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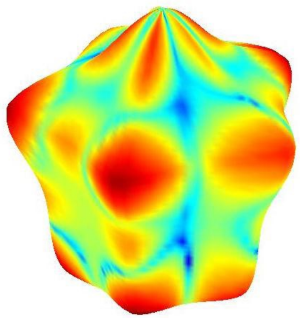
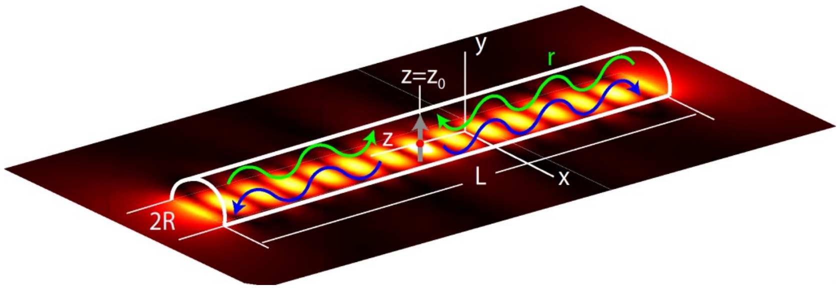
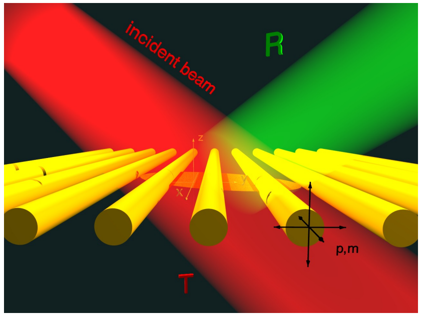
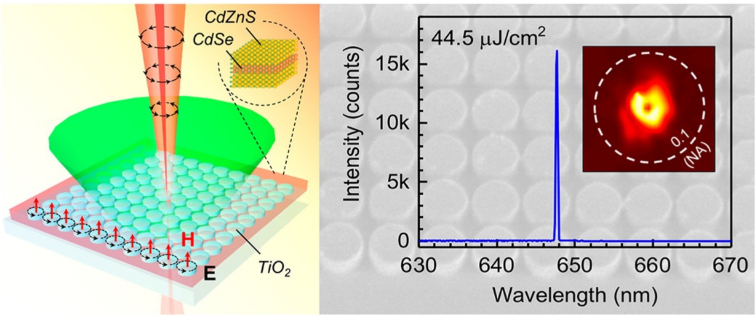


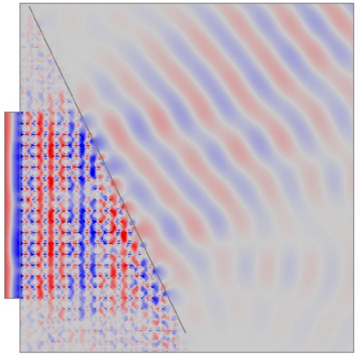


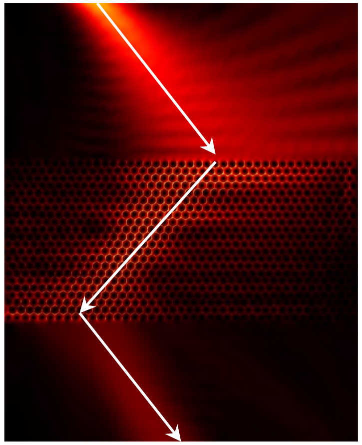


Nanofotónica y Metamateriales en el IEM

José A. Sánchez Gil







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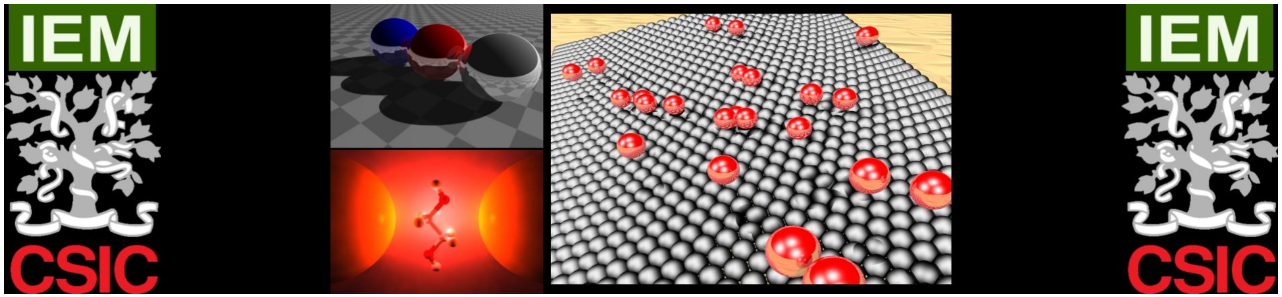
Dpto. Espectroscopía Nuclear, Vibracional y de Medios Desordenados

Espectroscopías Ópticas en Nanoestructuras Plasmonicas y Semiconductoras



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Teoría

Posdoc:
José L. Pura

Diego R. Abujetas

Estudiante doctorado FPI:
Álvaro Buendía

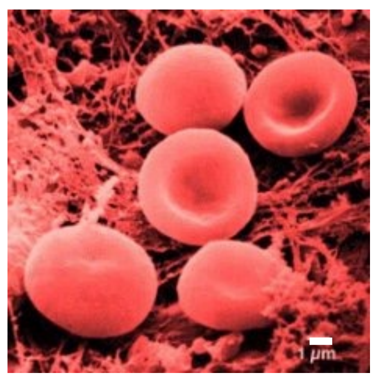
¿Qué es la nanofotónica?

