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Infrared nanospectroscopy of plasmons in semiconductors, metal nanoantennas and graphene

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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 images, beating the diffraction limit in the terahertz spectral range by more than three orders of magnitude. Combined with thermal radiation and a Fourier-transform (FT) spectrometer, s-SNOM can map broadband IR spectra with a spatial resolution below 100 nm (nano-FTIR) [2].

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 and nanowires [1, 2] or nanoimaging of strain [3].

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 or for verifying IR energy transport and compression in nanoscale transmission lines [4]. 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.

s-SNOM also enables the launching and detecting of propagating and localized plasmons in graphene nanostructures. 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.

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