

## 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.

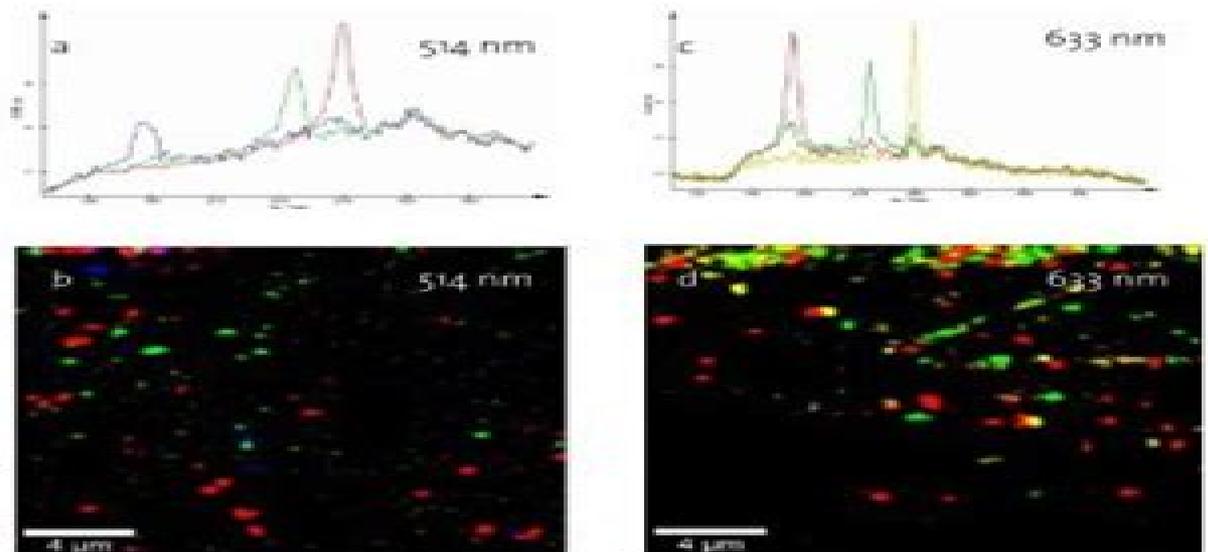


Fig. 1 Confocal Raman Imaging on Carbon Nanotubes. Scan Range: 20x20 μm, 100x100 pixels = 10000 spectra, 100 ms/spectrum, 1000 gr/s grating. (a) Typical spectra at 514 nm, (b) Distribution of corresponding nanotubes on the silicon substrate, (c) Typical spectra at 633 nm, (d) Distribution of corresponding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

# Application Note Witec

**Katrin Zwirgmaier**



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**Developments in Surface Contamination and Cleaning, Volume 12** Rajiv Kohli, K.L. Mittal, 2019-06-08

Developments in Surface Contamination and Cleaning Methods for Assessment and Verification of Cleanliness of Surfaces and Characterization of Surface Contaminants Volume Twelve the latest release in the Developments in Surface Contamination and Cleaning series provides best practices on determining surface cleanliness Chapters include an introduction to the nature and size of particles a discussion of cleanliness levels detailed coverage of measurement methods characterization methods and analytical methods for evaluating surfaces and an overview of analysis methods for various contaminants As a whole the series creates a unique and comprehensive knowledge base for those in research and development in a variety of industries Manufacturing quality control and procurement specification professionals in the aerospace automotive biomedical defense energy manufacturing microelectronics optics and xerography industries will find this book to be very helpful In addition researchers in an academic setting will also find these volumes excellent source books Includes an extensive listing with a description of available methods for the assessment of surface cleanliness Provides a single source of information on methods for verification of surface cleanliness Serves as a guide to the selection assessment and verification of methods for specific applications

**Applications of Vibrational Spectroscopy in Food Science, 2 Volume Set** Eunice Li-Chan, John M. Chalmers, Peter R. Griffiths, 2010-11-01 Bringing several disparate aspects of food science and analysis together in one place Applications of Vibrational Spectroscopy to Food Science provides a comprehensive state of the art text presenting the fundamentals of the methodology as well as underlying current areas of research in food science analysis All of the major spectroscopic techniques are also covered showing how each one can be used beneficially and in a complementary approach for certain applications Case studies illustrate the many applications in vibrational spectroscopy to the analysis of foodstuffs

**Oral Controlled Release Formulation Design and Drug Delivery** Hong Wen, Kinam Park, 2011-01-14 This book describes the theories applications and challenges for different oral controlled release formulations This book differs from most in its focus on oral controlled release formulation design and process development It also covers the related areas like preformulation biopharmaceutics in vitro in vivo correlations IVIVC quality by design QbD and regulatory issues

*A Practical Guide to Geometric Regulation for Distributed Parameter Systems* Eugenio Aulisa, David Gilliam, 2015-06-18 A Practical Guide to Geometric Regulation for Distributed Parameter Systems provides an introduction to geometric control design methodologies for asymptotic tracking and disturbance rejection of infinite dimensional systems The book also introduces several new control algorithms inspired by geometric invariance and asymptotic attraction for a wide range of dynamical control systems The first part of the book is devoted to regulation of linear systems beginning with the mathematical setup general theory and solution strategy for regulation problems with bounded input and output operators The book then considers the more interesting case of unbounded control

and sensing Mathematically this case is more complicated and general theorems in this area have become available only recently The authors also provide a collection of interesting linear regulation examples from physics and engineering The second part focuses on regulation for nonlinear systems It begins with a discussion of theoretical results characterizing solvability of nonlinear regulator problems with bounded input and output operators The book progresses to problems for which the geometric theory based on center manifolds does not directly apply The authors show how the idea of attractive invariance can be used to solve a series of increasingly complex regulation problems The book concludes with the solutions of challenging nonlinear regulation examples from physics and engineering

**Instrumental Analytical Chemistry** James W. Robinson, Eileen M. Skelly Frame, George M. Frame II, 2021-06-29 Analytical chemistry today is almost entirely instrumental analytical chemistry and it is performed by many scientists and engineers who are not chemists Analytical instrumentation is crucial to research in molecular biology medicine geology food science materials science and many other fields With the growing sophistication of laboratory equipment there is a danger that analytical instruments can be regarded as black boxes by those using them The well known phrase garbage in garbage out holds true for analytical instrumentation as well as computers This book serves to provide users of analytical instrumentation with an understanding of their instruments This book is written to teach undergraduate students and those working in chemical fields outside analytical chemistry how contemporary analytical instrumentation works as well as its uses and limitations Mathematics is kept to a minimum No background in calculus physics or physical chemistry is required The major fields of modern instrumentation are covered including applications of each type of instrumental technique Each chapter includes A discussion of the fundamental principles underlying each technique Detailed descriptions of the instrumentation An extensive and up to date bibliography End of chapter problems Suggested experiments appropriate to the technique where relevant This text uniquely combines instrumental analysis with organic spectral interpretation IR NMR and MS It provides detailed coverage of sampling sample handling sample storage and sample preparation In addition the authors have included many instrument manufacturers websites which contain extensive resources

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