Control of Second-Harmonic Generation in All-Dielectric Polaritonic Metasurfaces via Microscopic Control of $\chi^{(2)}$

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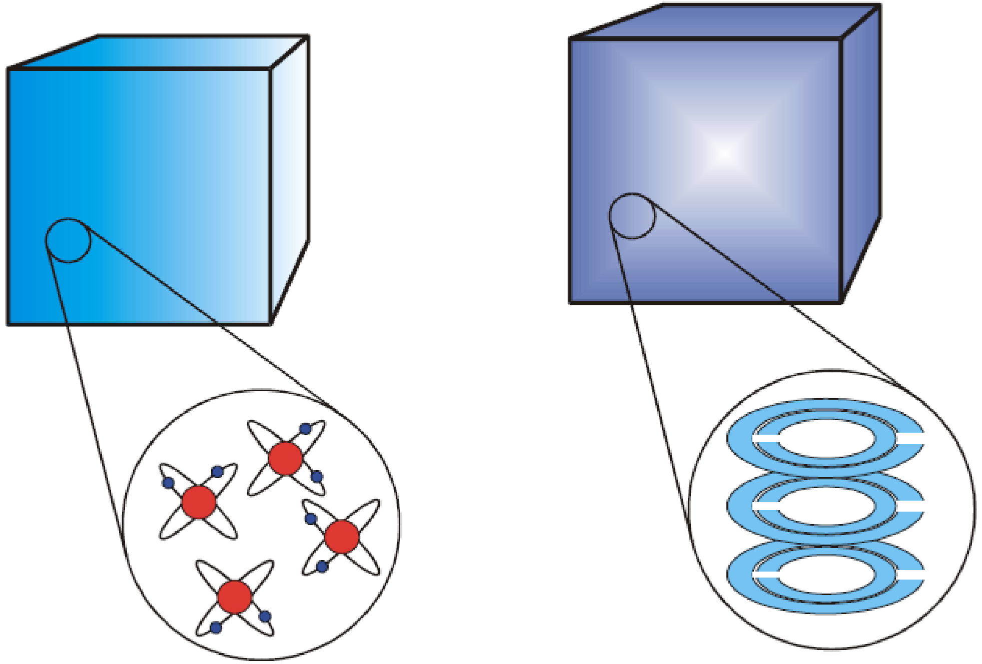
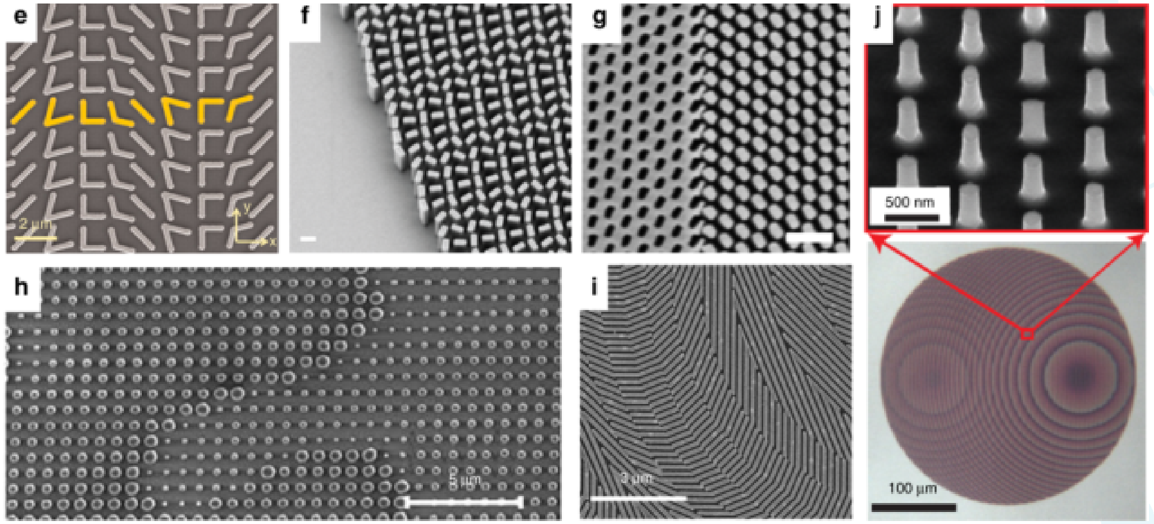
Metamaterials and Metasurfaces

