Plasmonic Nanonoantennas: building blocks for nanoscale control of optical fields

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Optical antennas or plasmonic antennas are nanoscale metallic structures which act as effective receivers, transmitters and receivers of visible light. Different canonical nanostructures such as metallic nanorings [1], nanorods [2], nanowires [3], dimers [4] or nanoshells [5] are commonly used as optical nanoantennas. These nanoatennas show the ability to focus electromagnetic radiation into tiny spots of nanometer-scale dimensions allowing for more effective field-enhanced visible spectroscopies such as in surface-enhanced Raman spectroscopy (SERS) or in SEIRA. We will address here the optical response of these nanoantennas in a variety of configurations.

We will show theoretically and experimentally how the optical response of a nanoantenna can be engineered through the manipulation of the antenna gap, bridging together concepts of optics and circuit theory [6-9]. With use of similar concepts, we also analyze theoretically the concept of ultrafast optical switches based on nonlinear plasmonic nanoantennas. We explore the use of a photoconductive load at the antenna gap to act as an effective optical nanoswitcher. The principle of switching is based on the transition from capacitive to conductive coupling between two plasmon modes when bringing two nanoparticles into physical contact, as schematically shown in Fig. 1a. We show that photoexcited free carriers in a semiconductor material can be used as a load to short circuit the antenna arms, leading to a strong modification of both the spectral resonance structure (Fig 1b) and near-field mode-profile (Fig 1c-d). As the plasmonic antenna switch is based on a strong confinement of optical fields in space rather than in time, the nanoantenna switch can operate at very low switching energy while potentially reaching a much faster response than microphotonic switching devices.

Another spectroscopy where the role of plasmonic resonances plays an important role is Raman-Brillouin scattering of single metallic nano-objects [10]. The interaction between the vibrations of a metallic nano-object and the plasmons induced on it determine the activation and deactivation of certain vibrational modes in the Raman scattering. To illustrate the wide range of applications of plasmonic interactions in totally different systems, we will conclude by analysing the forces originated from the excitation of plasmons by the fast electron beam in Scanning Transmission Electron Microscopy (STEM) [11]. Our model calculations show that metallic nanoparticles experience attractive or repulsive forces as a function of the position of the electron beam. This ability to manipulate the forces on the particles can be used in gold nanoparticles for example to produce coalescence.

From the overview and the examples shown here, it is straightforward to conclude that an understanding of the interactions occurring at the optical nanoantennas in such a variety of systems, and the knowledge on the electromagnetic response occurring in the different spectroscopy and microscopy configurations are crucial to engineer and design plasmonic devices for improved detection and controlled optical response.

References

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Figure

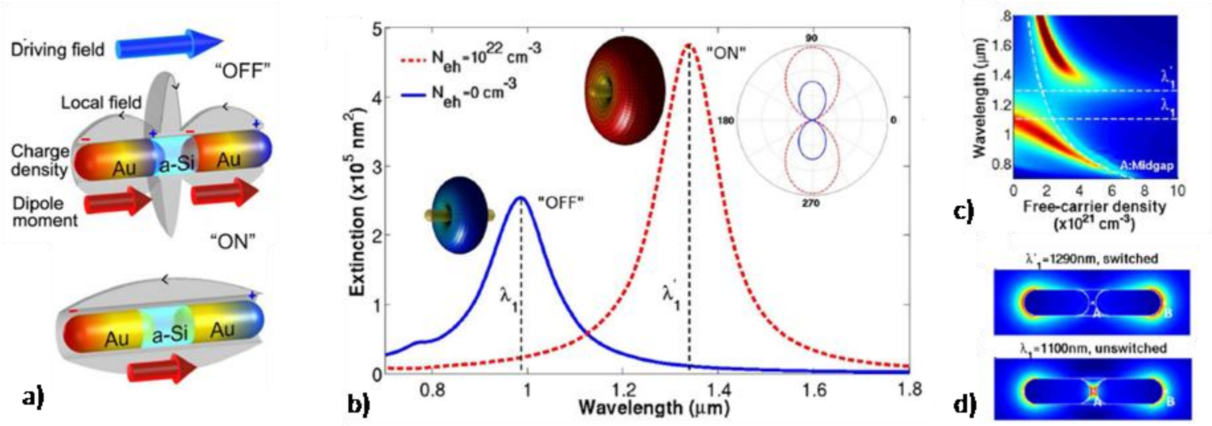

Figure: a) Schematics of the surface charge density in an "OFF" and "ON" nanoantenna switching situation. b) Extinction spectrum for "OFF" and "ON" switches. c) Near-Field peaks positions as a function of free-carrier concentration. d) Near-field distribution for the "ON" situation at λ=1290nm and "OFF" situation at λ =1100nm.