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Tailored Strong Light-Matter Interactions and Nonlinearities in Hybrid Dielectric Metasurfaces

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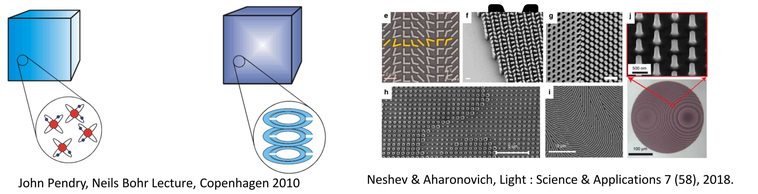
Introduction

Metamaterials and Metasurfaces

Metamaterial comprises of subwavelength sized and spaced resonators. Unlike natural materials, where light matter interaction is dictated by chemistry, in a metamaterial it can be controlled by controlling the shape, size, and spacing of resonators.

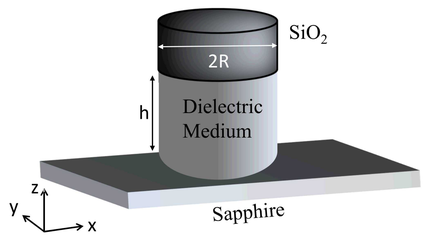
Natural Material | **Metamaterial** | **Metasurface : Two Dimensional Metamaterial**

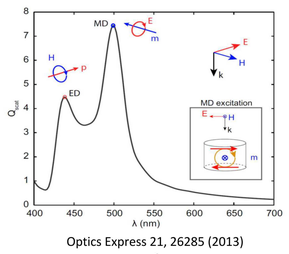


John Pendry, Neils Bohr Lecture, Copenhagen 2010

Neshev & Aharonovich, Light : Science & Applications 7 (58), 2018.

The All Dielectric Approach : Mie Modes



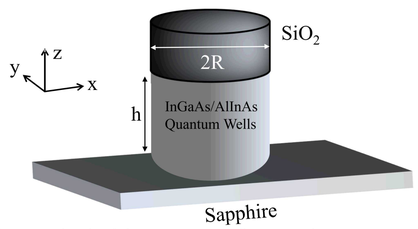


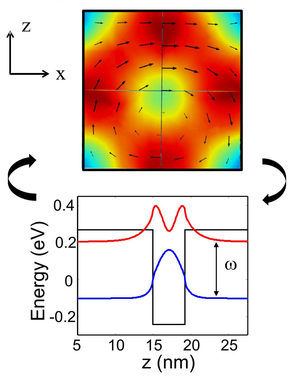
Optics Express 21, 26285 (2013)

Our all-dielectric approach uses dielectric resonators that support Mie modes and fabricated from high refractive index material [1].

Hybrid Dielectric Metasurface

Dielectric Metasurface Loaded with Quantum Wells

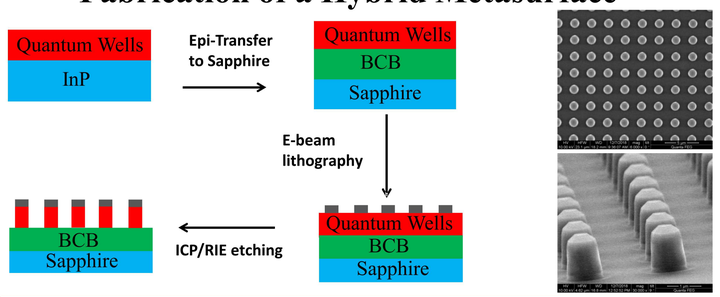




In a hybrid metasurface, the strength of light-matter interaction depends on [2] :

- The transition dipole moment and number of electrons.
- Field enhancement of the photonic mode.