Man-made "atoms" : Metamaterials



Metasurfaces



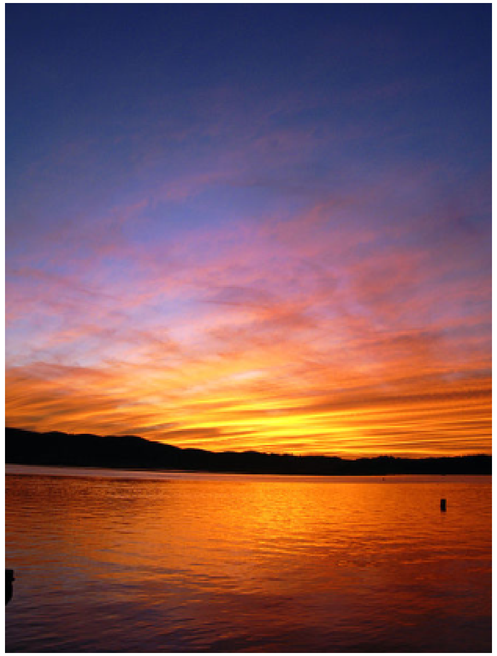
Ref. : Neshev & Aharonovich, Light : Science & Applications 7 (58), 2018.

In metamaterials, optical properties are determined by configuration and properties of meta-atoms.

Metasurfaces are planar (2D) equivalents of metamaterials.

The All-Dielectric Approach: Mie modes

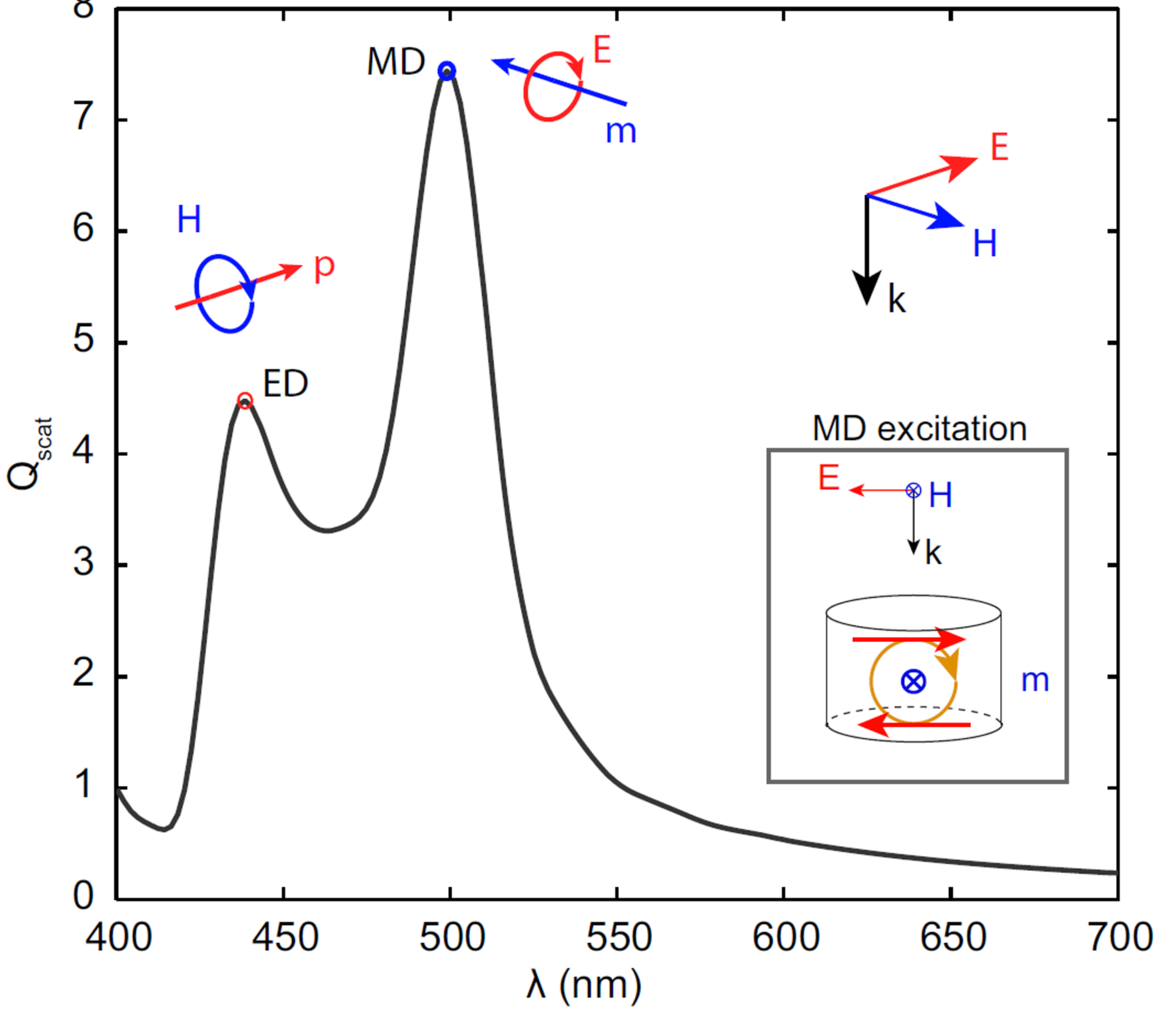
Dielectric particles much smaller than wavelength λ/n



