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Fano Resonances and Rabi Splitting in Plasmonic-Dielectric Metasurfaces

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Abstract

Two-dimensional optical nanostructures (metasurfaces) with subwavelength characteristic dimensions in both in- and out-of-plane directions have shown to have an exceptional ability to manipulate light and produce unique scattering features in spectral profiles. These properties have been employed as new platforms to control, confine, and enhance light-matter interactions in the nanostructures at the subwavelength level. Besides their lightweights, the simplicity in designing, and well-established fabrication process, compared to their three-dimensional counterparts (metamaterials), metasurfaces are of great interest in serving in a variety of real-life applications, such as lenses, imaging, sensing, beam steering, and solar energy harvesting. Here, we present the resonant response of plasmonic-dielectric hybrid metasurfaces using simulation modeling. We design scattering elements out of multilayer silver-silicon nanostructure, and we study periodic arrays of such scatterers. One or two elements (scatterers) are considered in the unit cell (lattice unit), and we show that scatterer dimensions define whether identical or mismatched resonances are excited in the array. A slight mismatch in the resonance positions controlled by scatterer size results in excitation of Fano resonances observed as peak splitting and characteristic asymmetric spectral profile.

Introduction

Metamaterial nanostructures that display Fano resonances have generated a considerable amount of growing interest by researchers in recent years [1]. The ability of Fano resonances to exhibit strong sensitivity to the local environment and their sharp asymmetric spectral profile play a very important role in designing and realizing photonic applications such as filters, sensors, modulators, lasers, optical switches, broadband reflectors, and various other devices [2]. Plasmonic metasurfaces, which are two-dimensional (2D), optically thin arrays of nanoantennas with subwavelength sizes distributed on a substrate, have shown to have an exceptional ability to manipulate light and produce unique scattering features in spectral profiles. The recent large interest in plasmonic metasurfaces has been driven by their small size, compared to their three-dimensional (3D) metamaterials counterparts, and their ability to control, confine, and enhance light-matter interactions at the nanoscale.

Results & Discussion

Nanostructures, such as dolmens and oligomers of nanoparticles as well as several plasmonic metasurface structures, have shown to exhibit Fano resonances in the optical domain. An example of such nanostructure is the ultrathin Babinet-inverted metasurface made up of asymmetric split-ring apertures fabricated in a metal plate, which produces high-quality-factor (high-Q) Fano resonances. The Fano resonances originate from the interaction of bright modes and dark modes that give rise to asymmetric linewidth profiles in the scattering parameters, such as absorption or reflection spectra. All-dielectric metasurfaces of various designs have been studied both experimentally and theoretically. These all-dielectric metasurfaces can excite both electric dipoles (EDs) and magnetic dipoles (MDs) at the nanoscale. Fano resonances observed in these nanostructures arise from the interaction of the EDs and MDs originating from the all-dielectric metasurface structures due to the interaction of resonant dark modes and the corresponding bright modes of the high-dielectric-constant nanostructures. For instance, Fano resonances in binary silicon nanodisk arrays have been experimentally realized in the visible region. In this work, we present the resonant response of plasmonic-dielectric hybrid metasurface using simulation modeling. We design and study the response of scattering parameters of multilayer silver-silicon nanodisk metasurfaces (Fig. 1).

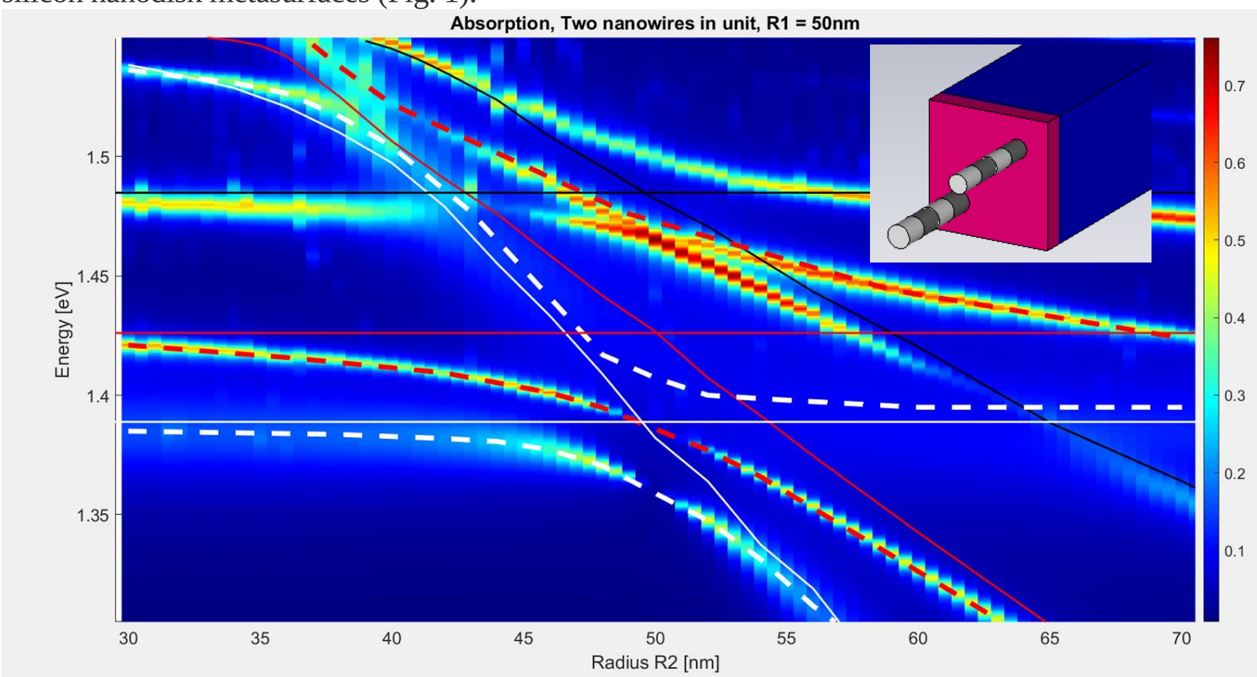

Fig. 1. Modes in the nanostructure. Inset: Geometry of structures under consideration, where the unit cell consists of one or two scatterers out of four layers including metal and dielectrics. Ultra-thin optical elements can be engineered based on transdimensional photonic lattices that include 3D-nanoparticles supporting multipole resonances arranged in 2D arrays to enhance collective effects in the nanostructure.

Conclusions

We considered plasmonic-dielectric hybrid metasurfaces with tunable resonant response. We designed scattering elements out of multilayer meta-dielectric nanostructures, and we studied periodic arrays of such scatterers. We aimed at designing efficient directional scatterers and their arrays for ultra-thin optical components, such as metasurfaces and transdimensional metastructures. We showed that a slight mismatch in the resonance positions controlled by the scatterers' size results in Rabi splitting, observed as changes in peak positions and characteristic asymmetric spectral profiles. Our design structure will enable the excitation of multi-resonances in the visible and near-infrared regimes, with tunable resonances originating from plasmonic multilayers and their periodic structuring.

References

1. W. Y. Zhao, D. Q. Ju, & Y. Y. Jiang, Plasmonics, 2015, **10**, 469–474.
2. Z. G. Liu, J. F. Li, Z. Liu, W. X. Li, J. J. Li, C. Z. Gu, & Z.-Y. Li, Scientific Reports, 2017, **7**, Art. 8010 (9 pp.).