Mode Switching in a Metallic Photonic Crystal Slab

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Introduction

Metallic photonic crystals (MPCs) have emerged as an interesting class of nanostructures for sub-wavelength manipulation of light. The MPC structure consists of a photonic waveguide, coupled to an array of plasmonic nanoantennas [1] and exhibits plasmonic-photonic Fano-like resonances. Enhanced fields and strong dispersion associated with these resonances enable a variety of applications including electromagnetically-induced transparency (EIT), slow light [2], sensing [3], [4] and light emission [5].

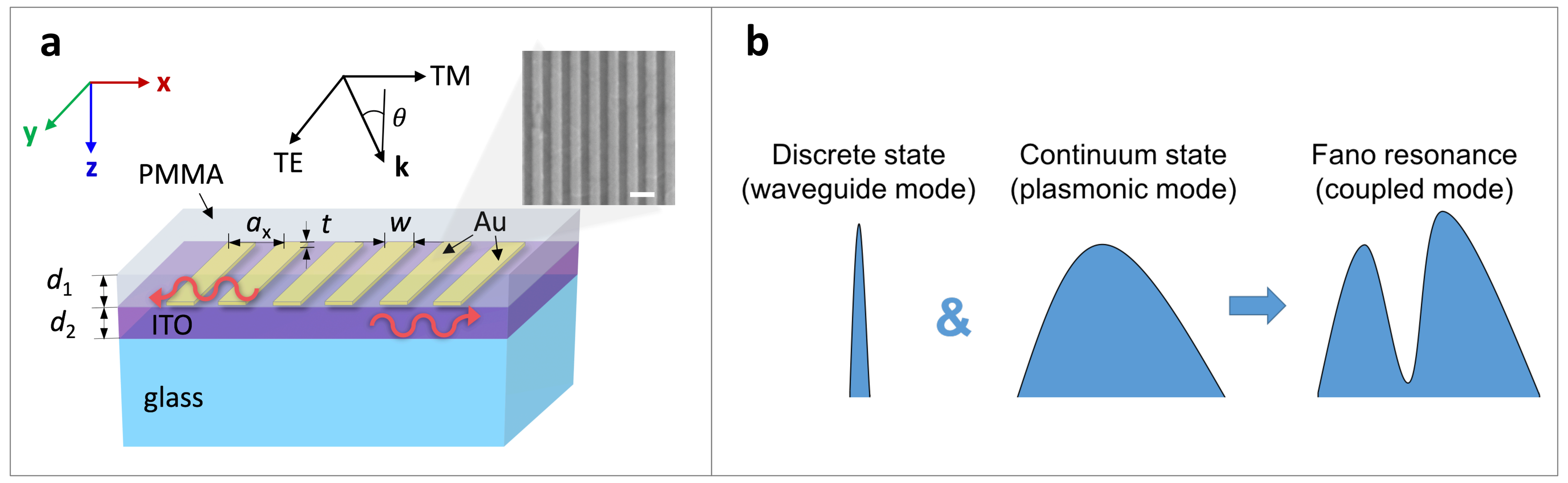

Figure 1. Fano-resonant metallic photonic crystal (MPC) structure. (a) Device schematic. Inset: SEM image (scale bar = 500 nm). (b) Fano resonance. Incident light excites localized surface plasmon resonances (LSPRs) in the gold nanogratings which in turn excite non-radiative waveguide modes. Interaction between these two modes produces the coupled Fano-like resonance, resulting in sharp dips in the reflection spectra.

Active control over these resonances is desirable for flexible, reconfigurable on-chip applications, including enhanced sensing and tunable lasing. Here, we demonstrate a new dual-waveguide MPC structure which enables dynamic spectral and spatial tuning of the Fano resonances. Reversible mode tuning is accomplished by varying the superstrate refractive index (RI).

Principle of Operation

Our device consists of plasmonic gold nanogratings sandwiched between two dielectric films: indium tin oxide (ITO) below, and poly[methyl methacrylate] (PMMA) above (**Fig. 1a**).

- Light diffracted from the gratings is scattered into superstrate and substrate (**Fig. 2** bottom panels).
- Top & bottom waveguides confine the scattered light.
- Index mismatch between top & bottom waveguides enables spectral separation of confined modes.
- Modes can be tuned by varying superstrate RI and/or top waveguide properties.

