



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.

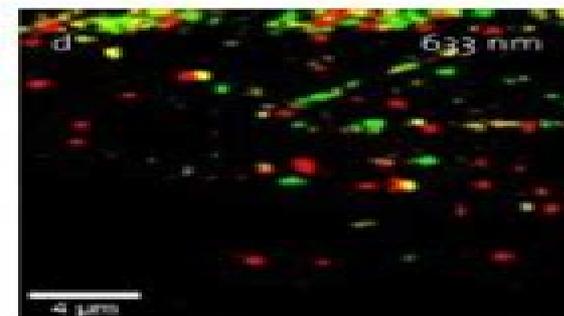
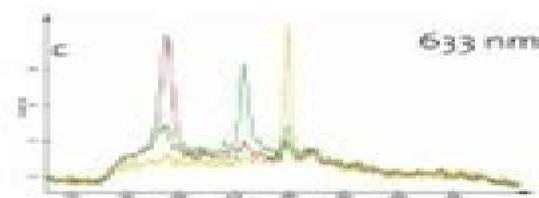


Fig. 1 Confocal Raman Imaging on Carbon Nanotubes, Scan Range: 20x20 μm, 100x100 pixels = 10000 spectra, 100 ms/spectrum, 1000 gr/s grating. (a) Typical spectra at 514 nm, (b) Distribution of corresponding nanotubes on the silicon substrate, (c) Typical spectra at 633 nm, (d) Distribution of corresponding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

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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

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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

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Vis is discussed This order is more in keeping with the preference of most instructors Naturally once the fundamentals are introduced instructors are free to change the order of presentation Mathematics beyond algebra is kept to a minimum but for the interested student in this edition we provide an expanded discussion of measurement uncertainty that uses elementary calculus although a formula approach can be used with no loss of context Unique among all instrumental analysis texts we explicitly discuss safety up front in Chapter 2 The presentation intentionally avoids a finger wagging thou shalt not approach in favor of a how to discussion of good laboratory and industrial practice It is focused on hazards and remedies that might be encountered in the use of instrumentation Among the new topics introduced in this edition are Photoacoustic spectroscopy Cryogenic NMR probes and actively shielded magnets The nature of mixtures in the context of separations Troubleshooting and leaks in high vacuum systems such as mass spectrometers Instrumentation laboratory safety Standard reference materials and standard reference data In addition the authors have included many instrument manufacturer s websites which contain extensive resources We have also included many government websites and a discussion of resources available from National Measurement Laboratories in all industrialized countries Students are introduced to standard methods and protocols developed by regulatory agencies and consensus standards organizations in this context as well

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1. Understanding the eBook Application Note Witec
 - The Rise of Digital Reading Application Note Witec
 - Advantages of eBooks Over Traditional Books
2. Identifying Application Note Witec
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Application Note Witec
 - User-Friendly Interface
4. Exploring eBook Recommendations from Application Note Witec
 - Personalized Recommendations
 - Application Note Witec User Reviews and Ratings
 - Application Note Witec and Bestseller Lists
5. Accessing Application Note Witec Free and Paid eBooks

- Application Note Witec Public Domain eBooks
- Application Note Witec eBook Subscription Services
- Application Note Witec Budget-Friendly Options
- 6. Navigating Application Note Witec eBook Formats
 - ePub, PDF, MOBI, and More
 - Application Note Witec Compatibility with Devices
 - Application Note Witec Enhanced eBook Features
- 7. Enhancing Your Reading Experience
 - Adjustable Fonts and Text Sizes of Application Note Witec
 - Highlighting and Note-Taking Application Note Witec
 - Interactive Elements Application Note Witec
- 8. Staying Engaged with Application Note Witec
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Application Note Witec
- 9. Balancing eBooks and Physical Books Application Note Witec
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Application Note Witec
- 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
- 11. Cultivating a Reading Routine Application Note Witec
 - Setting Reading Goals Application Note Witec
 - Carving Out Dedicated Reading Time
- 12. Sourcing Reliable Information of Application Note Witec
 - Fact-Checking eBook Content of Application Note Witec
 - Distinguishing Credible Sources
- 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development

- Exploring Educational eBooks
- 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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