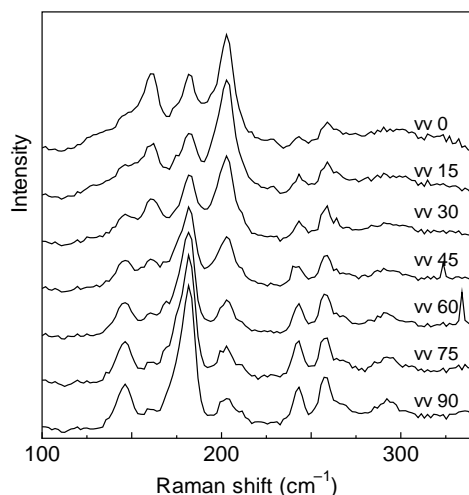
Polarized Raman experiments were carried out with two configurations, where the orientation of the polarizer for inspecting the scattered light is parallel (VV) or perpendicular (VH) to the incident light polarization. By changing the angle of the incident light with respect to the VA-SWNT growth direction, two different polarization dependences were found for the RBM peaks (Fig. 1). The peaks at 160  $\text{cm}^{-1}$  and 203  $\text{cm}^{-1}$  behave consistently with the “antenna effect”, where optical spectra are dominated by absorption/emission of light polarized parallel to the tube axis. However, peaks at 145  $\text{cm}^{-1}$ , 181  $\text{cm}^{-1}$ , 244  $\text{cm}^{-1}$  and 256  $\text{cm}^{-1}$  exhibit the opposite behavior in the VV configuration (Fig. 2), which may due to the cross polarized excitation/emission process or the presence of isolated tubes within the array.

[1] Y. Murakami, S. Chiashi, Y. Miyauchi, M. Hu, M. Ogura, T. Okubo, S. Maruyama: *Chem. Phys. Lett.* **385** (2004) 298.

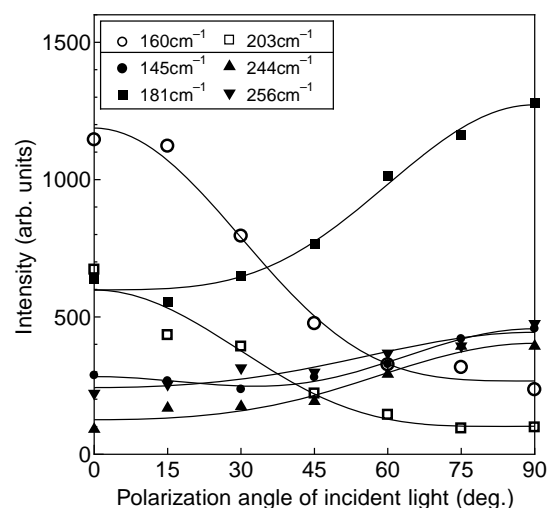
[2] Y. Murakami, S. Chiashi, E. Einarsson, S. Maruyama: *Phys. Rev. B* **71** (2005) 085403.

[3] E. Einarsson, H. Shiozawa, C. Kramberger, M. H. Rümeli, et al.: *J. Phys. Chem. C* **111** (2007) 17861.

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**Fig. 1.** Raman spectra of a VA-SWNT film in the VV configuration, and changing the incident polarization from 0° (along alignment direction) to 90° (perpendicular to the alignment direction).



**Fig. 2.** RBM Peak intensity changes for incident light polarization from 0° to 90° with respect to the VA-SWNT growth direction (VV configuration).