Near-field infrared spectroscopy and microscopy on nanotubes

Katalin Kamarás[1], Dániel Datz[1], Gergely Németh[1], Áron Pekker[1], Hajnalka M. Tóháti[1], Adrian Cernescu[2], Keigo Otsuka[3], Taiki Inoue[3], Shigeo Maruyama[3]
[1]*Wigner Research Centre for Physics, P.O. Box 49, 1525 Budapest, Hungary*
[2]*Neaspec GmbH, Bunsenstr. 5, 82152 Martinsried, Germany*
[3]*Department of Mechanical Engineering, School of Engineering, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan*

Email: kamaras.katalin@wigner.mta.hu

Optical imaging of nanotubes on the individual tube level in the infrared range promises a wealth of information. Images can be correlated with electronic type (metallic or semiconducting) in carbon nanotubes, and local maps can be used for defect detection in boron nitride nanotubes. We use scattering-type scanning near-field optical microscopy (s-SNOM) with two infrared lasers and a spectroscopy setup in the tunable range (spectral regions 960 – 1020 and 1320 – 1450 cm^{-1}), to extract optical information with effective spatial resolution of a few nanometers.

The s-SNOM method is based on a metal-clad atomic force microscope tip, the outgoing signal contains both topographic and optical scattering information. From the phase contrast of the scattered light with the substrate, the optical conductivity can be estimated. Below, we show the phase contrast map of an array consisting of individual carbon nanotubes. The topographic image of these nanotubes shows similar diameters, but the phase of one of the species is markedly stronger than the others, indicating metallic behavior.

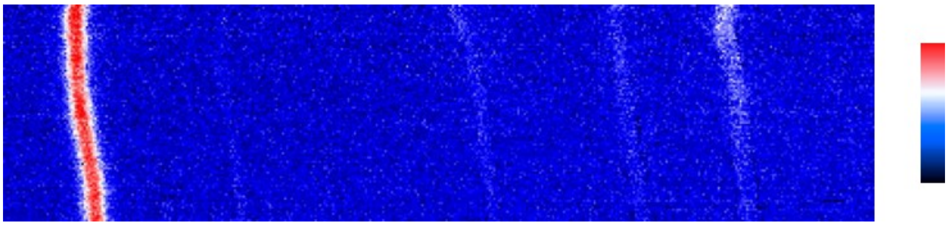

Figure. Optical phase contrast of a horizontally aligned carbon nanotube ensemble on SiO_2 at 940 cm^{-1}. High contrast of the individual nanotube on the left indicates high conductivity and hence metallic character. The other tubes of about the same size are semiconducting and therefore exhibit low contrast to the substrate. The diameter of the individual nanotubes is between 1.5 and 3 nm. The color scale on the right indicates phase values increasing from bottom to top.

Multiwall, large-diameter boron nitride nanotubes were studied in the higher frequency range, where boron nitride shows a strong phonon-polariton excitation. Besides this significant feature, a defect-induced mode was found in the spectra around 1430 cm^{-1}. Images taken at this frequency reveal the defect distribution of individual tubes and thus can be used for process control during various purification steps.

References

[1] Németh G, Pekker Á, Datz D et al 2017 *Phys. Stat. Sol. (b)* **254,** 1700433
[2] Datz D, Németh G, Tóháti HM et al 2017 *Phys. Stat. Sol. (b)* **254,** 1700277