Resonant Dipole Nanoantenna Arrays for Enhanced Terahertz Spectroscopy

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Abstract- Our recent studies on dipole nanoantenna arrays resonating in the terahertz frequency range (0.1 – 10 THz) will be presented. The main near- and far-field properties of these nanostructures will be shown and their application in enhanced terahertz spectroscopy of tiny quantities of nanomaterials will be discussed.

Improving the sensitivity of terahertz spectroscopy is a longstanding challenge that promises to have a great impact on fundamental and applied studies involving the interaction of such long wavelengths with nanostructures (such as quantum dots, nanorods, nanotubes etc.), as well as with biomolecules, explosives, and drugs at extremely low concentrations.

In the past few years, we have shown that THz resonant dipole nanoantennas are effective in confining the radiation on a deep sub-wavelength scale, with a significant field enhancement in close proximity of the nanoantenna ends [1,2]. These properties are particularly promising for improving nano-localized THz sensing. In fact, the effective absorption of an object scales with the square of the local field [3], and thus nanoantennas can be used for enhancing direct-absorption spectroscopies, as it has been successfully shown in the infrared spectral region [4,5].

Recently, we have investigated the end-to-end coupling of THz nanoantennas in chains with “nanogaps” of around 20 nm (Gx in Fig. 1a). We have found that this configuration enables a giant THz field enhancement within such gaps (see simulation results in Fig. 1b). We have exploited these properties to perform “Nanoantenna Enhanced THz Spectroscopy” (NETS) of a monolayer of cadmium selenide quantum dots (QDs) [6] (see Fig. 1c), estimating that a significant portion of the overall monolayer absorption takes place within the antenna nanocavities.
Compared with recently proposed nanoslit sensing [7], NETS is able to retrieve the spectroscopic signature of the investigated specimen, requiring only a coarse alignment between the antenna resonance and the sample absorption features. Moreover, it is based on a distinctive three-dimensional localization of THz radiation, which enables unprecedented THz investigations within nanovolumes. Besides applications in THz spectroscopic studies of nanocrystals and molecules at extremely low concentrations, NETS shows a practicable route towards the spectroscopic characterization of individual nano-objects at these frequencies.

Figure 1. (a), Sketch of a portion of the terahertz dipole nanoantenna array; (b) Color map of the electric field enhancement in a nanogap region under resonant conditions (L = 8 µm, Gx = 20 nm, Gy = 14 µm, f = 5.65 THz); (c) SEM detail of a nanogap region covered with the QD monolayer.

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