Simulation Of Plasmonic Band Gap Structures

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Abstract

Surface plasmons in metal rectangular gratings can form bands and band gaps in their dispersion relations, analogous to those in photonic band-gap crystals and electronic bands in semiconductors. Introducing a dielectric coating atop the metal redshifts the plasmonic band gap, enabling a pathway to tunable dispersion and reconfigurable nanophotonic systems. To explore this tunability, we performed electromagnetic simulations using COMSOL Multiphysics® with the RF Module, modeling plasmonic excitations in rectangular silver gratings with and without dielectric coatings. The Electromagnetic Waves, Frequency Domain (EMW) interface was used to compute time-harmonic Maxwell's equations. Geometry was constructed and parameterized in Application Builder, and material properties were defined using a combination of COMSOL's built-in libraries and user-imported experimental data. While the RF Module is traditionally applied to lower-frequency systems, it was intentionally selected here for its S-parameter functionality, port-based power normalization, and stable frequency-domain solvers, enabling direct evaluation of optical reflection and transmission at subwavelength scales.

Key simulation parameters included the grating height (h), metal film thickness (d), and the complex permittivity of the dielectric layer. Dielectrics were modeled using Lorentzian dispersion functions based on measured optical constants. All simulations were conducted under TM illumination, with mesh refinement applied near metal-dielectric interfaces. Outputs included field profiles, power density maps, and port-based S-parameters for reflectance and transmission spectra.

In the absence of a dielectric coating, simulations revealed distinct band gaps associated with the interaction of plasmonic waves propagating in opposite directions. These were confirmed through electric field plots showing energy suppression at specific wavelengths. The band gap width and position were found to vary with the grating height, with h = 80 nm closely matching experimental TM-mode spectra. Upon addition of a dielectric layer (e.g., dye-like material), the band gap redshifted significantly. This shift is attributed to increased effective refractive index and altered boundary conditions, demonstrating that surface dielectric tuning enables band gap engineering without changing the underlying metal structure.

These results are consistent with analytical dispersion predictions and reproducible across frequency sweeps. Our study highlights the value of combining structural modulation with refractive index control to tune SPP behavior. The RF Module's built-in port analysis features facilitated efficient extraction of optical S-parameters, making this method ideal for applications involving reflectance-based sensing or tunable photonic filters. The findings support the development of reconfigurable meta surfaces, optical filters, and integrated plasmonic circuits, where dynamic photonic response and field localization are essential.

Reference

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Figures used in the abstract

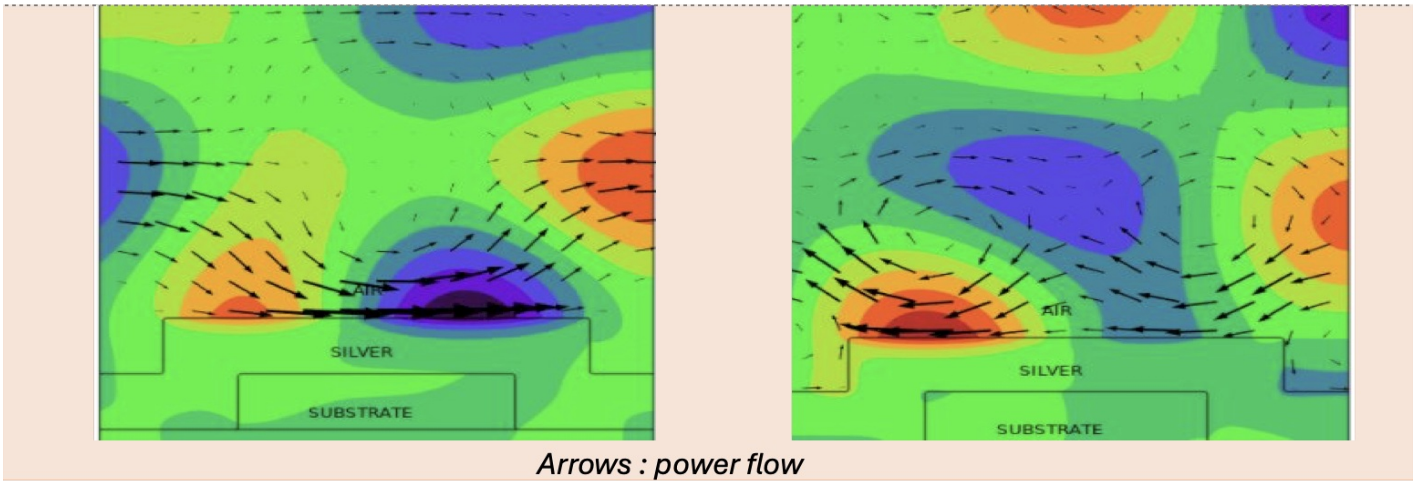

Figure 1 : Simulations predict plasmons propagating in different directions at wavelengths below or above the gap. The angular positions of resonances correspond to the experiment.