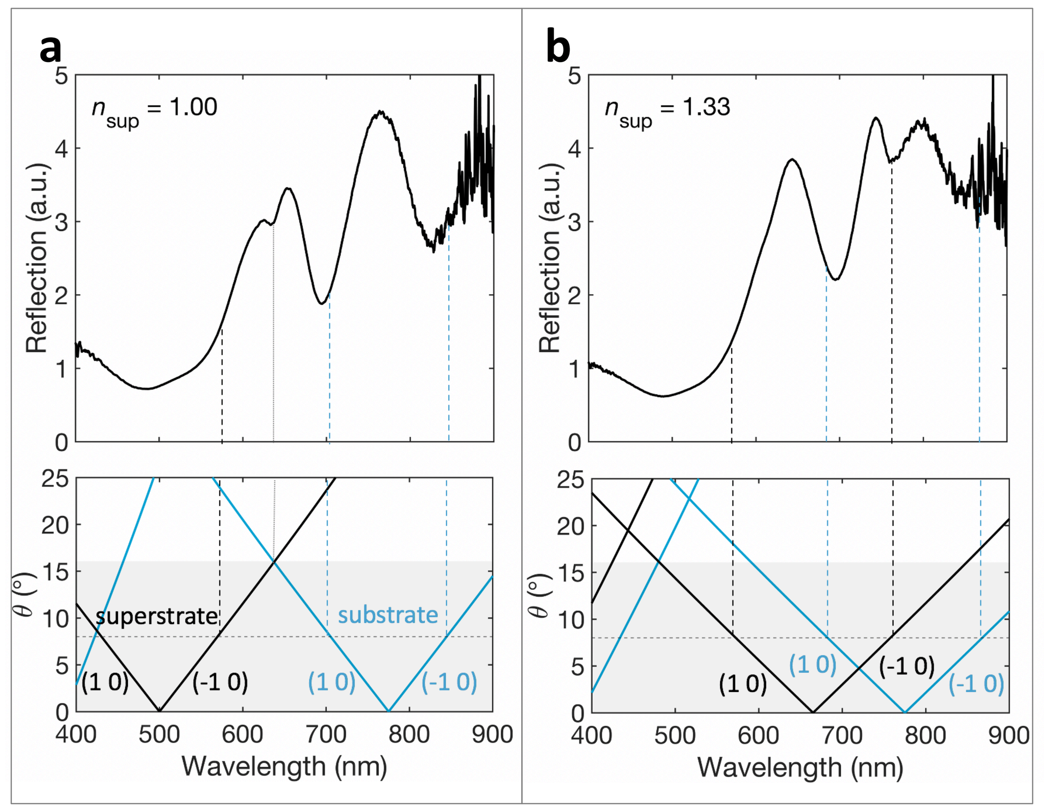

Figure 2. Control over Fano resonances by varying superstrate bulk refractive index (RI). (a) n_{sup} = 1.00, (b) n_{sup} = 1.33. d_1 = 0 nm. Top panels: reflection spectra. Bottom panels: grating dispersion. Gray shaded region corresponds to range of angles in light cone of objective lens (NA = 0.28). Mode splitting in spectra arises from finite NA of objective.

Results

As a proof-of-principle, we experimentally demonstrate reversible mode tuning by varying the refractive index surrounding the MPC structure. Mode splitting due to finite NA of objective lens (**Fig. 2**) is harnessed to fine tune overlap between superstrate and substrate modes [3]. Structural parameters for this study: a_x = 500 nm, t = 35 nm, w = 300 nm, d_2 = 175 nm, and d_1 = 85 nm.

Mode tuning via refractive index

- MPC structure in air (n=1.00) has a well-defined resonance dip at ~760 nm [sup (-1 0)].
- Upon immersion in water (n=1.33) resonance dip at 760 nm is replaced by a peak as superstrate modes are redshifted.
- Increasing RI with glycerol (n=1.47) shifts superstrate modes further to red, causing super/subs modes to overlap as $n_{sup} \approx n_{sub}$.

✓ Index mismatch opens a window of tunability.

✓ Large ON/OFF contrasts at a fixed wavelength.