Wikipedia

Rayleigh << λ/n

Mie modes in dielectric particles comparable ~ λ/n



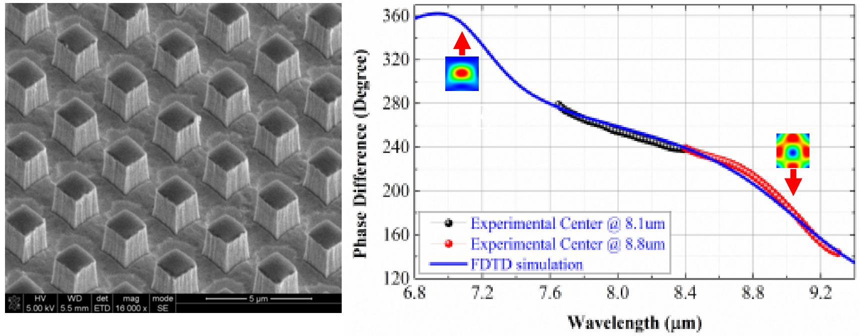
Ref. : Optics Express 21, 26285 (2013)

For dielectric particles, the polarizabilities of the electric and magnetic dipole resonances are <u>comparable at optical frequencies</u>

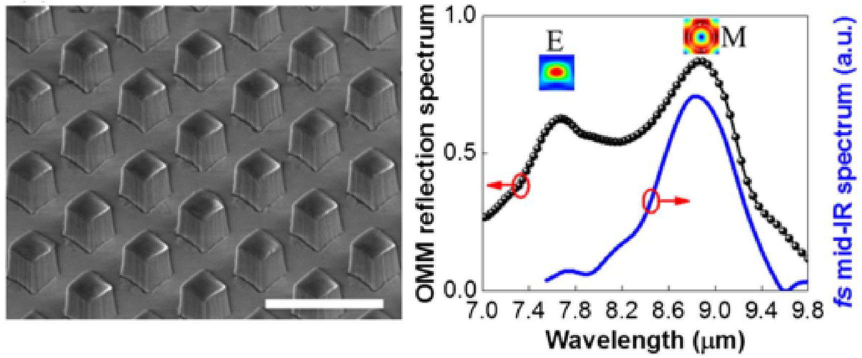
This is not the case for metallic resonators at optical frequencies because of metal losses

