Nanoplasmonics: New Design Concepts For Nanoscale Optical Cavities

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Abstract

The design of nanoplasmonic cavities exploiting coherent processes such as sub- and superradiance as well as Fano-type interactions will be discussed, under the framework of plasmon hybridization theory. In such cavities, interactions between bright and dark localized plasmon modes lead to a complex mode spectrum, which can be visualized using electron energy loss spectroscopy. First implementations fabricated using electron beam lithography will be presented. Furthermore, it will be shown how the concept of transformation optics can be utilized for the design of nanoresonators with a broadband absorption spectrum, showing high promise for light harvesting over the whole visible and infrared range of the spectrum.

1. Introduction

Plasmonic nanocavities show the hallmark of an ultrasmall modal volume, enabling light concentration on the nanoscale. While a lot of effort has been placed on the design of nanoscale spatial light localization [1], control over the spectral properties has received less attention. This conference contribution will survey prominent concepts for achieving control over the radiative properties of plasmonic nanocavities, utilizing concepts from plasmon hybridization theory [2] and transformation optics [3-4]. Furthermore, experimental visualizations of the complete mode spectrum of complex nanocavities will be presented, achieved using electron energy loss spectroscopy [5,6].

2. Designer Plasmon Nanocavities

A simple and intuitive concept for the design of plasmonic nanocavities with desired radiative properties is given by plasmon hybridization theory, which allows to decompose the mode spectrum of complex, multi-component cavities into the parent plasmon modes of its constituents. A particularly simple example is that of sub- and superradiant modes in disk/ring plasmonic nanocavities, enabled via either antiparallel or parallel coupling of the parent dipoles of the disk and the ring [2]. Higher-order modes can be made dipole active via symmetry breaking, leading to the appearance of Fano resonances, due to the overlap between a broad, contiuum-like resonance (the bright dipole) and spectrally much sharper, higher-order modes.

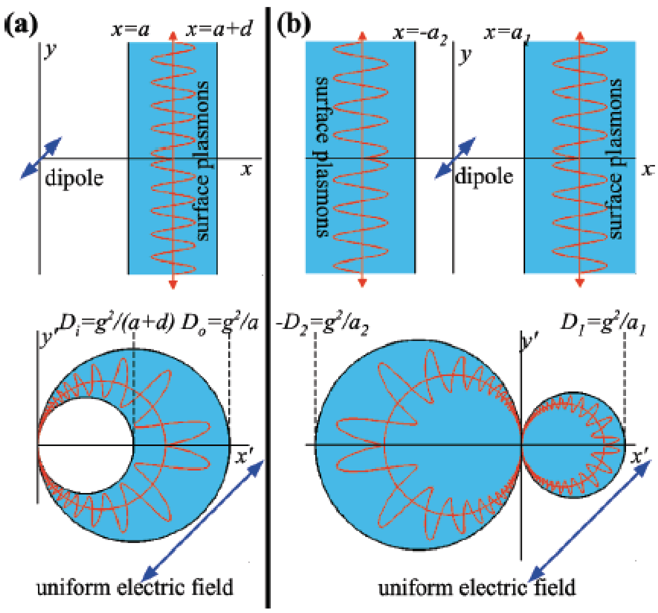

FIGURE 1. Using conformal transformations for the design of nanocavities with the electromagnetic properties of infinite systems.

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A unique tool to investigate and image the complete mode spectrum of such complex cavities is electron energy loss spectroscopy [5-6], allowing the mapping of both bright and dark modes. We have recently succeeded to apply this technique to top-down fabricated nanocavities.

While such concepts allow the shaping of plasmonic mode spectra, for example via quenching extinction in a small spectral fraction of a broad dipolar resonance [2], what is very difficult to achieve but highly desirable for practical applications are nanocavities exhibiting broadband absorption. One might think of applications in photovoltaics, for example, where light harvesting over a large part of the solar spectrum is of paramount importance.

However, the only plasmonic system showing truly broadband absorption is an infinite system, for example a metallic thin film. Indeed, a dipole placed in close proximity to the film can excite surface plasmon polaritons over a broad spectral range, all the way up to the surface plasmon frequency. This can be exploited for the design of broadband nanocavities using transformation optics: a simple conformal transformation, namely an inversion, maps this structure into a compact nanocavity (Figure 1). Hence, energy transported to infinity in the original frame, is now concentrated at a structural singularity [3,4]. This new design paradigm should allow the exploration of a whole new class of plasmonic nanocavities for electromagnetic energy concentration, with applications in photovoltaics, optical sensing, and the exploitation of nonlinear processes.

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7. References

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