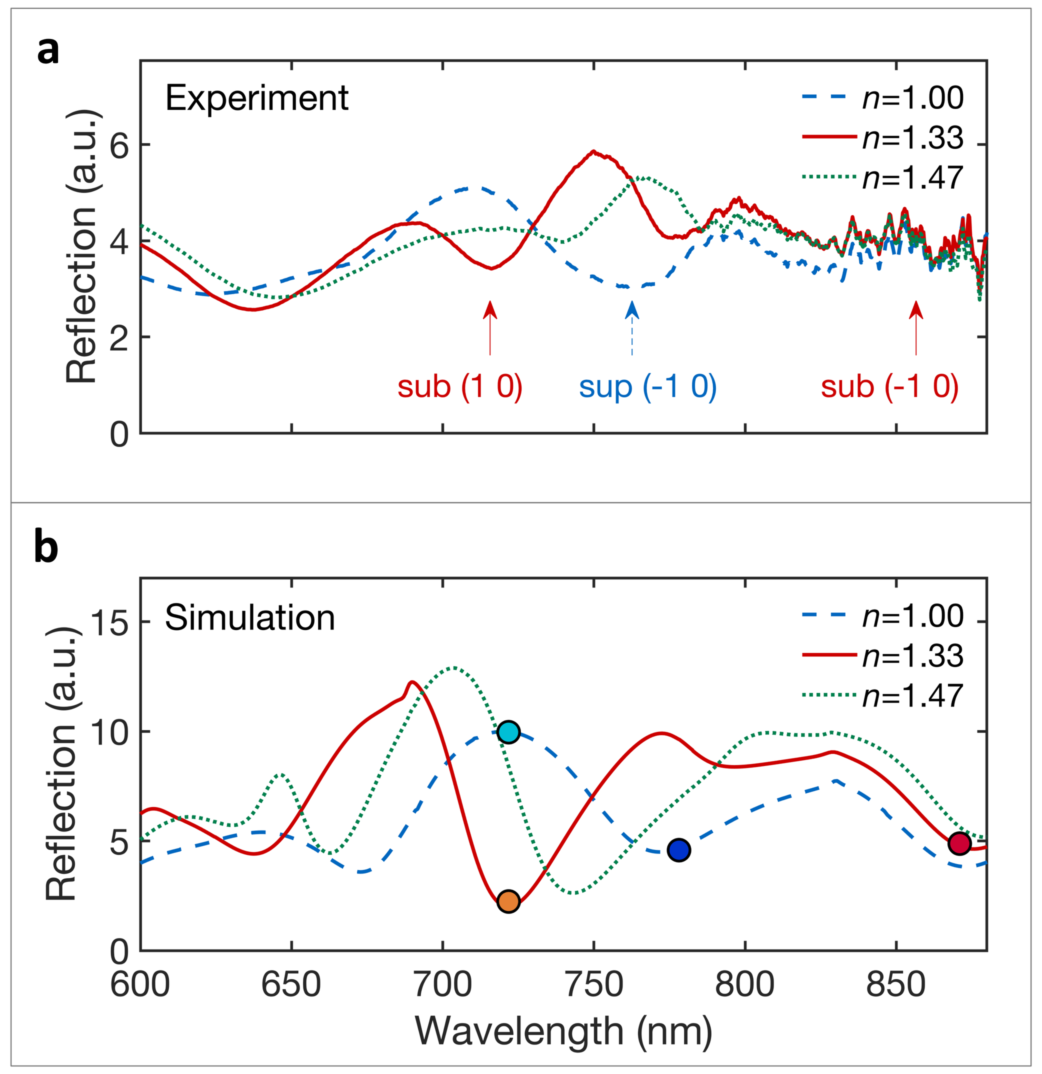

Figure 3. Mode tuning demonstration. (a) Experiment. Arrows indicate positions of selected substrate and superstrate modes. (b) Simulation. Colored markers indicate spectral locations in **Fig. 4**.

