Boosting Chirality and Strong Coupling with Bound States in the Continuum in Plasmonic Metasurfaces

Hanan Ali[1], Emilija Petronijevic[2] , Giovanni Pellegrini[1], Lucio Andreani[1]

[1]Department of Physics "A. Volta", University of Pavia, Pavia, Italy

[2]Department S.B.A.I., Sapienza University of Rome, Rome, Italy

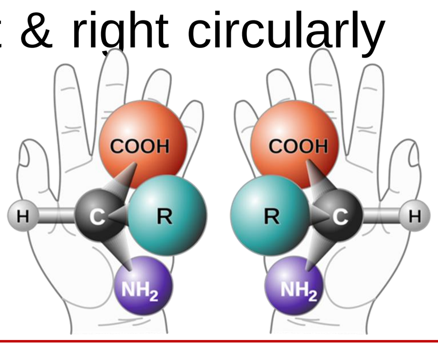
In this work, we demonstrate that the bound states in the continuum (BICs) can also appear in plasmonic metasurfaces and can be exploited to yield a strong chiral response [1]. We consider a metasurface consisting of a gold layer on glass, which is etched with a square lattice of nanoholes, whose shape is deformed from circular to oval. Upon symmetry breaking, a quasi-BIC appears in absorption spectra at the low-energy side of the surface-plasmon polariton peak. At a finite angle of incidence along the *x*-orientation, the BIC has a strongly chiral optical response with nearly maximum circular dichroism (CD). The maximum CD is nearly independent of the deformation, thus the chiroptical response is robust with respect to structure parameters [1]. Moreover, we report the prediction of of optical chiral optical response in the strong coupling regime, produced by the plasmonic BIC coupled with an active medium defined by a Lorentz model that allows to tune the oscillator strength to achieve the strong coupling [2].

Chirality

Chiral objects (and molecules) have no plane of symmetry and cannot be superimposed on their mirror images.

- Circular dichroism = difference in absorption of left & right circularly polarized light.

$$CD = \frac{A_{lcp} - A_{rcp}}{A_{lcp} + A_{rcp}}$$



Oval nanohole array in gold film on glass. [1]

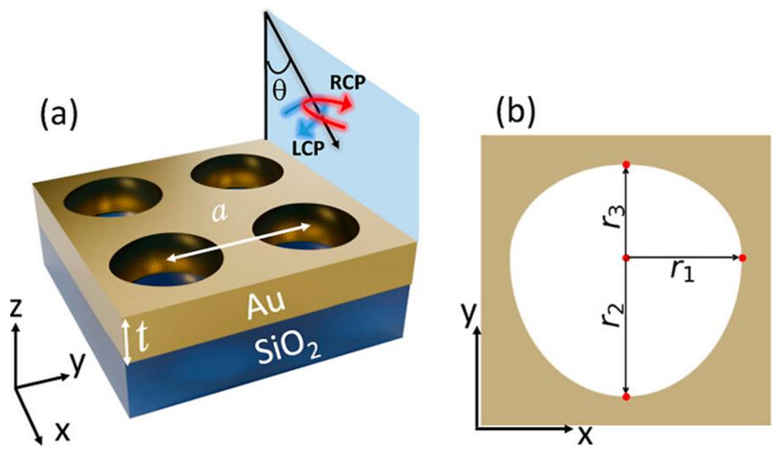
Gold thickness t = 100nm, lattice constant *a*

Varying parameters: r_1, r_2, r_3

Oval deformation of circular holes with the condition:

