How to design a plasmonic sensor more sensitive to the environment?

Noble metal nanoparticles (NPs) such as Au NPs and Ag NPs support localized surface plasmon resonances (LSPRs), which are the light-coupled coherent oscillations of free electrons confined within the NPs. The LSPRs, which are characterized by the scattering or absorption spectra, can be developed as an optical sensor which is sensitive to the refractive index of the surrounding environment:

$$\lambda_{\mathrm{m}} = \frac{2\pi c}{\omega_{\mathrm{p}}}\sqrt{2{n_{\mathrm{m}}}^{2}+1}$$

where ?$_{\mathrm{m}}$ is the peak wavelength of LSPRs, ?$_{\mathrm{p}}$ is the plasma frequency of the bulk metal, n_{m} is the refractive index of the media surrounding the metal NPs. The spectral shift of the LSPRs-based plasmonic sensors reaches hundreds of nanometers per refractive index unit (RIU). However, the overall sensing performance is characterized by their figure of merit (FOM), which is defined as the sensitivity of resonance shift upon the change of environment refractive index by the resonance linewidth. The broad linewidth of LSPRs caused by radiative damping restricts development of plasmonic sensors with high FOM.

One of the strategy to improve the sensing performance is to employ the nanoparticle arrays, in which the light-particles interaction causes multiple scattering and leads to propagating waves in the plane of the nanoparticle arrays. Once the wavelength of the diffraction waves overlaps with the resonance wavelength of the LSPRs, a strong coherent interaction dramatically modifies the optical responses of the nanoparticle arrays, which is called lattice plasmon resonances (LPRs). Specifically, a sharp and narrow linewidth in the Au or Ag nanoparticle arrays is obtained due to the suppression of radiative damping. However, the generation of LPRs requires a homogeneous environment to support the plasmonic-photonic coupling between the LSPRs and the diffraction orders, which makes it difficult to obtain a practical LPRs-based plasmonic sensors.

Recently, a research group from the University of Texas at Austin (PI: Prof. Yuebing Zheng) proposed a new plasmonic structure to obtain a high-performance refractive index sensor.

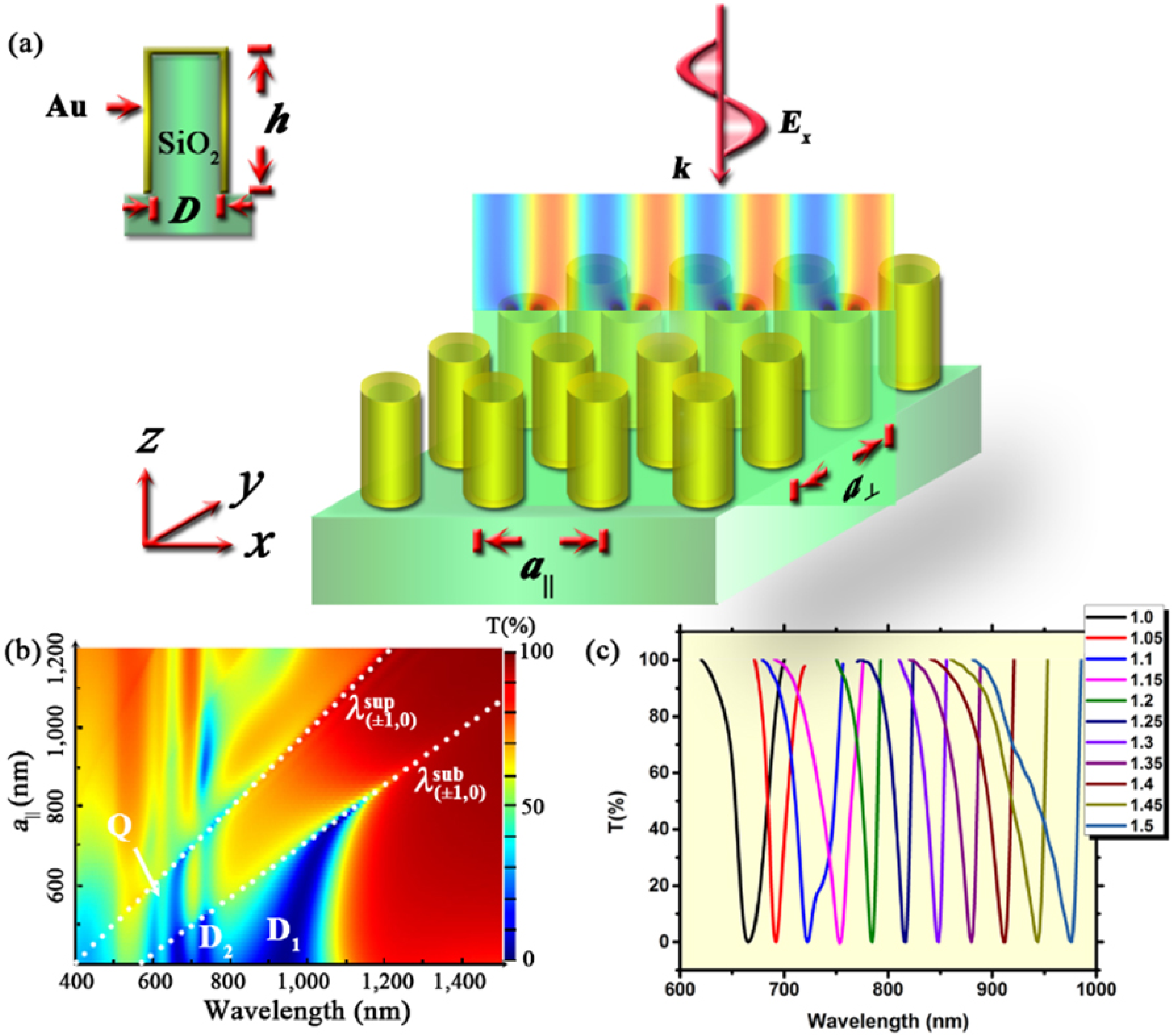

Fig. 1. (a) Schematic of the core/shell SiO2/Au NCAs. The inset shows the cross section of a single core/shell NC. (b) Transmission spectra of the core/shell SiO2/Au NCAs and (c) the optical response to the environmental refractive index.

The structure is schematically displayed in Fig. 1a, with a thin Au film coated on the high height-to-diameter aspect ratio SiO_2 nanocylinder arrays (NCAs). The increase of aspect ratio suppresses the interaction between the substrate and the plasmonic-photonic coupling, and introduce the new plasmonic modes (indicated as Q mode and D2 mode in Fig. 1b). Different from the dipolar interactions in the conventionally studied orthogonal coupling, the horizontal propagating electric field introduces the out-of-plane “hot spots” and results in electric field delocalization. Through controlling the aspect ratio to manipulate the “hot spot” distributions of the LSPRs in the NCAs, we demonstrate a high-performance refractive index sensor with a wide dynamic range of refractive indexes ranging from 1.0 to 1.5 (Fig. 1c). Both FOM and high signal-to-noise ratio can be maintained under these detectable refractive indexes. Furthermore, we studie the electromagnetic field distributions, which confirm that the high FOM in the wide dynamic range is attributed to the parallel coupling between the superstrate diffraction orders and the height-induced LSPR modes. Our study on the near-field “hot spot” engineering and far-field parallel coupling paves the way towards improved understanding of the parallel LPRs and the design of high-performance on-chip refractive index sensors.

Publication

Engineering of parallel plasmonic-photonic interactions for on-chip refractive index sensors.
Lin L, Zheng Y.
Nanoscale. 2015 Jul 28