Novel Nanophotonic Devices

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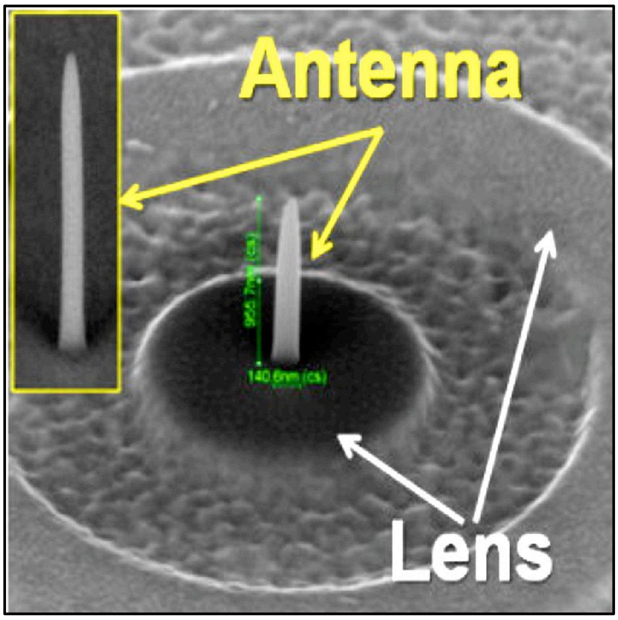
The current challenges in micro-electronics and photonics are partially directed to increase the speed of devices and reduce their physical dimensions and operation power. The current micro-electronic technology achieved significant progress in high-scale integration and miniaturization reaching the dimensions of the electron's de Broglie wavelength. However, the modulation speed of electronic components is rapidly approaching the electronic bottleneck accompanied by increased power dissipation. On the other hand, photonic components may operate in dozens of THz frequency range with negligible power losses, however the miniaturization of photonic circuits is virtually limited by diffraction to the scale of optical wavelengths. A possible interface between electronic components and photonic devices is based on plasmonic circuits and one of their important applications – metamaterials.



Coupled nanoantenna and plasmonic lens.

In the optical domain, noble metals exhibit negative electric permittivity. Dielectric-metal interfaces can support surface waves called Surface Plasmon Polaritons (SPP). SPP are not obeying the diffraction limit of light, and under certain circumstances may be confined on the nano-scale. We demonstrated both theoretically and experimentally the nano-confinement of visible and infrared light in various configurations: waveguide tapering, downscaled radiofrequency-like quarter-wavelength transformers, and nano-antennas excited by plasmonic planar lenses. Rings, etched in a gold film, act as a lens redirecting a free-space excitation into focused propagating SPP waves (see Figure). The waves efficiently excite the vertical antenna and nano-sized spots appear on its apex.

Fundamental limits of plasmonic confinement were tested along with the investigation of a new type of inherent ponderomotive nonlinearity. Charge carriers, situated in electromagnetic fields with strong gradients (enforced in plasmonics) experience nonlinear repelling drift. Electrons, being repelled from interfaces, change local permittivity of metal substrates violating required conditions for localization.

In addition, new types of plasmonic particles with widely-tunable resonances were investigated together with a new algorithm for the generation of optimal particle shapes. Such particles may serve as building blocks for new materials – metamaterials.

Metamaterials are artificial electromagnetic multi-functional materials engineered to satisfy the prescribed requirements, which have properties that transcend the characteristics of natural media. Electromagnetic metamaterials will play a key role in providing new functionalities and enhancements to future high-speed optoelectronic devices, multifunctional nano-antennas, and high-resolution imaging systems. One of the outstanding examples is materials with negative refraction index, which are commonly constructed by shaped metal inclusions. An original proposal is to incorporate quantum structures such as quantum wells, wires and dots as inclusions. We demonstrate theoretically all-semiconductor tunable low-loss negative-index metamaterials based on coupled quantum wells and dots and quantum-cascade based active plasmonics.