1 m=1.000.000.000 nm

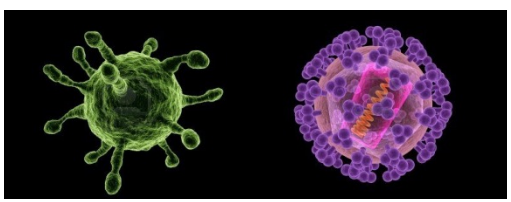
LUZ

Cabeza de alfiler: ~1 mm =1.000.000 nm

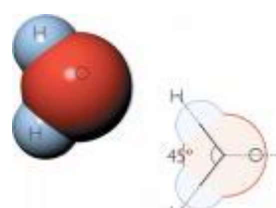
Glóbulo rojo: ~7-8 micras=7000-8000 nm

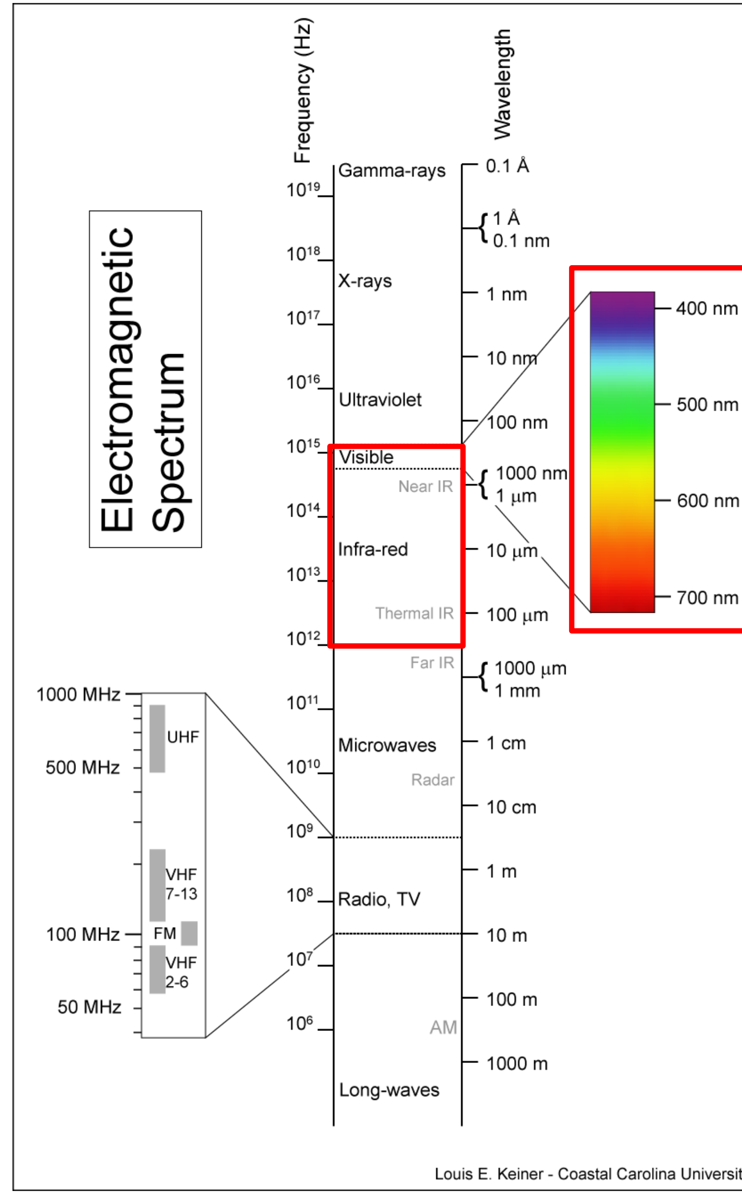


Virus: 24 – 300 nm



Molécula de agua: ~0.275 nm





¿Qué es la nanofotónica?

ELECTROMAGNETISMO + MATERIA CONDENSADA:

PROPAGACIÓN, CONFINAMIENTO E INTERACCIÓN RADIACIÓN-MATERIA EN ESCALAS POR DEBAJO DE LA LONG. DE ONDA (λ)

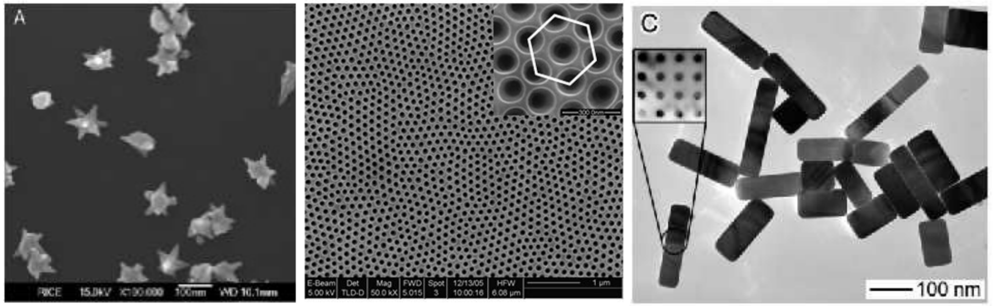
$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \cdot \mathbf{D} = \rho$$

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

- Medio contínuo
- Propiedades Macroscópicas
- Ecs. Constitutivas para ***D*** y ***B***



ENTONCES… ¿QUÉ HACEMOS NOSOTROS, EXACTAMENTE?

- Estudiamos cómo se comporta la luz al interactuar con un objeto (nanométrico)
- Estudiamos qué diseño es el mas adecuado para un propósito concreto.

y… ¿CÓMO LO HACEMOS?

- ¡Es muy sencillo!

  escribimos las ecuaciones que describen la física del sistema y, generalmente:

  - Modelos analíticos
  - Cálculos numéricos: métodos caseros y/o software comercial

Fenomenología de interés en Nanofotónica

- Metasuperficies & Metamateriales
- Luz Magnética en dieléctricos de alto índice
- Fotónica Topológica → Vincenzo
- Plasmones Superficiales Localizados → todo Grupo
- Nanohilos semiconductores: Fotoluminiscencia y absorción

METALES EN EL VISIBLE

Teoría de Drude para metales: el modelo de electrones libres

$$\mathbf{D}(\mathbf{r},\omega) = \epsilon(\omega)\mathbf{E}(\mathbf{r},\omega), \epsilon(\omega) = 1 - \frac{\omega_p^2}{\omega(\omega + \imath\gamma)}$$

$$\omega_p \equiv \text{frecuencia de plasma}$$

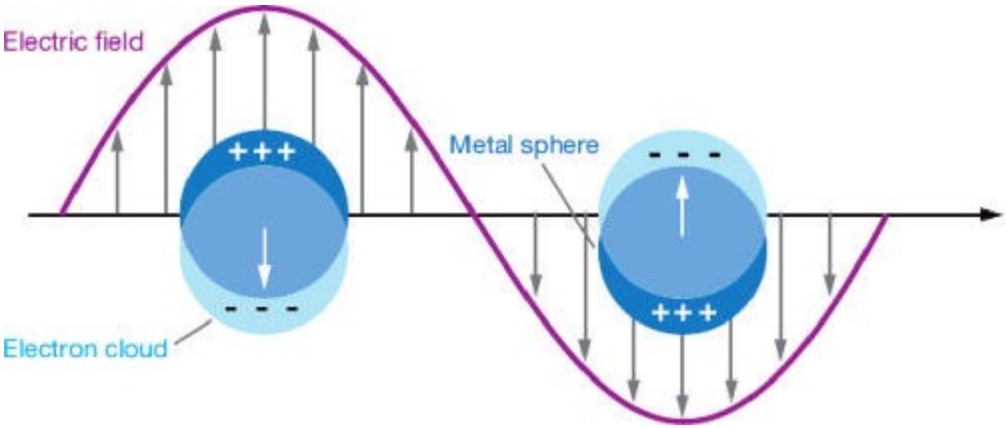
$$\text{Si}:$$
$$\omega < \omega_p, \text{material opaco}$$
$$\omega > \omega_p, \text{material transparente}$$
$$\omega = \omega_p, \text{oscilaciones densidad de carga}$$

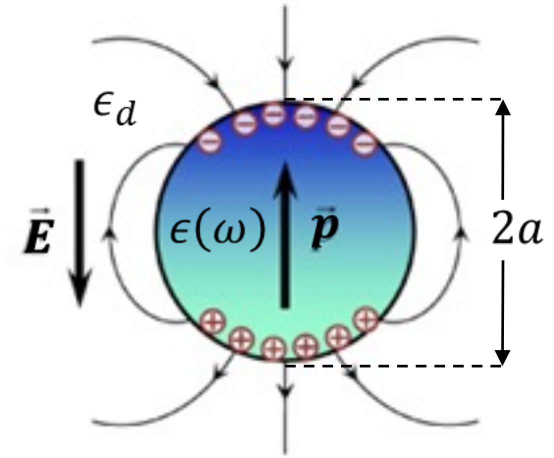
¡SOLUCIONES CONFINADAS EN LA FRONTERA METAL-DIELÉCTRICO!