$r_2 + r_3 = 2r_1$= constant

$$\textbf{Deformation} \quad D = \frac{r_2 - r_3}{2r_1}$$

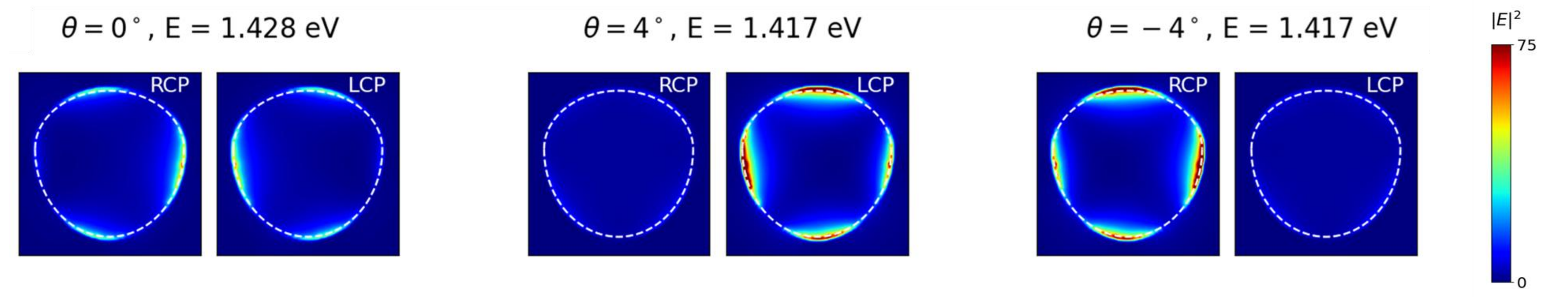


Methods

1) 3D FDTD Lumerical - Ansys
2) EMUstack

Both methods are able to calculate circular dichroism as well as extraordinary optical transmission (EOT).

Electric field enhancement of plasmonic BIC mode. [1]



It is a selective metasurface, meaning it couples to one of the polarizations.

With nanohole array with oval shape supporting plasmonic BIC we obtained a |CD| > 90% with a robust 2D design based on symmetry breaking.

Strong coupling regime. [2]

Strong coupling = formation of hybrid (polariton) modes from coupled BIC and active medium, which is characterized by three parameters: $\omega_0, \gamma,$ & the oscillator strength per unit volume $\frac{f}{V}$

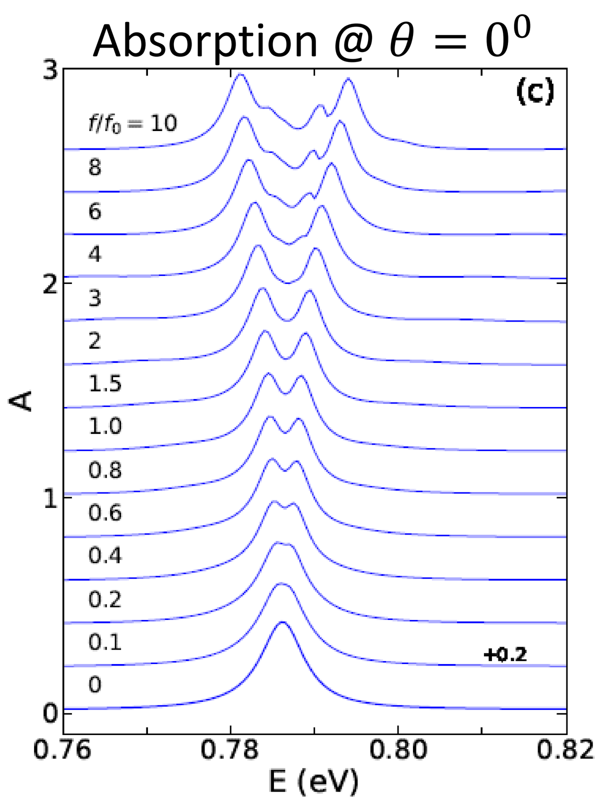
$$\varepsilon(\omega) = 1 + \frac{e^2}{\varepsilon_0 m_0} \frac{f/V}{\omega_0^2 - \omega^2 - i\gamma\omega}$$

Coupling constant: $g = \left(\frac{\hbar^2 e^2}{4m_0\epsilon_0}\frac{f}{V}\right)^{\frac{1}{2}} I$ ⟵ Overlap integral

