



## Confocal Raman Imaging of Carbon Nanotubes Application Examples

### Carbon Nanotubes

A Carbon nanotube (CNT) is a member of the fullerene structural family that forms cylindrical carbon molecules, their name being derived from their size and composition. The diameter of a CNT is on the order of a few nanometers, while they can be up to several centimeters in length. They exhibit extraordinary strength and unique electrical properties, and are efficient conductors of heat. Their remarkable mechanical and electrical properties make them potentially useful in a wide variety of applications (e.g., nano-electronics, optics, materials applications, etc.). There are two main types of nanotubes: single-walled (SWNTs) and multi-walled nanotubes

### Wavelength Dependent Raman Imaging

Raman signals of CNTs show dependence of the exciting laser wavelength. Raman spectroscopy on SWNT is a resonant Raman scattering process of single photons, providing insight into the photonic and electronic structure of one-dimensional carbon molecules in their bonding environment. The radial breathing modes (RBM), can be found at low wavenumbers (100-350/cm) and are the result of coherent vibration of carbon atoms in the radial direction. The position of the RBM provides information on the diameter of the nanotube, the intensity of the peak elucidates the electronic structure of individual tubes, the combination of both parameters then allows the characterization of the structure of SWNTs. Like all resonant processes, the intensity of the Raman scattering from SWNT strongly depends on the wavelength of the excitation laser. This study shows results from one and the same sample area analyzed with 514 nm (Fig. 1a and b) and 633 nm (Fig. 1c and d) excitation wavelength, respectively. Using a 514 nm excitation, SWNT with a diameter ranging from 0.9 nm (Fig. 1a red spectrum) to 1.2 nm (Fig. 1a blue spectrum) are detected, their distribution is shown color coded in Fig. 1b. Application of a 633 nm excitation laser, SWNT are detected with structural properties fulfilling the resonance conditions,

(MWNNTs). Other than impurities, the CNT is formed entirely of carbon atoms. The structure of the carbon is a hexagonal web ("graphene sheet") rolled into a cylindrical tube, sometimes with a "cap" at each end of the cylinder (SWNT). Cylinders may exist inside other cylinders like the layers of a leaf vegetable, with a gap of 0.34 nm between cylinders (MWNNT). Some pentagonal (five-sided) and heptagonal (seven-sided) defects can cause cylinders to bend, change diameter, or twist. Well established characterization methods for CNTs include scanning tunneling microscopy or transmission electron microscopy, which provide the ability to measure the nanotube diameter or the chiral angle. The nanotubes

however, can be damaged by the electron beam in the microscope. In order to nondestructively characterize the tubes, Atomic Force Microscopy (AFM) and Confocal Raman Microscopy can be used. AFM reveals information concerning the structural morphology, whereas the Raman spectra of the tubes directly describe the chemical composition and the molecular structure. For example, it is possible to identify the diameter of the tubes, their orientation depending on polarization, different electrical properties, and even to distinguish SWNT and MWNNT. To show the capabilities of Confocal Raman Microscopy, this study investigates carbon nanotubes with the Witec alphagoo II.

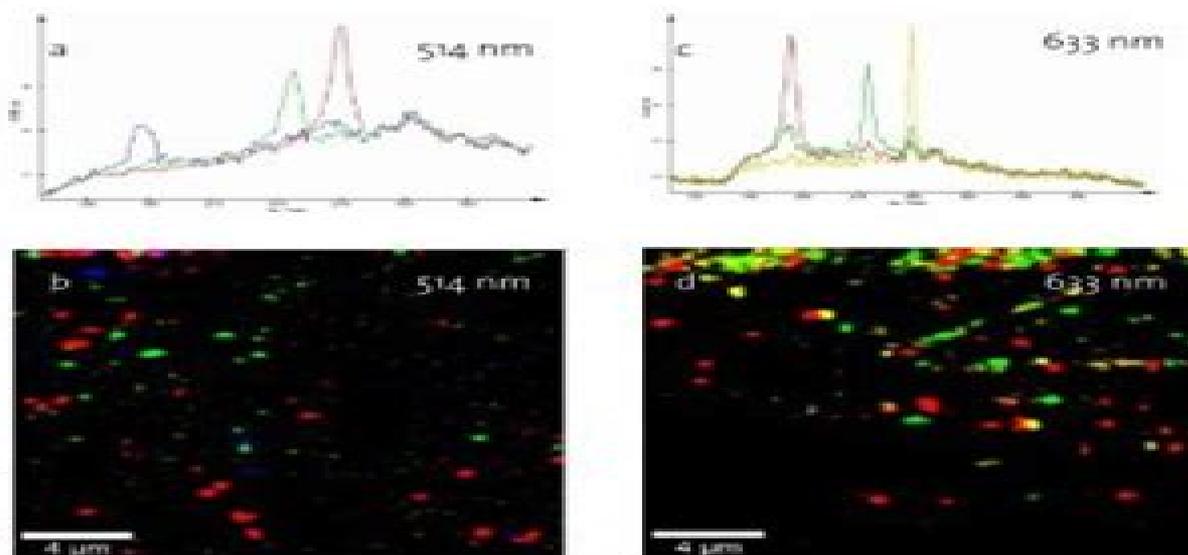


Fig. 1 Confocal Raman Imaging on Carbon Nanotubes. Scan Range: 20x20 μm, 100x100 pixels = 10000 spectra, 100 ms/spectrum, 1000 gr/cm grating. (a) Typical spectra at 514 nm, (b) Distribution of corresponding nanotubes on the silicon substrate, (c) Typical spectra at 633 nm, (d) Distribution of corresponding nanotubes.

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