PLASMONES SUPERFICIALES

PLASMONES SUPERFICIALES LOCALIZADOS

(LOCALIZED SURFACE PLASMON RESONANCES)





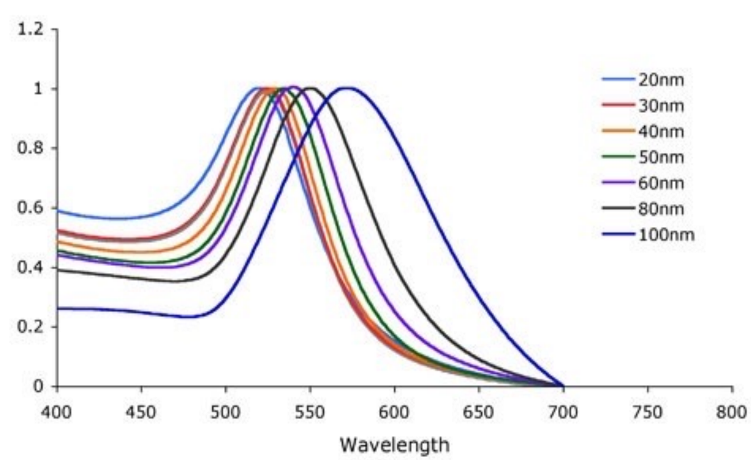
TEORÍA DE G. MIE (1908)

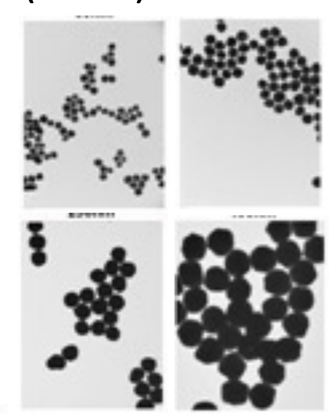
ELECTROSTÁTICA

$$\boldsymbol{p} \propto \alpha_E \boldsymbol{E}, \qquad \alpha_E = a^3 \frac{\epsilon(\omega) - \epsilon_d}{\epsilon(\omega) + 2\epsilon_d}$$

$$\omega_{res} \rightarrow \epsilon(\omega_{res}) = -2\epsilon_d$$

$$\omega_{res} = \frac{\omega_p}{\sqrt{3}}$$





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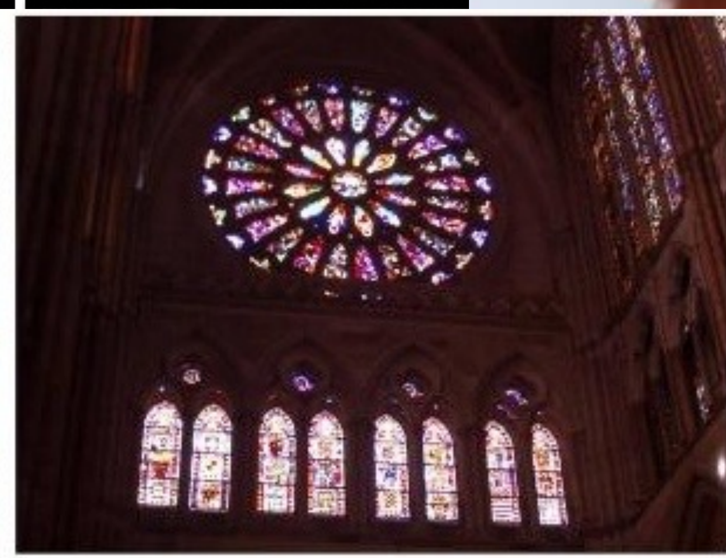
SURFACE PLASMON

Sensores

índice de ref

RFACE PLASMONS

mbarazo

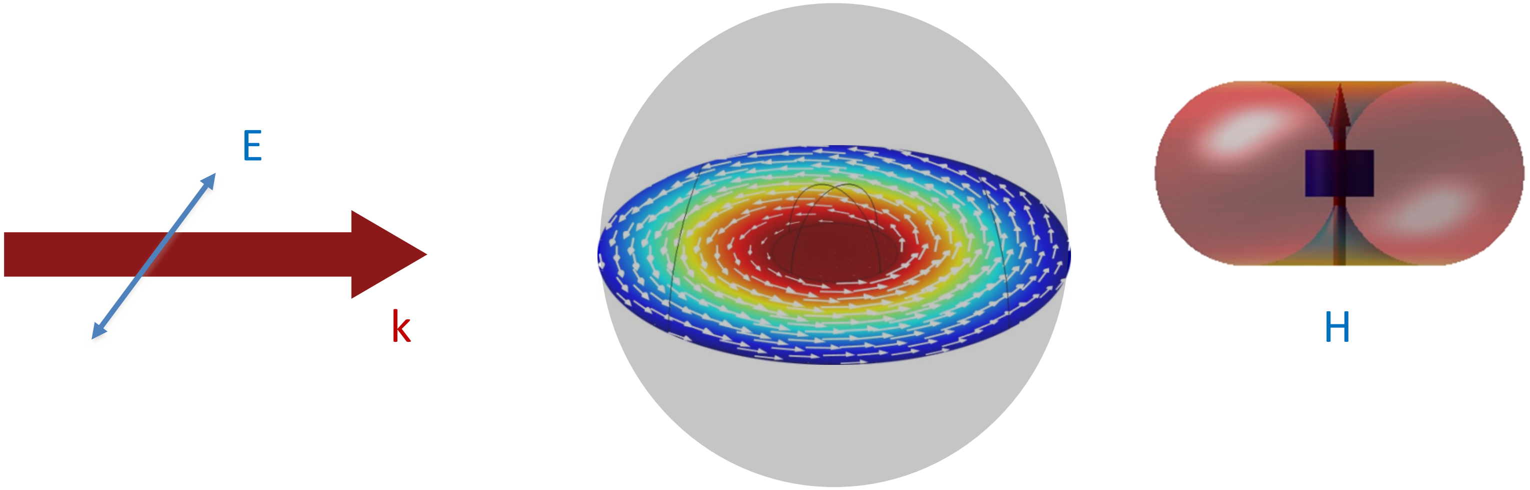


DIELÉCTRICOS DE ALTO ÍNDICE

EN TODO EL ESPECTRO, INCLUSO EL VISIBLE (con semiconductores)

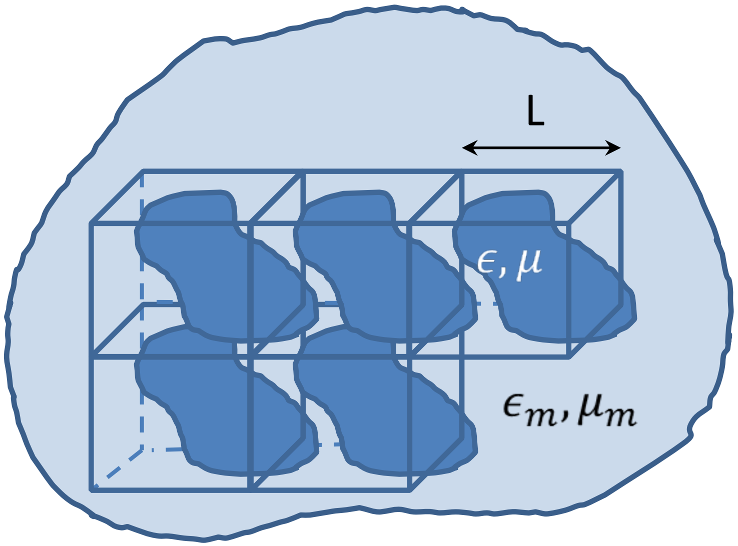
Teoría de Mie para esferas/cilindros: RESONANCIAS MIE