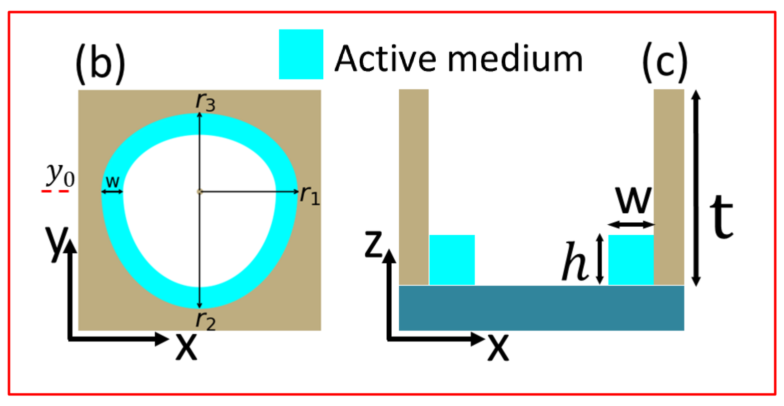
Conditions for strong coupling: $\omega_0 = \omega_{BIC}$, $g > \gamma_{BIC}, \gamma \equiv \gamma_{a.m.}$

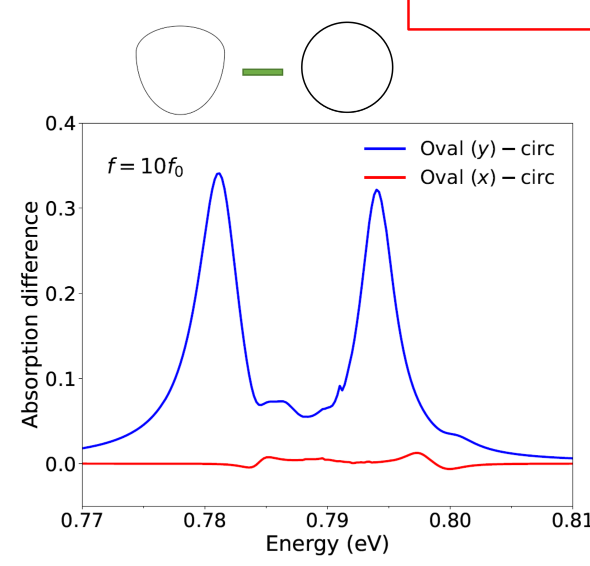
$\gamma_{BIC}, \gamma_{a.m.}$ = linewidths of the interacting eigenmodes

Strong coupling regime: Forming the hybrid modes. [2]



