



Raman Analysis of Single-Walled Carbon Nanotube (SWCNT) Films

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Raman spectroscopy is an ideal tool for examining the structural and electronic properties of carbon nanotubes (CNTs) and in particular SWCNTs (1). Diameter, chirality, and phonon structure are reflected in first- and second-order Raman frequencies, i.e., radial breathing modes (RBM, 150–350 cm^{-1}) and carbon-carbon stretching in the graphene plane (G mode 1565–1595 cm^{-1}). These are the foundation of SWCNT mechanical and functional properties. The RBM and G-mode are diameter-sensitive. In addition, the complex G-mode in SWCNTs is complex in structure and is an indicator of metallic or semiconductive properties, while the G-mode in multi-walls is symmetrical and shifted to lower frequencies. The ratio of the intensity of the G-mode to the second order, D-mode, measures amorphous carbon. The challenge to efficient SWCNT production, such as the level of combustion fuel conditioner to be used, is to achieve yield with correct physical properties. A comprehensive, rapid analysis of SWCNT films is performed here with a compact, low cost, high throughput Raman system. Raman spectra reveal tube diameter, semiconductive properties, and degree of amorphous carbon and are used to optimize production methods.

Experimental Conditions

CNT films were produced at Nanocomp Technologies, Inc. utilizing either 0.2 or 0.5% of a proprietary fuel conditioner, and the properties were analyzed using Raman spectroscopy. Samples were examined with an LSI Dimension-P2-HR Raman spectrometer equipped with LSI-785 RVP (200 micron spot size), TE stabilized LSI LDS-785 laser, and LSI XYZ-PM for precise positioning. Laser power was attenuated and controlled through LSI RamanSoft. Typical spectra were collected for 5 seconds and 5 repeats. Spectra were efficiency and baseline corrected with LSI RamanSoft.

Results

The spectrum of the 0.2% fuel conditioner sample, Figure 1, has well-defined RBM peaks at 201, 211, 230, and 263 cm^{-1} . The peak at 230 cm^{-1} indicates a dominant SWCNT of approximately 1.5 nm diameter. The near absence of RBM peaks in the 0.5% sample reflects the virtual absence of SWCNTs. The greater G:D ratio in the sample produced with 0.2% fuel conditioner sample shows a lower level of amorphous carbon. Lorentzian deconvolution of the G-band in the 0.2% and 5% samples (Inserts A & B, respectively) shows a major peak for the 0.2% sample at 1585 cm^{-1} and a minor shoulder shifted to lower frequencies by 24 cm^{-1} , characteristic of semiconductive, high capacitance SWCNTs (1). In contrast, the 0.5% sample G-mode has only one symmet-

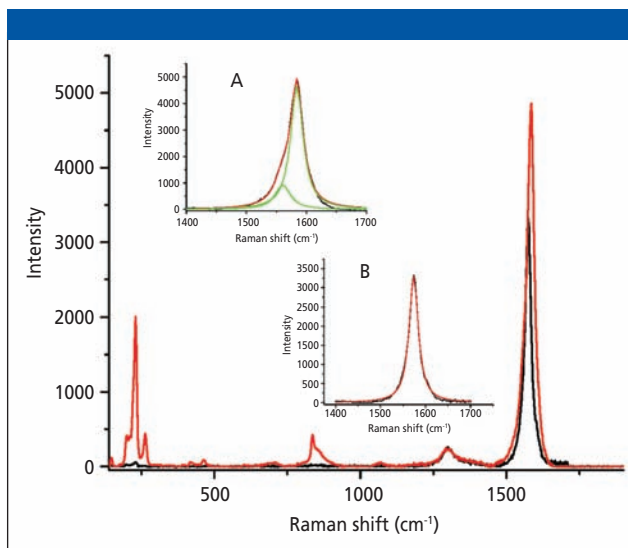


Figure 1: Raman spectra of CNTs produced with 0.2% (red curve) and 0.5% (black curve) fuel conditioner. Insert A: Lorentzian deconvolution of G-mode from the 2% sample; actual (black), Lorentzian-fitted (red) and Lorentzian deconvoluted peaks (green). Insert B: G-mode of the 0.5% sample: same as A except for the absence of Lorentzian deconvoluted peaks.

rical peak but a lower frequency (1574 cm^{-1}), as expected from graphite-like multi-walls.

Conclusions

The LSI Dimension-P2 Raman system employed here is low cost yet high performance and provides effective analysis of SWCNT diameters, amorphous structures, and semiconductive properties. These analyses are critical to the production of high tensile strength, high capacitance SWCNT composites. New Dimension-P2 models with more than twice the sensitivity permit similar analyses with the speed needed for in-line production monitoring.

Reference

- (1) M.S. Dresselhaus, G. Dresselhaus, R. Saito, and A. Jorio, *Phys. Rep.* **409**, 44–99 (2005).

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