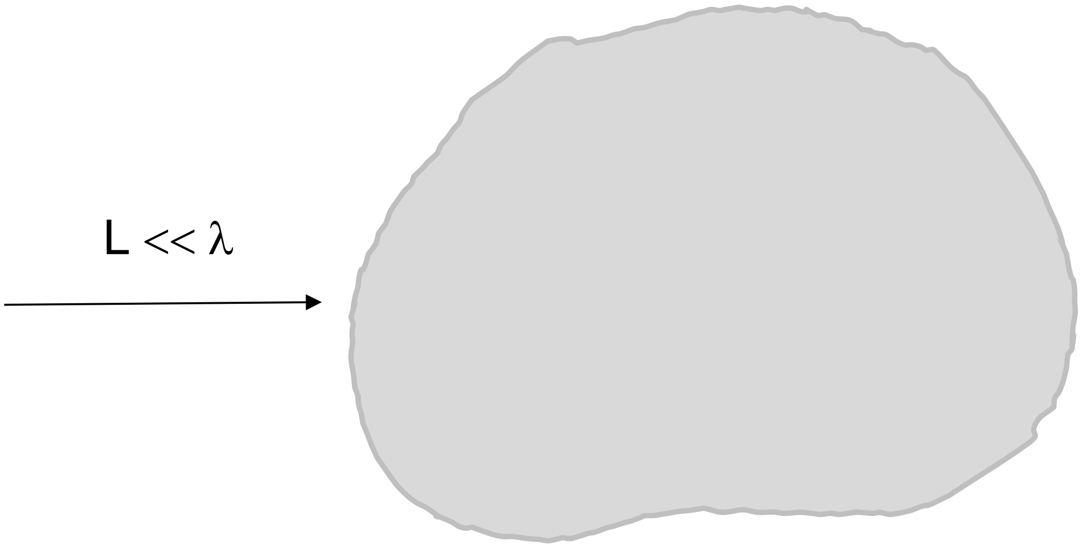
Orden mas bajo: resonancia dipolar magnética!!



➔ LUZ MAGNÉTICA!!

¿Qué son los **metamateriales**?





$$\boldsymbol{D}(\boldsymbol{r}) = \epsilon_0 \epsilon(\omega) \boldsymbol{E}(\boldsymbol{r}),$$
$$\boldsymbol{B}(\boldsymbol{r}) = \mu_0 \mu(\omega) \boldsymbol{H}(\boldsymbol{r})$$

$$\langle \boldsymbol{D}(\boldsymbol{r}) \rangle = \epsilon_0 \epsilon_{eff}(\omega) \langle \boldsymbol{E}(\boldsymbol{r}) \rangle,$$
$$\langle \boldsymbol{B}(\boldsymbol{r}) \rangle = \mu_0 \mu_{eff}(\omega) \langle \boldsymbol{H}(\boldsymbol{r}) \rangle$$

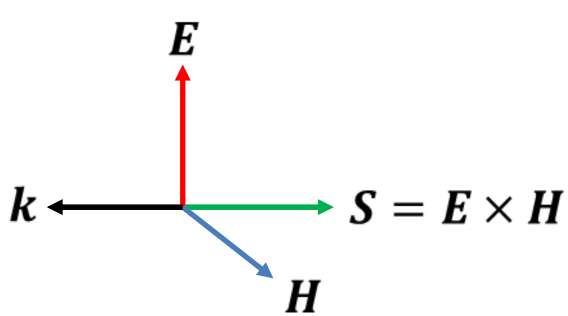
$$¿\epsilon_{eff}, \mu_{eff} \leftrightarrow \epsilon_m, \mu_m, \epsilon, \mu?$$

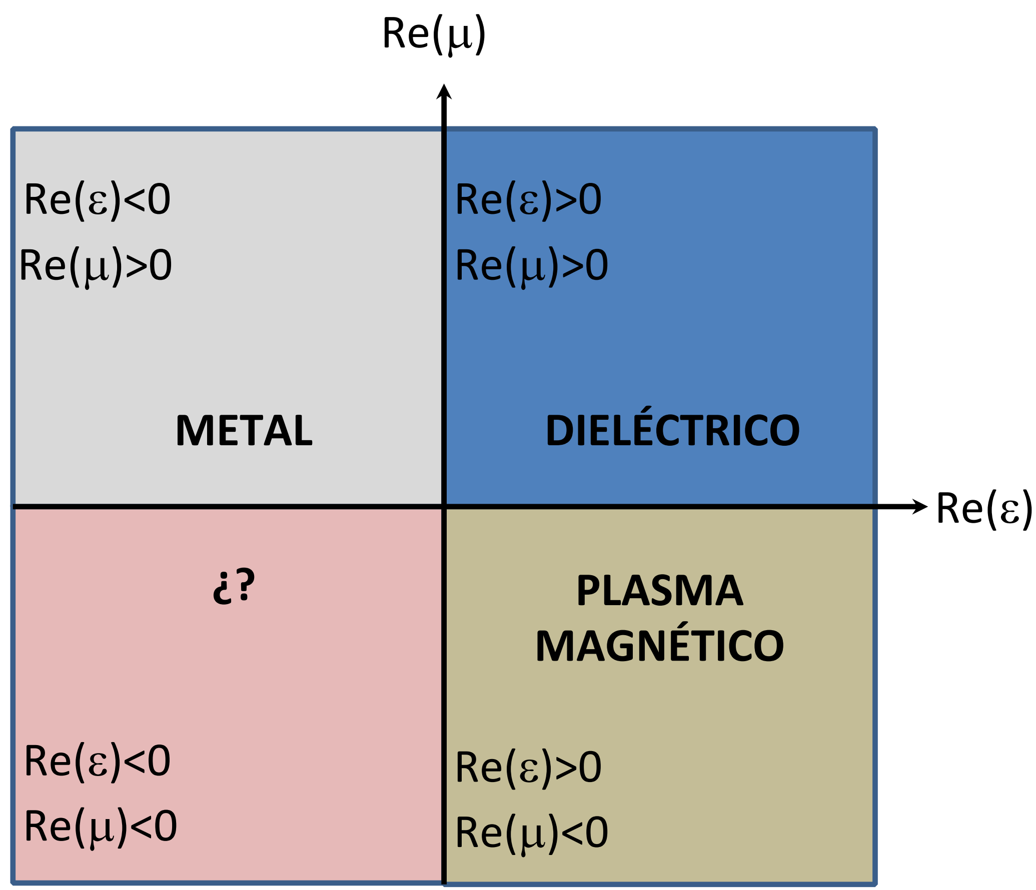
"Jugando con las piezas" podemos obtener…

…cualquier valor de Re(ε_{eff}) y de Re(μ_{eff})!!!