$$\frac{f_0}{V} = 10^{24}\,\mathrm{m}^{-3}$$

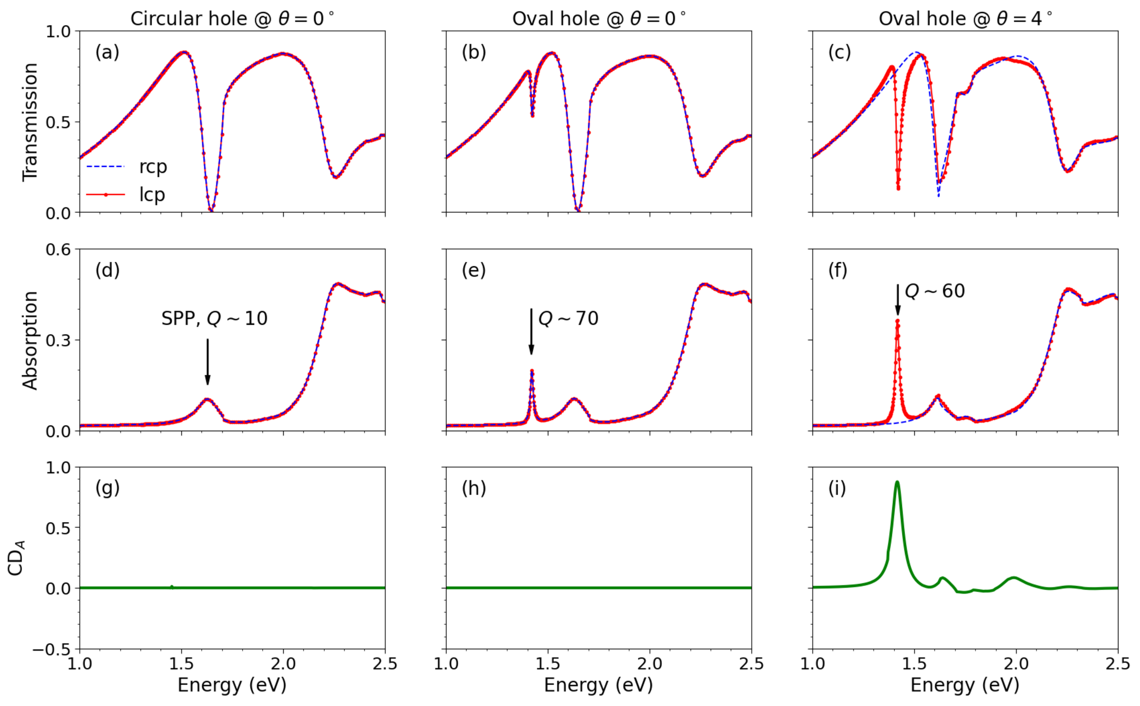




$a = 1000nm, t = 100nm$
$r_1 = 400nm$
$r_2 = 480nm$
$r_3 = 320nm$
$w = 50nm,$
$h = 10nm$
$\omega_0 = 0.7864eV,$
$\gamma = 0.002eV$

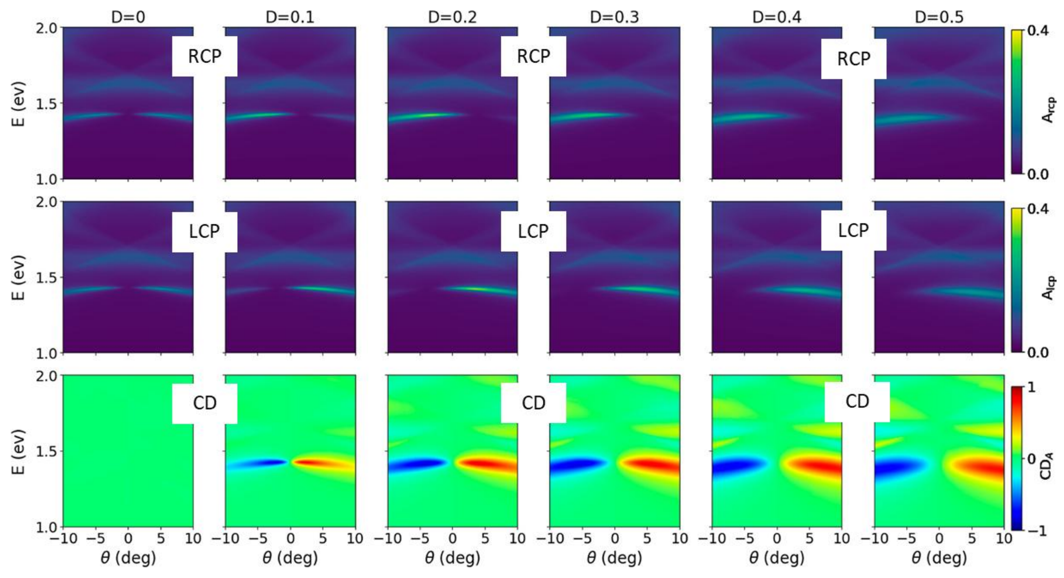
The peaks of the active medium alone have been subtracted. We identify the two prominent peaks as the hybrid polariton modes that result from strong coupling of the plasmonic BIC to the active medium.

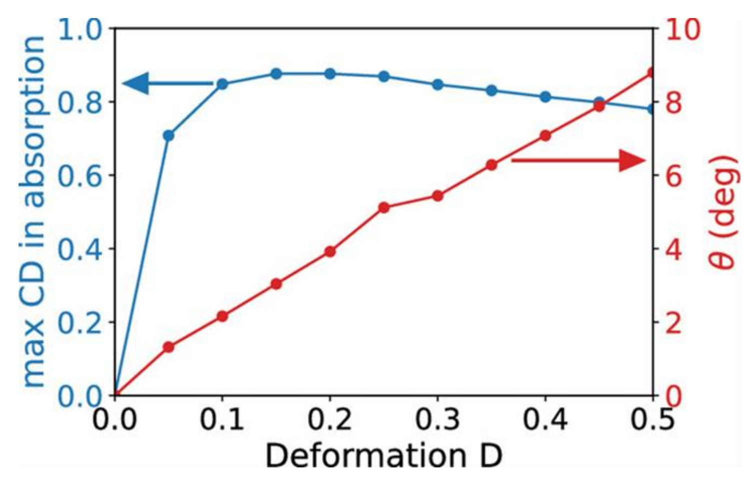
Deformation of circular holes leading to a robust CD. [1]



