Confocal Raman microscopy in combination with Atomic force microscope – a tool for subwavelength optical resolution

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Optical microscopy integrated with spectroscopy has become a common and comprehensive sample characterization technique. Resolution of common optical techniques is naturally limited by the wavelength of light and rarely goes below a few hundred of nanometers. Meanwhile, Atomic Force Microscopy has proven itself to be a very flexible and powerful tool for sample *physical* characterization with the nanometer spatial resolution. Surface topography as well as electrical, magnetic and even mechanical properties of the sample can be studied by a wide range of scanning probe techniques (Kelvin-, Electrostatic-, Acoustic- many others types of Atomic Force microscopy) based of different types of interaction between AFM probe and surface. In this report, we demonstrate the power of integration of the AFM and all optical techniques in one experimental setup. Physical characterization properties of AFM merge with chemical resolution of confocal Raman microscope and general capabilities of optical microscope.

Various applications of the technique will be demonstrated. Combined AFM topography and confocal Raman maps of the same sample area allow to separate single-walled from multi-walled nanotubes as well as to distinguish nanotube material from amorphous carbon residuals. Applications of combined AFM + Raman to another carbon-based system, graphene monolayers, will be shown. AFM phase imaging together with Raman maps allows separation of different phases in polymer blends; confocal Raman mapping in Z-direction (sample depth) provides information about thickness of polymer coatings.

Waveguiding properties of semiconductor nanofibers are studied. Light of different wavelengths is injected into an individual nanofiber either by a SNOM fiber tip or by a diffraction limited (~400 nm) spot of a high aperture objective. The point of light injection is chosen to be either nanofiber end, body or defect. A portion of light transmitted through nanofiber is collected from its end by a high aperture objective, and analyzed by a spectrometer. We study spectra of transmitted light with respect to the injected light wavelength. We also estimate light transmission efficiency for nanofibers of different diameters and materials paying attention on the role of defects on the transmission coefficient.

The ultimate goal of integrating AFM with optics is to bring resolution of optical methods (mainly, Raman and fluorescence) down to resolution of AFM (a few nm). There exists a number of ways how to use light interaction with the apex of AFM cantilever to produce an optical signal originated from a substantially *subwavelength* sample area (<100x100 nm^2) located *right below* apex of AFM probe. By scanning the AFM probe along the sample, getting 2D maps of Raman or fluorescence signals with subwavelength resolution (down to a few dozens of nm) is possible. In this report, we demonstrate the results on Tip Enhanced Raman Scattering (TERS) experiments – where Raman signal from narrow sample area below the metallized AFM tip is resonantly enhanced due to interaction with plasmons localized at the tip apex. The resulting resolution of 2D Raman mapping is about 50 nm that goes far beyond the optical diffraction limit. Such enhancement of optical resolution is especially important for Raman mapping of stress in modern silicon-germanium nanostructures.