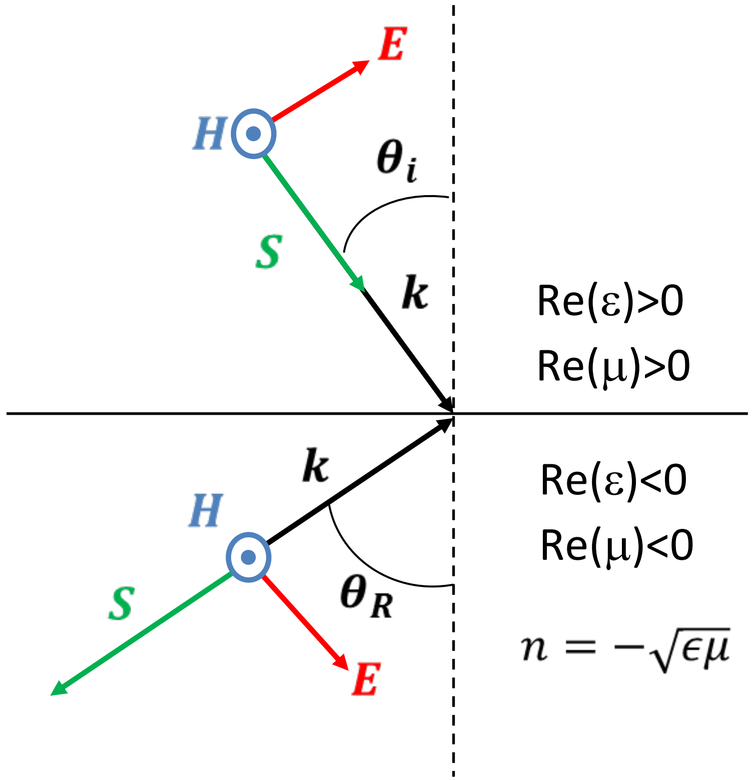
Metamateriales "zurdos"

$$\boldsymbol{k} \times \boldsymbol{E} = \omega\mu\mu_0\boldsymbol{H}$$
$$\boldsymbol{k} \times \boldsymbol{H} = -\omega\epsilon\epsilon_0\boldsymbol{E}$$