$a = 500nm$
$r_1 = 200nm$
$D = 0.2$

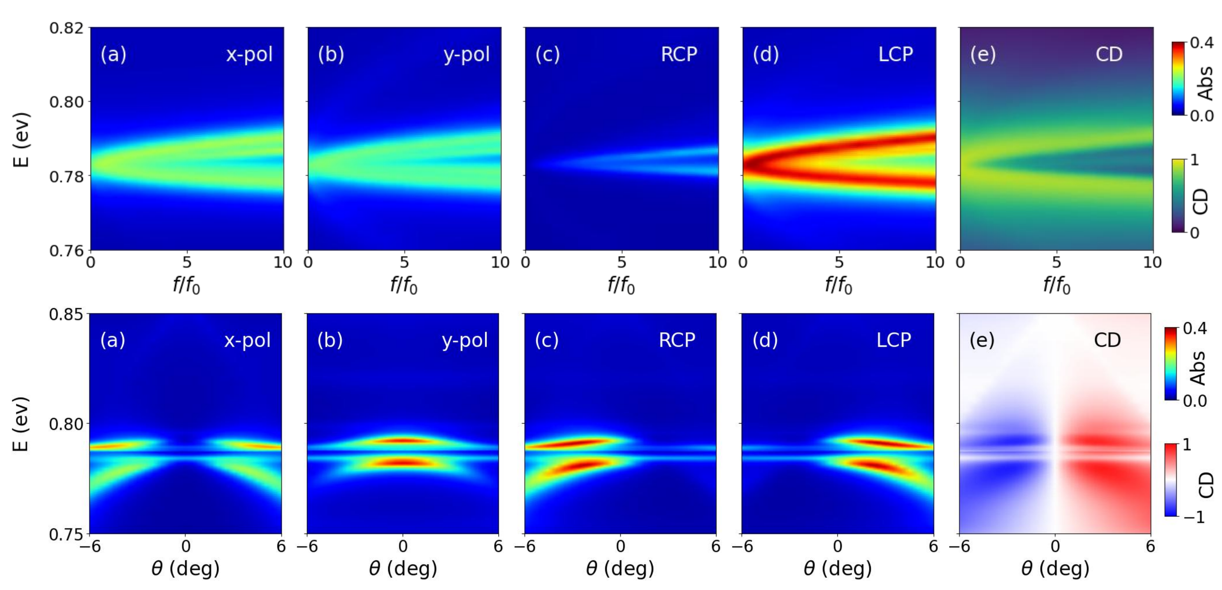
The q-BIC is present only for left -CPL but absent for right-CPL. This selectivity means that the incident field couples selectively to a resonant mode that is fully left circularly polarized, revealing an extrinsic chirality.