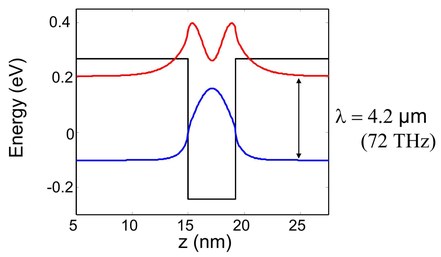
Fabrication of a Hybrid Metasurface



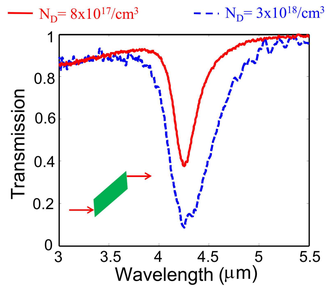
Tailored Light-Matter Interaction

Tailoring Polaritons by Engineering Heterostructure

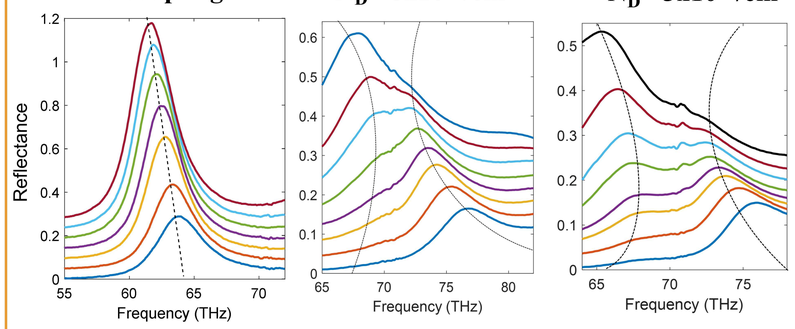
8 band k.p calculation



Transmission Measurement



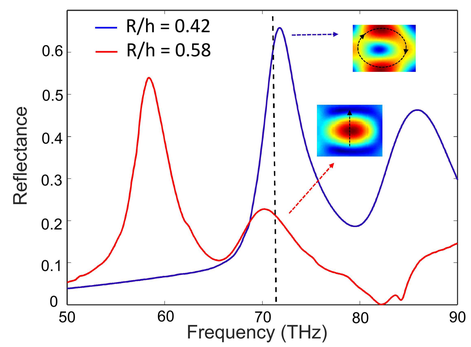
No coupling | **N_D= 8x10^{17}/cm^3** | **N_D= 3x10^{18}/cm^3**



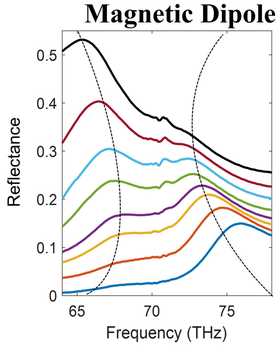
The strength of light-matter interactions can be engineered by controlling the doping or number of quantum wells.

Tailoring Polaritons Using Different Mie Modes

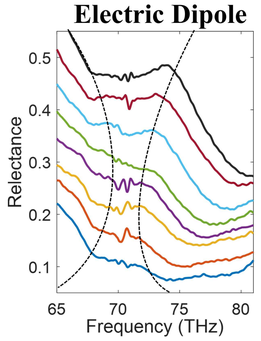
By controlling the geometry of the resonators we can make different Mie modes with different field distributions couple to the intersubband transitions in the quantum wells.



Magnetic Dipole



Electric Dipole

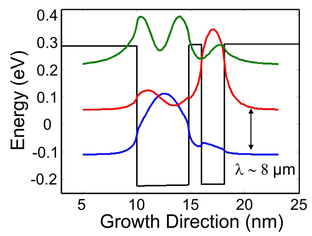


Second Harmonic Generation

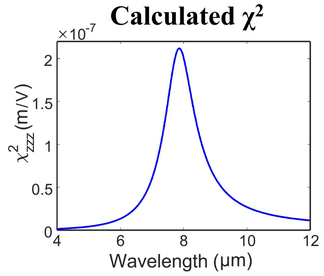
Resonant Second Order Nonlinearity

Intersubband transitions in multi-quantum well semiconductor heterostructures can generate one of the largest known second order nonlinearities [3, 4]. We use this resonant nonlinearity to fabricate ultrathin nonlinear optical devices which have relaxed phase matching requirements.

8 band k.p calculation

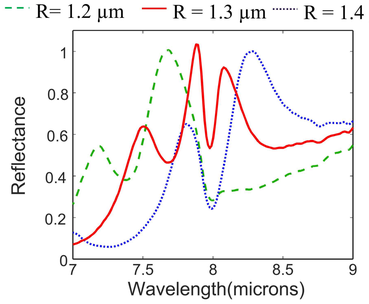


Calculated χ^2

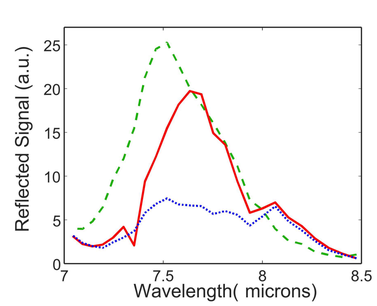


Experimental Demonstration

Linear Reflectance Measurement



Measured Second Harmonic



We fabricate metasurfaces with magnetic dipole resonances spectrally aligned to the first electronic transition to generate second harmonic.

Conclusion & References

- We have demonstrated a flexible and efficient all-dielectric metasurface based platform for tailoring strong light-matter interactions and for generating optical nonlinearities.
- Unlike plasmonic based approaches, our all-dielectric approach is free from ohmic losses and has high optical damage thresholds. Our approach is therefore ideal for fabricating efficient nonlinear optical devices with relaxed phase matching conditions.
- Although demonstrated for one wavelength, our approach can be scaled to other wavelengths by optimizing the heterostructure.

References:
[1] J. Ginn et al., *Phys Rev. Lett.* **108**, 097402 (2012).
[2] A. Benz et al., *Nat. Comm.* **4**, 2882 (2013).
[3] O. Wolf et al., *Nat. Comm.* **6**, 7667 (2015).
[4] J. Lee et al., *Adv. Optic. Mater.* **4**, 664 (2016).

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