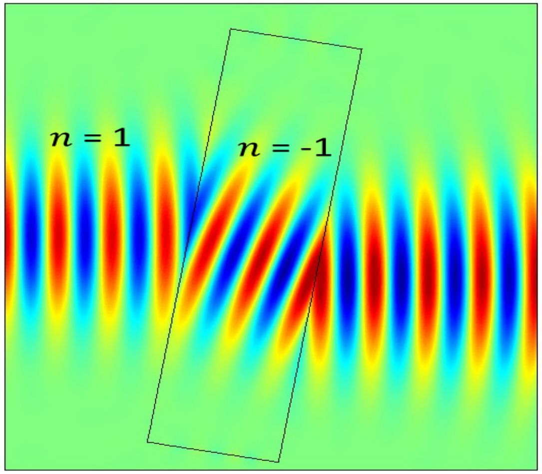


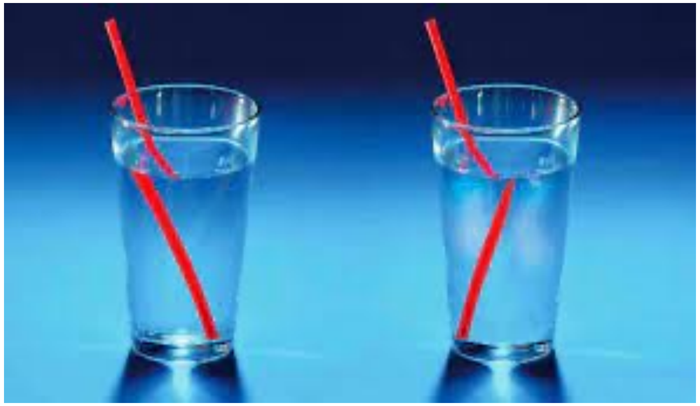
Refracción negativa

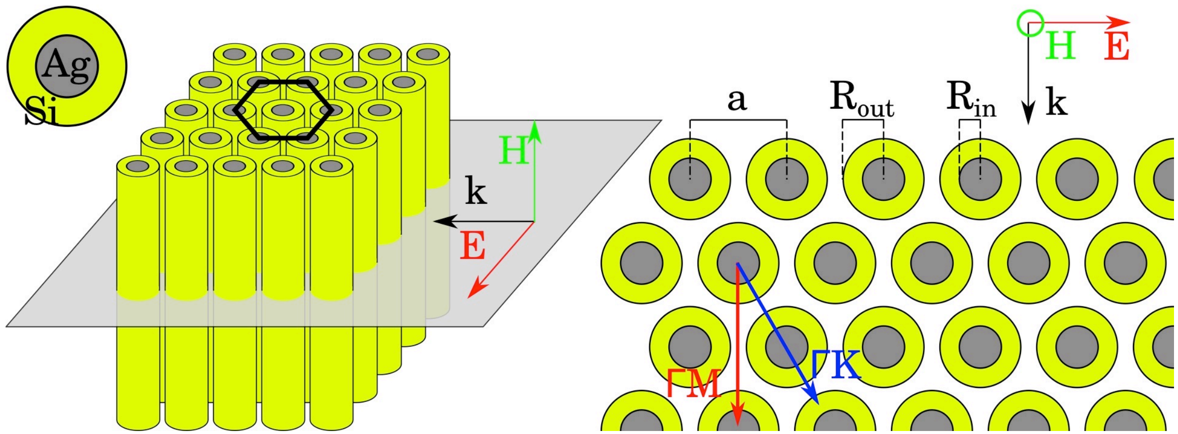


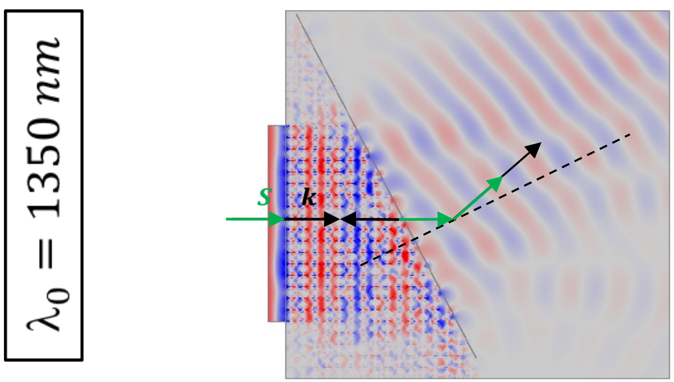
$$n = -\sqrt{\epsilon\mu}$$

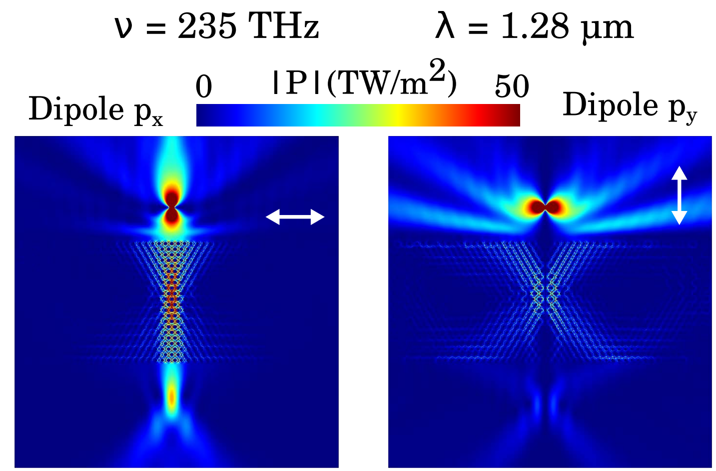
$$n_i \sin\theta_i = n_R \sin\theta_R$$











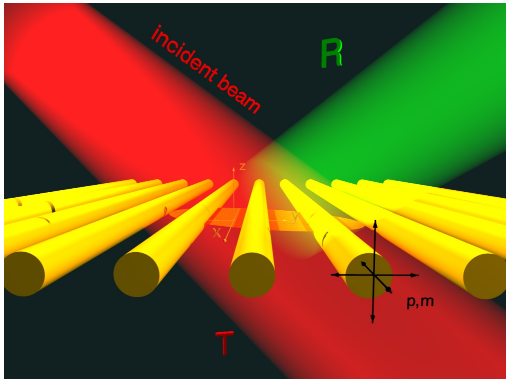
Negative Refraction

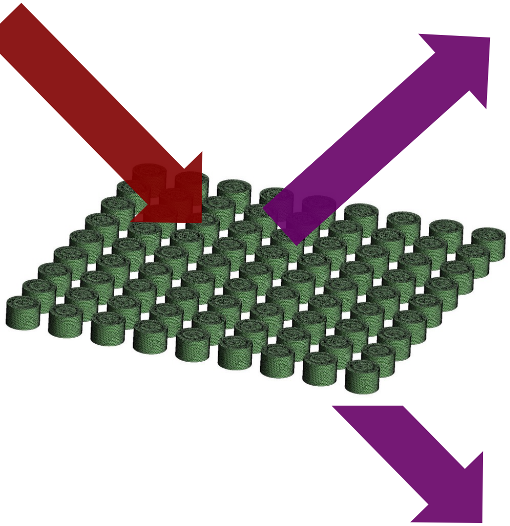
R. Paniagua-Domínguez et al., *New. J. Phys.* (2011)
, *Sci. Reports* (2013)

Flat lensing

Abujetas et al., *J. Opt.* (2015)

Non-diffractive regime imposes that there are only 2 (specular) outgoing channels





Exotic optical properties in (very thin) planar arrays!!

Bound states in the continuum

"a wave state with the frequency inside the continuous spectrum can only be a 'resonance' that leaks and radiates out to infinity. A ***bound state in the continuum*** *(BIC) is an exception to this conventional wisdom: it lies inside the continuum and coexists with extended waves, but it remains perfectly confined without any radiation."*

Hsu, Zhen, Stone, Joannopoulos, Soljačić, Nat. Rev. Mater. 1, 16048 (2016).

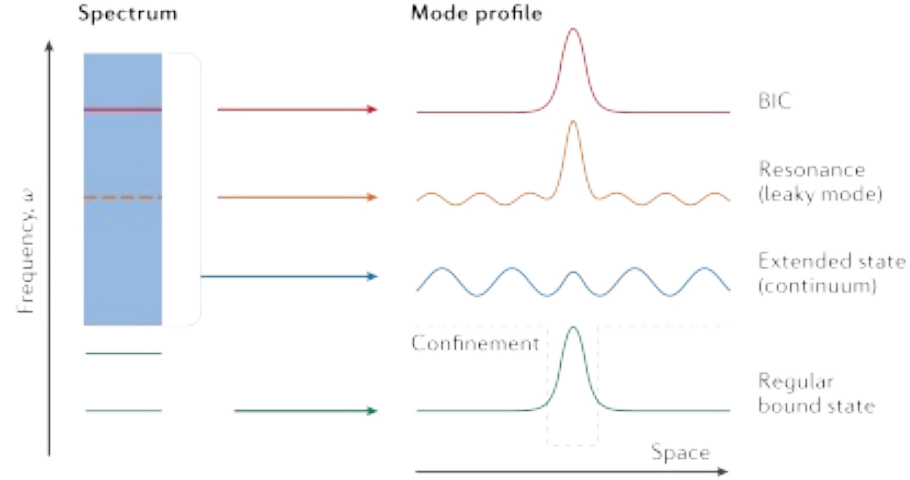
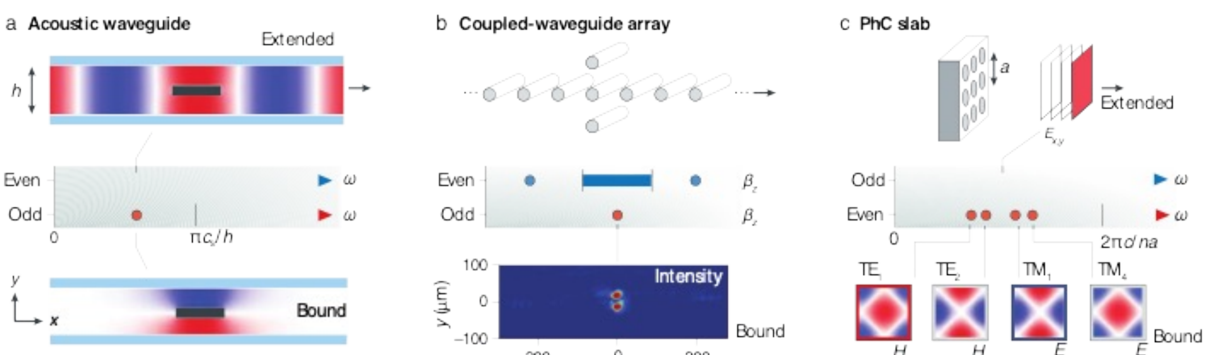
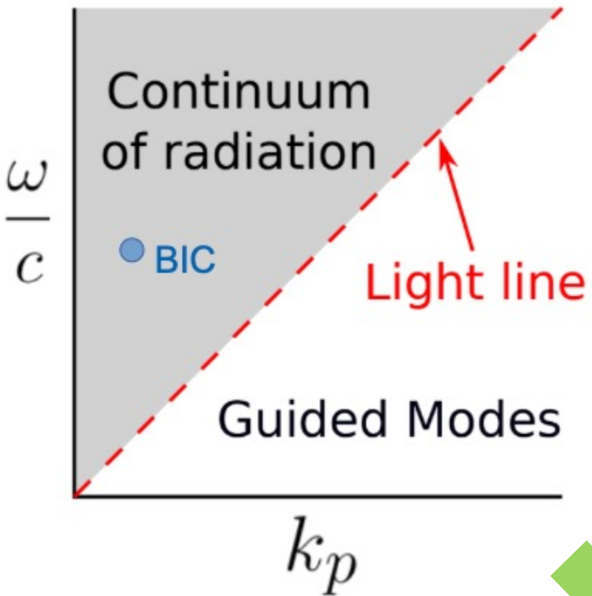


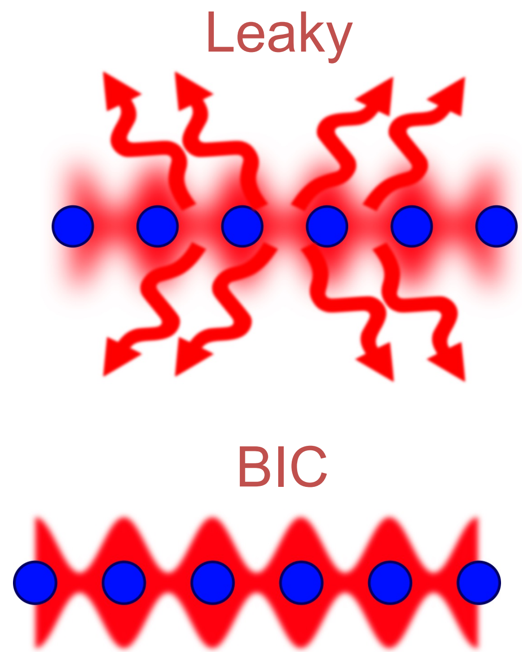
Figure 1 | **Illustration of a BIC.** In an open system, the frequency spectrum consists of a continuum or several continua of spatially extended states (blue) and discrete levels of bound states (green) that carry no outgoing flux. The spatial localization of the bound states is a consequence of a confining structure or potential (black dashed line). States inside the continuous spectrum typically couple to the extended waves and radiate, becoming leaky resonances (orange). Bound states in the continuum (BICs; red) are special states that lie inside the continuum but remain localized with no radiation.

