Infrared Nanospectroscopy - From Nanoscale Chemical Identification of Polymers to Real-space Imaging of Graphene Plasmons

R. Hillenbrand

CIC nanoGUNE Consolider, San Sebastian, Spain
Ikerbasque, Basque Science Foundation, Bilbao, Spain

r.hillenbrand@nanogune.eu

Optical spectroscopy has tremendous impact in science and technology, particularly in the infrared (IR) and terahertz (THz) spectral range, where photons can probe molecule vibrations, phonons, as well as plasmons and electrons in non-metallic conductors. However, diffraction limits the spatial resolution to the micrometer scale, thus strongly limiting its application in nano- and biosciences. To overcome this drawback, we developed near-field microscopy based on elastic light scattering from atomic force microscope tips (scattering-type scanning near-field optical microscopy, s-SNOM) [1]. Collection of the tip-scattered light yields nanoscale resolved IR and THz [2] images, beating the diffraction limit in the terahertz spectral range by more than three orders of magnitude.

For nanoscale infrared dielectric mapping and vibrational spectroscopy we employ metalized AFM tips acting as infrared antennas. The illuminating light is converted into strongly concentrated near fields at the tip apex (nanofocus), which provides a means for localized excitation of molecule vibrations, plasmons or phonons in the sample surface. Spectroscopic mapping of the scattered light thus allows for nanoscale chemical recognition of (bio)materials, mapping of free-carrier concentration in semiconductor nanodevices [2] and nanowires [3] or nanoimaging of strain.

Using broadband IR illumination and Fourier-transform (FT) spectroscopy of the tip-scattered light, we are able to record IR spectra with nanoscale spatial resolution (nano-FTIR), even when employing the weak radiation from an incoherent thermal source [4]. Particularly, we demonstrate that nano-FTIR can acquire near-field absorption spectra of molecular vibrations throughout the mid-infrared fingerprint region at a spatial resolution of 20 nm. To that end, we employ a novel laser-based continuum source and perform spectroscopic imaging and identification of polymer nanostructures [5].

s-SNOM also enables the launching and detecting of propagating and localized plasmons in graphene nanostructures (Fig. 1). Spectroscopic real-space images of the plasmon modes allow for direct measurement of the ultrashort plasmon wavelength and for visualizing plasmon control by gating the graphene structures.

Another application of s-SNOM is the imaging of the vectorial infrared near-field distribution of plasmonic nanostructures. In this application, a dielectric tip scatters the near fields at the sample surface, allowing for mapping the hot spots in plasmonic infrared gap antennas [8] or for verifying IR energy transport and compression in nanoscale transmission lines [9]. With these studies we establish a basis for the development of nanoscale infrared circuits based on antennas and transmission lines, which could have interesting application potential for the development of ultra-compact infrared sensors, spectrometers and novel near-field probes.

References

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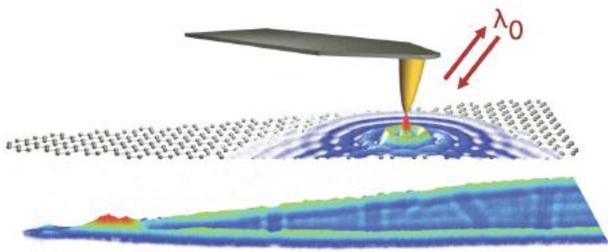

Figure 1: Optical nanoimaging of graphene plasmons. Upper panel: Sketch of the imaging method. A laser illuminated scanning tip launches plasmons on graphene. Detection is by recording the light backscattered from the tip. Lower panel: Optical image of graphene, where the fringes visualize the interference of the graphene plasmons.