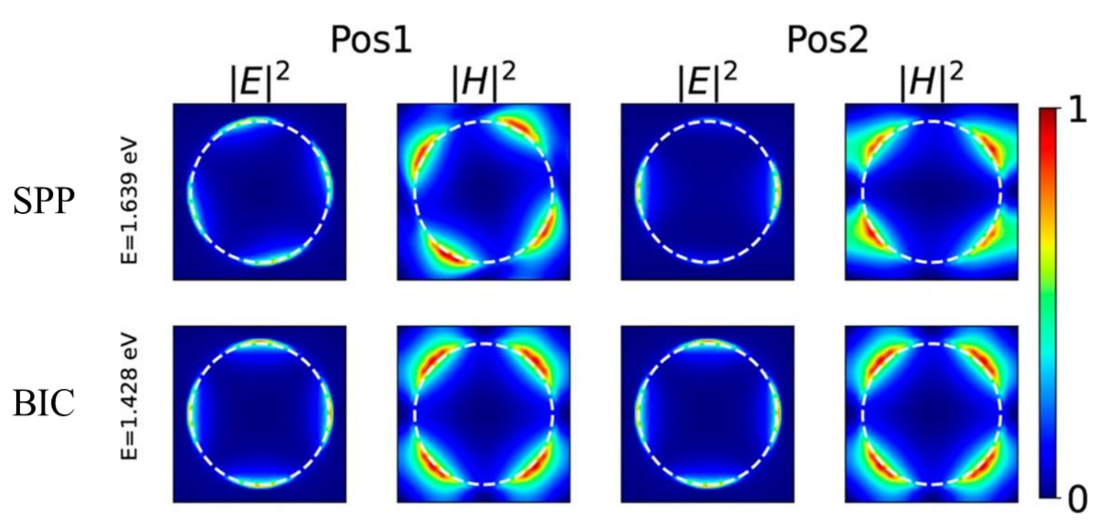
1- For any deformation, the q-BIC becomes asymmetric in θ, leading to a CD of opposite behavior CD(-θ) = - CD(θ).
2- The maximum CD is nearly constant, it tends to zero only for very small deformations.
3- The angle θ of the max CD increases almost linearly with the deformation.
Such results are very similar to those of dielectric systems [3]

Chiral properties of plasmonic polariton BIC. [2]



1- The chiral properties of the BIC are transferred to the active medium via the hybroid polariton modes.
2- The angular dispersion of the q-BIC coupled to the active medium for both positive & negative angles, showing a clear anticrossing at angles of ±3⁰.

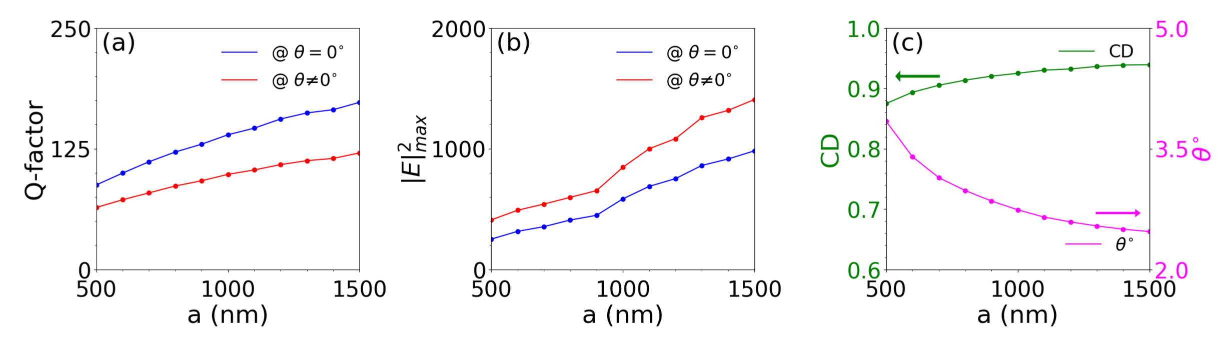
Mode Profile Analysis of plasmonic BIC. [1]



Twofold degenerate

Nondegenerate

Chiral plasmonic q-BIC in the infrared range. [4]



1- Q-factor and local field enhancement increase with lattice constants.
2- CD values are less than one because of the dissipation losses.

This trend reflects the enhanced optical confinement and reduced dissipative and radiative losses associated with larger periodicities, which better support the formation of high-Q factors in the IR.

[1] H. Ali et all. ACS Appl. Opt. Mater. 2024, 2, 5, 825-833.
[2] H. Ali et al. Opt. Express 33(9) 19700-19714 (2025).
[3] L. Zagaglia et al. Opt. Lett. 48 (19) 5017-5020 (2025).
[4] Hanan Ali, et al. JPhys Photonics. Accepted (2026). DOI: 10.1088/2515-7647/ae3cd7