Spectrally-selective field enhancement

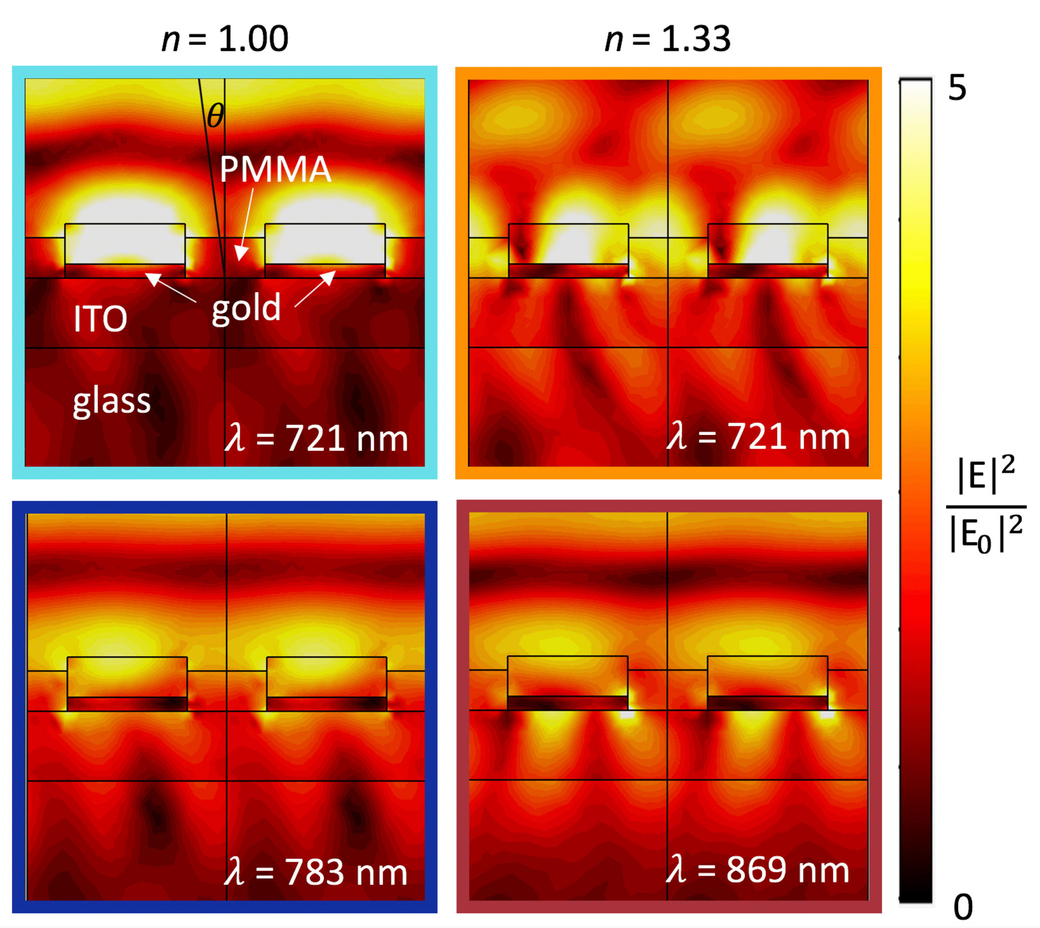

Figure 4. Magnitude of electric field for different resonance features in air, n=1.00 (left) and water, n=1.33 (right). Color code corresponds to markers in **Fig. 3**.

- ON/OFF switching between modes controls fields at fixed wavelength (**Fig. 4** top panels):
  - High reflection (left)
  - High transmission (right)
- Simultaneous strong field enhancement *and* high transmission (top right).

✓ EIT-like transparency windows.

✓ Transparency can be tuned by varying surrounding RI.

Results (continued)

Spatial control of fields

Thin film on top of gratings traps some of the diffracted light, enabling simultaneous, spatially-separated counterpropagating modes at the same resonance wavelength.

