# Bound States in the Continuum Empowering Maximum Chirality and Strong Coupling Regime in Plasmonic Metasurfaces

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***Abstract*— We theoretically demonstrate that Bound States in the Continuum (BICs) can appear in plasmonic metasurfaces, specifically in a metal nanohole array with broken symmetry, and can be exploited to yield a strong chiral response with high Q-factor and local field enhancement. When the nanoholes are filled with a medium supporting a Lorentz-like resonance, the interaction between the quasi-BIC and the active medium can gives rise to strongly coupled hybrid modes, which represent chiral polariton BICs in the plasmonic system.**

***Keywords—Plasmonic metasurfaces, bound states in the continuum, chirality, strong-coupling regime***

## I. Introduction

Maximing the chiral response in photonic and plasmonic systems is a key goal in current nanophotonics research. Bound states in a continuum (BIC) in dielectric metasurfaces are known to yield ultra-narrow resonances, with low radiative losses and enhanced radiation-matter interaction [1]. They give rise to topological singularities that split into circularly polarized states (CPS) with maximum chirality upon symmetry breaking [2,3]. In this work, we demonstrate that BICs can also appear in plasmonic metasurfaces and can be exploited to yield a strong chiral response.

## II. Chiral Bound States in the Continuum in a Plasmonic Nanohole Array

We consider a metasurface consisting of a gold layer on glass, which is etched with a square lattice of nanoholes (Fig. 1a), whose shape is deformed from circular to oval (Fig. 1b). The symmetry breaking is such that $r_2 + r_3 = 2r_1$, i.e, it maintains the area of the circular nanoholes.

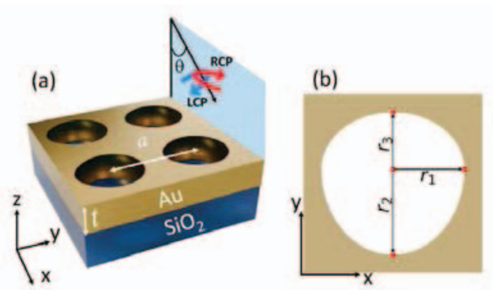


**Fig. 1** (a), (b): Sketch of the metasurface with broken-symmetry holes studied in this work, with Au thickness $t = 100$ nm. Light is incident from the air along the *xz* orientation.

Upon symmetry breaking, a quasi-BIC appears in absorption spectra at the low-energy side of the surface-plasmon polariton (SPP) peak. The Q-factor of the q-BIC is much larger compared to the Q-factor of the SPP resonance. At a finite angle of incidence along the *xz* orientation, all mirror symmetries are broken and the system acquires extrinsic chirality. The BIC has a strongly chiral optical response with nearly unit circular dichroism (CD), see Fig. 2 – again in contrast with the SPP, which is very weakly chiral. The maximum CD defined as CD=$(A_{lcp}-A_{rcp})/(A_{lcp}+A_{rcp})$ is nearly independent of the deformation, thus the chiroptical response is robust with respect to structure parameters. This is a definite advantage of the design. Analysis of the symmetry properties and of the local field profiles confirms that the resonance is indeed a symmetry-protected BIC, with strong enhancement of the local electric field [4]. Maximum CD is also found in calculated emission spectra.

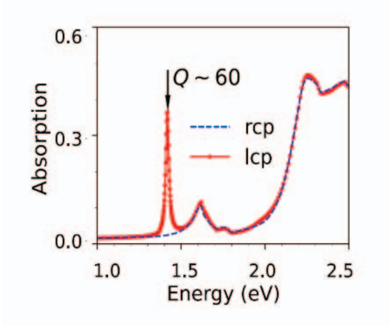


**Fig. 2** Absorption spectra for a metasurface with lattice constant $a = 500$ nm, $r_1 = 200$ nm, $r_2 = 240$ nm, $r_3 = 160$ nm, at $\theta = 4°$ for right and left circular polarizations (rcp, lcp), showing a BIC resonance with chiral response.

Next, we include an active medium at the bottom of the nanoholes (which can consist, e.g., in colloidal quantum dots) and consider the interaction of the BIC with a Lorentz-like resonance of the active medium. On increasing the oscillator strength of the resonance, the interaction between the BIC and the active medium gives rise to two absorption peaks that show a vacuum Rabi splitting, typical of the strong coupling regime. For oval holes at finite incidence angle, as shown in Fig. 3, the strongly coupled quasiparticles are chiral with polaritons being formed only for left circular polarization and with nearly maximum CD.

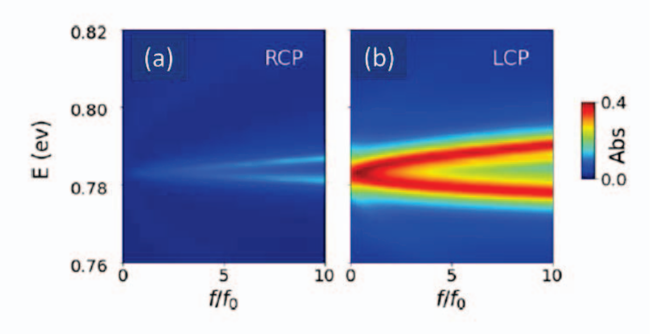


**Fig. 3** Absorption for a metafurface with $a = 1000$ nm, $r_1 = 400$ nm, $r_2 = 480$ nm, $r_3 = 320$ nm, at $\theta = 3°$ for rcp (a) and lcp (b). The metasurface contains a resonant medium at the bottom of the nanoholes, in a ring of 50 nm width and 10 nm height, with a linewidth $\gamma = 0.002$ eV. The absorption map is shown as a function of the oscillator strength of the active medium, in units of $f_0$ where $f_0/V = 10^{24}\ \mathrm{m}^{-3}$.

Absorption maps as a function of the angle of incidence show the typical anticrossing behaviour of the strong coupling regime [5]. Thus, the present metasurface with active medium supports the formation of chiral hybrid polariton BICs, which are the analog of polaritons in microcavities [6] or in photonic crystal slabs [7-9].

## III. Conclusions

The results of the present work may prove useful in order to maximize the chiral response of plasmonic metasurfaces by means of a simple design concept, which is based on BICs with symmetry breaking. The results can also be used in order to demonstrate strong light-matter coupling with hybrid chiral polariton BICs in plasmonic metasurfaces, possibly leading to quantum and nonlinear phenomena related to polariton interactions.

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