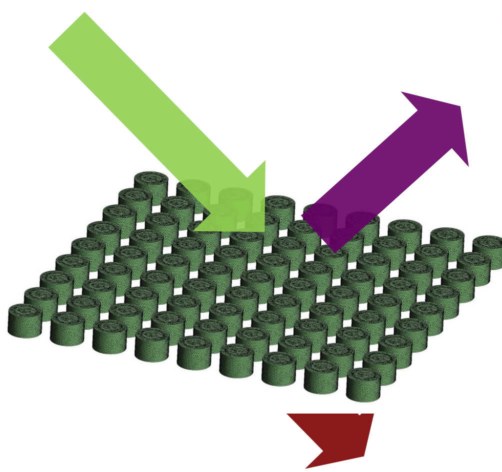
Mechanisms: symmetry, parameter tuning,…



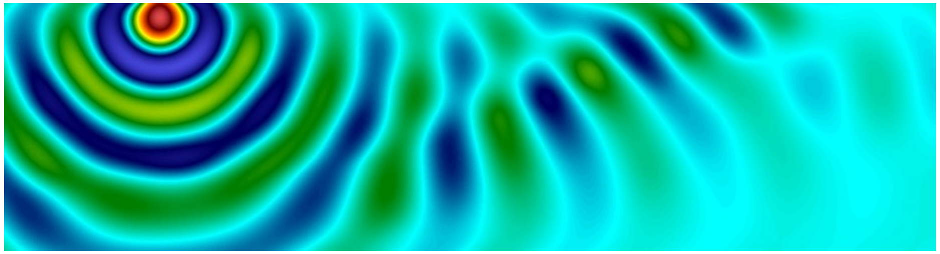
Metasurface BICs



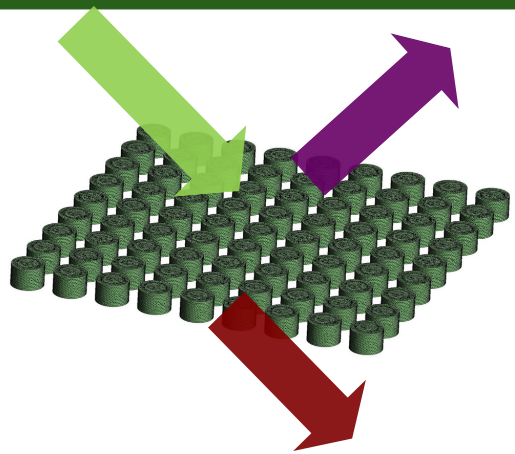


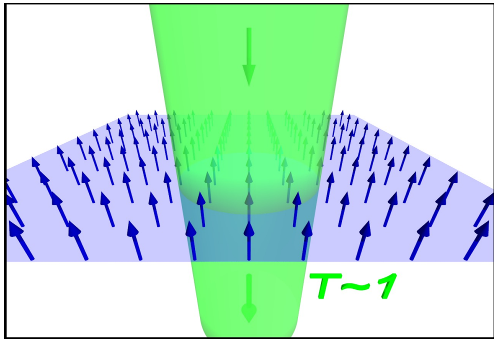


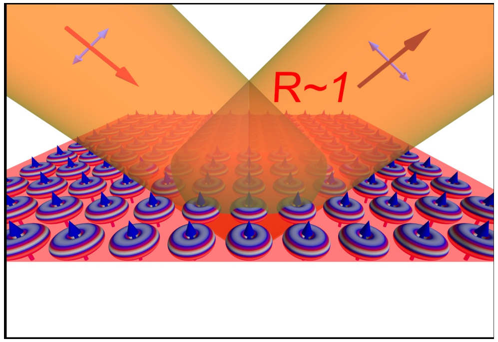
What cancels outcoupling??

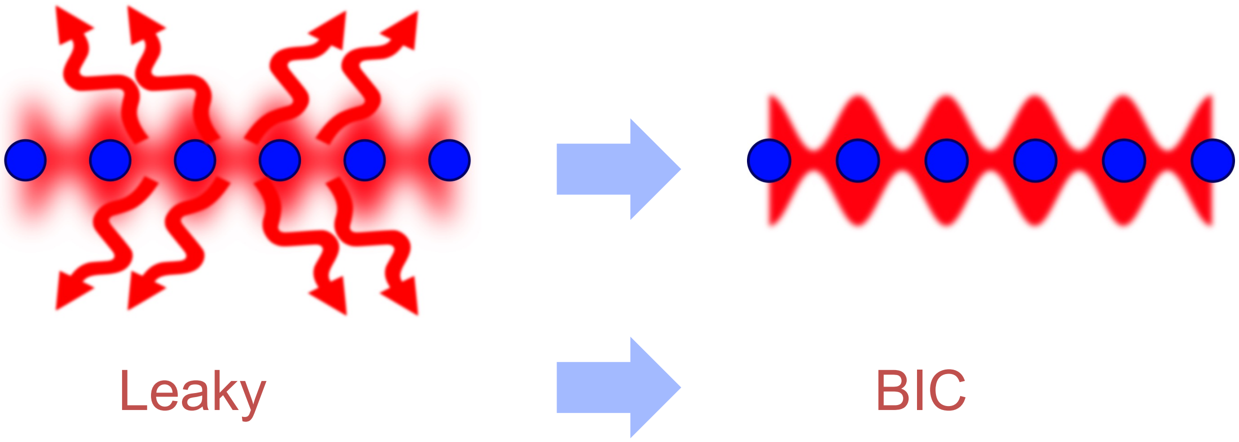


HRI disk Metasurfaces









Symmetry-protected
Bound states in the continuum

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Bound states in the continuum in resonant-structure metasurfaces

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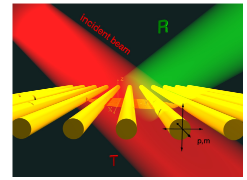
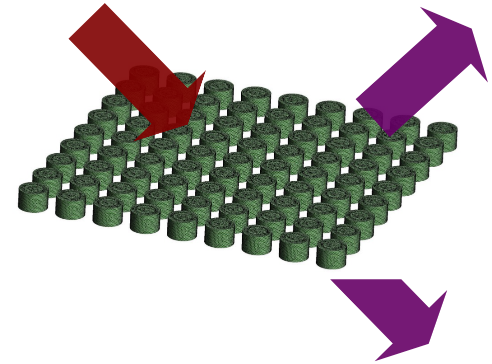
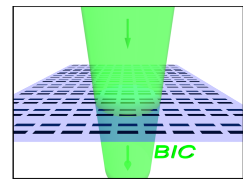
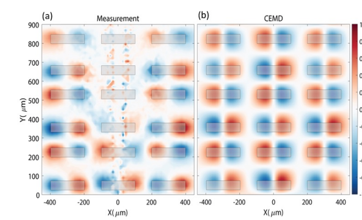
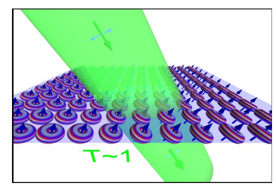