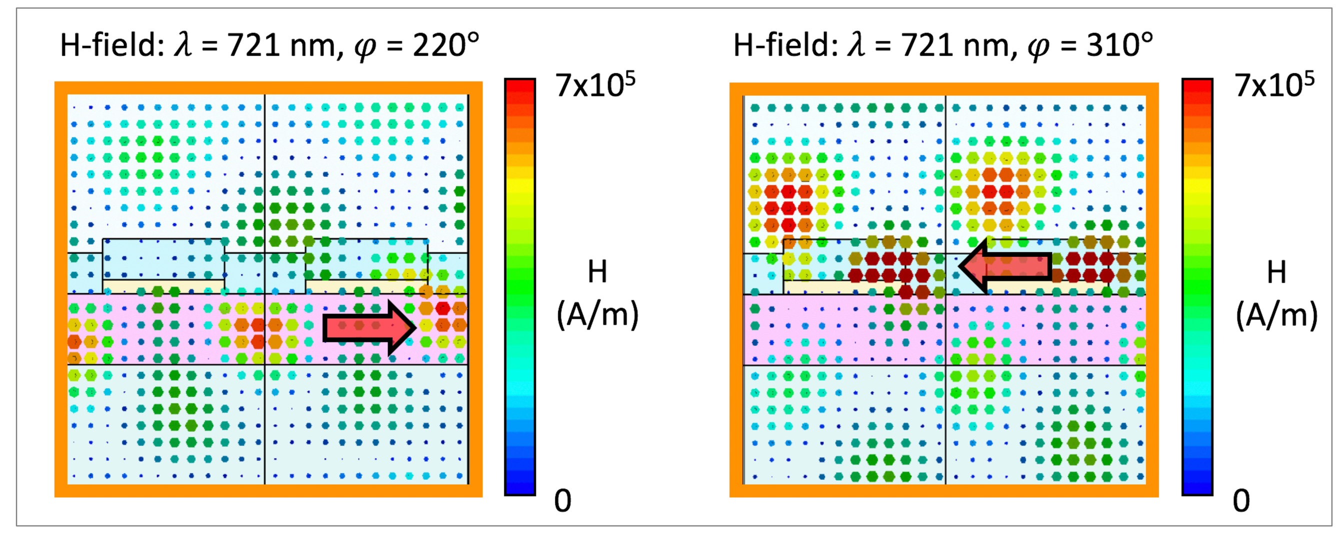

Figure 5. Magnetic field distributions for counterpropagating modes at λ = 721 nm. Left: guided mode in substrate waveguide. Right: guided mode in superstrate waveguide.

Application to thin-film monitoring

- Real-time thin-film monitoring:
  - Uncoated (d_1=0 nm) MPC structure was placed in cryogenic vacuum chamber.
  - Upon cooling, residual vapors condensed on MPC surface forming a thin film.
  - Presence of thin film is manifested by new resonance features (**Fig. 6**).
  - This structure may be used to monitor contamination in cryogenic vacuum chambers in real-time.
- Can also be applied to monitor thin-film bio/chem. interactions.

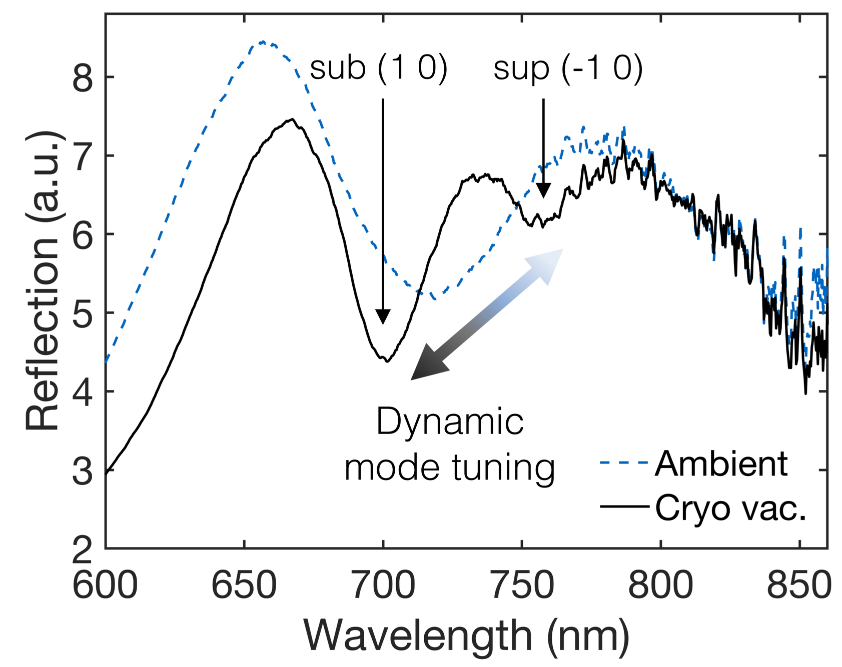

Figure 6. Dynamic mode tuning in response to thin films adsorbed onto MPC structure in cryogenic vacuum chamber.

Summary

- We have demonstrated a new dual-waveguide MPC structure which may be applied towards actively manipulating light on-chip.
- Proof-of-principle experiments demonstrated reversible mode tuning.
- Electromagnetic simulations revealed spectrally- and spatially selective field enhancement, and ON/OFF switching of transparency windows.
- Applications: thin-film monitoring, sensing, and tunable light emission.

References

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