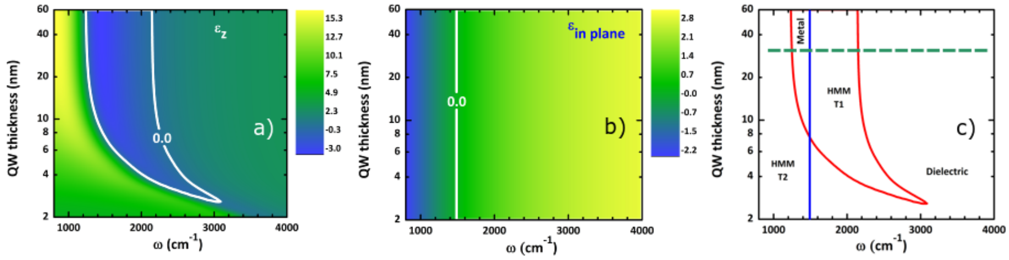
Optical phase transition in semiconductor quantum metamaterials

OPTO NANO ELECTRO



Hyperbolic metamaterial condition with a nominal doping of $n{\sim}5 \cdot 10^{19} cm^{-3}$ *and* $l_{ZnO}/l_{MgZnO} = 3$.
(a,b) *Real part of the effective permittivity out-of-plane (a) and in-plane*
(b) *as a function of the frequency and QW thickness. The white solid curves show the sign inversions.*
(c) *Optical phase transition diagram of the system as a function of frequency and QW thickness.*

Prediction and observation of an optical phase transition in a quantum metamaterial based on heterostructured semiconductors

The direction of refracted light at an interface between two media generally follows the conventional Snell-Descartes law. By stacking subwavelength-thick metallic and dielectric layers to form metamaterials, it is possible to realize unexpected behavior such as negative refraction. These effects result from the interaction with metallic or dielectric / amorphous nanostructured materials. Here we report on the optical phase transition in quantum metamaterials based on heterostructured semiconductors. We demonstrate that the hyperbolic response in quantum superlattices is generic and can be unambiguously attributed to the electronic quantum confinement of the electrons in quantum wells, acting as an adjustable resonance to achieve negative refraction behaviour at mid-infrared wavelength. We show theoretically and demonstrate experimentally that both the thicknesses and the doping levels, carefully chosen for each layer to feature strong intersubband transitions, lead to type 1 and type 2 hyperbolic response in highly doped ZnO/(Zn,Mg)O semiconductor material. Taking into consideration these results would enable new designs of mid-IR and THz quantum devices.

Breakthroughs

This work connects for the first time the concepts of intersubband plasmons with the photonic response of hyperbolic metamaterials. This work highlights the role of quantum confinement in the photonic response of quantum heterostructured materials, and proves that the electronic intersubband resonance in some of the most conventional heterostructured materials could lead to unexpected metamaterial behavior such as optical phase transitions.

Perspectives

- Extension of the wavelentgth operation in the THz and visible.
- Active optical response of the metamaterial

Collaborations : ISOM-Madrid

More information : funded by ERC “Flatlight” GA No 639109 (https://2dphotonics.weebly.com/) and FET-OPEN “Zoterac” GA No 665107 (www.Zoterac.eu)

Contact: Jean-Michel Chauveau - jmc@crhea.cnrs.fr