Free Carriers Photoexcitation as a Platform for Ultrafast Tunable Dielectric and Hybrid Nanoantennas

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Optical nanoantennas enable enhancement and flexible manipulation of light on a scale much smaller than free-space wavelength. Due to this property, they offer unique opportunities for applications such as optical communications, photovoltaics, non-classical light emission, subwavelength light confinement and enhancement, sensing, and single photon sources. A specific type of optical nanoantennas, the Yagi-Uda one, has recently received a widespread attention in the literature. Such nanoantennas consist of several small scatterers that operate similarly to their radio frequency analogues. Yagi-Uda nanoantennas composed of different scatterers, such as core-shell nanoparticles, plasmonic nanoparticles, high-index dielectric nanoparticles were recently studied. Regardless of the scatterer type, such nanoantennas are characterized by a high directivity over a relatively wide frequency range.

The ability to control the scattering of light by nanoantennas is crucial for the development of nanodevices for optical data processing. Nanoantenna switching usually requires the control of extinction and absorption cross-sections, scattering patterns, and near field distributions. Such alteration of optical properties can be achieved via an external input, e.g., electro-optic, magneto-optic, or thermo-optical effect or carriers injection. One may also utilize the nonlinear response of the structure materials and control the scattering with the intensity of incident light.

Recently we have employed photoexcitation of electron-hole plasma in high-index semiconductor nanoparticles for ultrafast tuning of their optical response. We have shown that an excitation of electrons to the conduction band modifies refractive index of the semiconductor and thus overall scattering by the nanoantenna. Here, we present recent advances in this platform for ultrafast dynamical tuning of all-dielectric and hybrid nanoantennas based on photoexcitation of electron-hole plasma within semiconductor nanoparticles. We develop an analytical framework describing temporal dynamics of nanoantennas and demonstrate the capabilities of such nanostructures for ultrafast and advanced manipulation of the scattering and emission patterns. Based on this framework, we propose a novel type of tunable Yagi-Uda nanoantenna composed of metal-dielectric (Ag-Ge) core-shell nanoparticles. By choosing the appropriate nanoantenna parameters we excite a Van Hove singularity, supporting high values of directivity and Purcell factor within the same narrow frequency range. Our analysis reveals the possibility of flexible dynamical tuning of the hybrid nanoantenna emission pattern via electron-hole plasma excitation by additional fs-laser signal pulses.