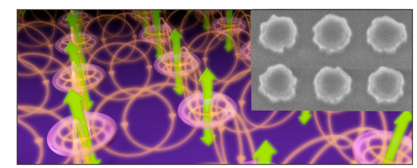


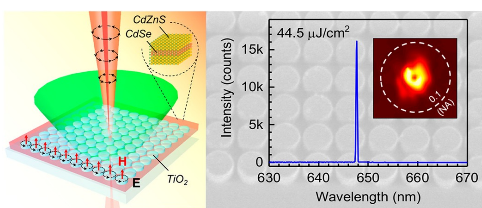
- Coupled electric-magnetic dipole theory for planar arrays: Brewster, Fano, BICs…
- Dimer metasurfaces (THz & visible): detuned-dipole BICs
- HRI Disk metasurface (GHz & visible): MD-BICs & Brewster quasi BICs
- Apps: BIC-mediated EIT, Lasing & MO switching











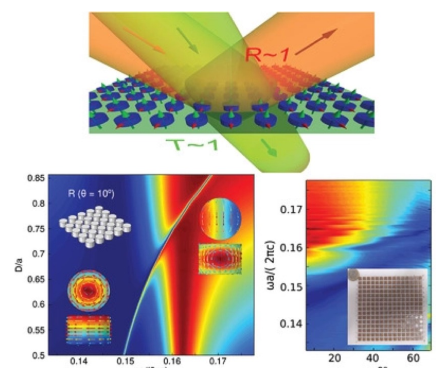
NANO LETTERS

pubs.acs.org/NanoLett Letter

Room-Temperature Lasing in Colloidal Nanoplatelets via Mie-Resonant Bound States in the Continuum

Mengfei Wu,⊥ Son Tung Ha,⊥ Sushant Shendre, Emek G. Durmusoglu, Weon-Kyu Koh, Diego R. Abujetas, José A. Sánchez-Gil, Ramón Paniagua-Domínguez, Hilmi Volkan Demir,* and Arseniy I. Kuznetsov*

Cite This: Nano Lett. 2020, 20, 6005−6011 Read Online



ORIGINAL PAPER

LASER & PHOTONICS REVIEWS
www.lpr-journal.org

High-Q Transparency Band in All-Dielectric Metasurfaces Induced by a Quasi Bound State in the Continuum

Diego R. Abujetas, Ángela Barreda, Fernando Moreno, Amelie Litman, Jean-Michel Geffrin, and José A. Sánchez-Gil**

IEM Instituto de Estructura de la Materia

Collaborators

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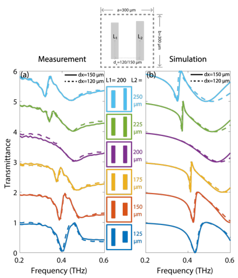
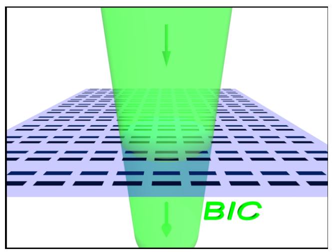
Niels van Hoof, Stan ter Huurne, J. Gómez Rivas

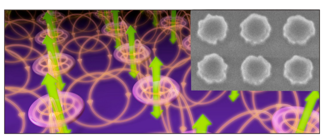
Technical University Eindhoven

TU/e

Surface Photonics







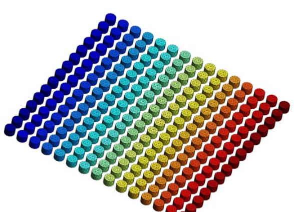
Shunsuke Murai

Kyoto University

Kyoto University Founded 1897

R. Paniagua, Arseniy Kuznetsov

*IMRE, A*Star, Singapore*



Institute of Materials Research and Engineering

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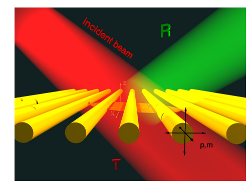
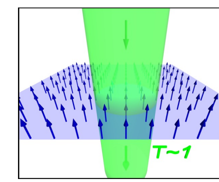
Nuno de Sousa

Jorge Olmos

Donostia International Physics Center





UC UNIVERSIDAD DE CANTABRIA

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Group Research Lines

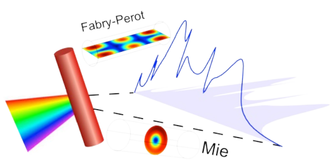
CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

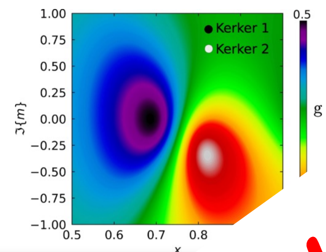
Resonant HRI Nanostructrures & Metasurfaces

ACS Photonics Article pubs.acs.org/journal/apchd5

High-Contrast Fano Resonances in Single Semiconductor Nanorods

Diego R. Abujetas,† Miguel A. G. Mandujano,† Eugenio R. Méndez,† and José A. Sánchez-Gil*,†

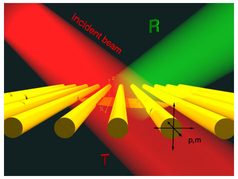




Research Article Vol. 26, No. 24 | 26 Nov 2018 | OPTICS EXPRESS 31523
Optics EXPRESS

Generalized Brewster effect in high-refractive-index nanorod-based metasurfaces

DIEGO ROMERO ABUJETAS,[1,2,*] . SÁNCHEZ-GIL,[1] AND JUAN JOSÉ SÁENZ[2,3]



W LETTERS 125, 073205 (2020)

upon Lossless, Absorption, and Optical Gain Regimes

..una Sanz-Fernández,[2] Diego R. Abujetas,[1,3] Jon Lasa-Alonso,[1,2] Nuno de Sousa,[1] ..arri,[1,2] José A. Sánchez-Gil,[3] Gabriel Molina-Terriza,[1,2,4] and Juan José Sáenz[1,4]

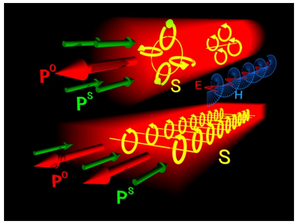
Help wanted!!

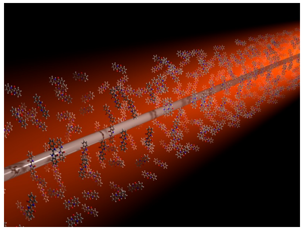
Nanowire Pho... SAM + Stro...ng

ACS Photonics pubs.acs.org/journal/apchd5 Artic

Spin Angular Momentum of Guided Light Induced by Transverse Confinement and Intrinsic Helicity

Diego R. Abujetas* and José A. Sánchez-Gil





PHYSICAL REVIEW B 99, 205409 (2019)

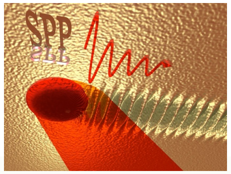
Strong coupling between weakly guided semiconductor nanowire modes and an organic dye

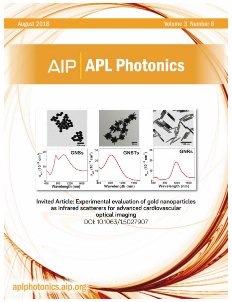
Diego R. Abujetas,[1] Johannes Feist,[2] Francisco J. García-Vidal,[2] Jaime Gómez Rivas,[1] and José A. Sánchez-Gil[1]

ACS OMEGA Article http://pubs.acs.org/journal/acsodf

Surface Plasmon Polaritons on Rough Metal Surfaces: Role in the Formation of Laser-Induced Periodic Surface Structures

Yasser Fuentes-Edfuf,† José A. Sánchez-Gil,*,† Camilo Florian,† Vincenzo Giannini,† Javier Solis,† and Jan Siegel*,†





Plasmonics: LIPSS & Au NPs

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