Applications of Mie Modes in Dielectric Metasurfaces

Magnetic Response

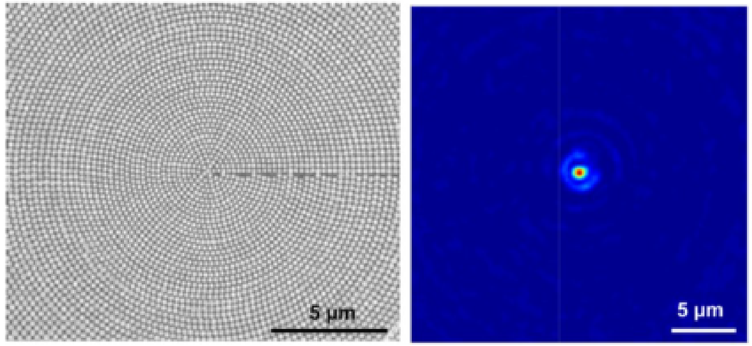


PRL. 108, 097402 (2012)

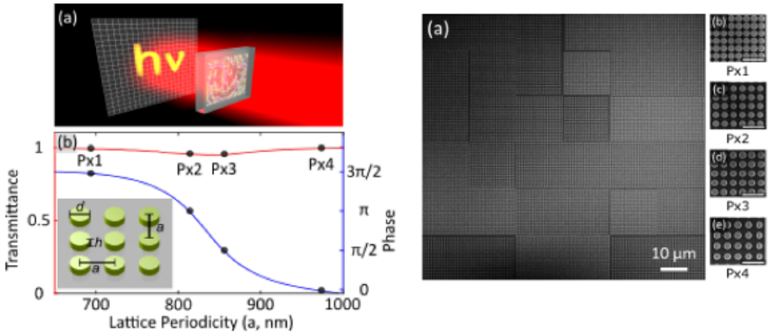


Optica 1, 250 (2014)

Tailoring Linear Transmission

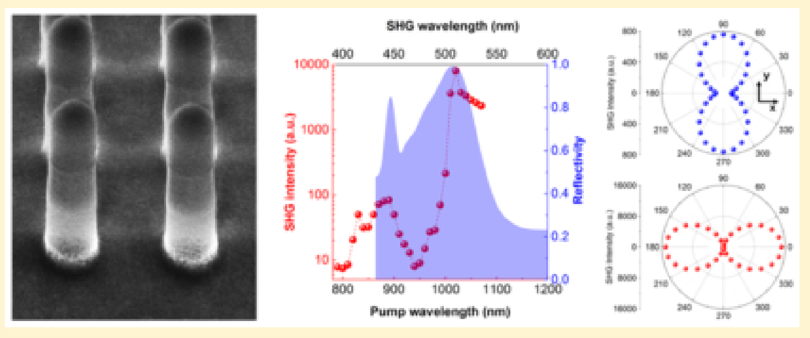


Argonne National Labs

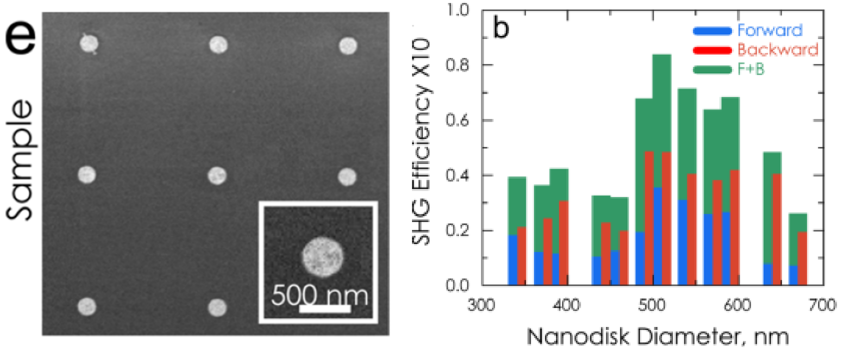


ACS Photonics 3, 514 (2016)

Nonlinear Optics



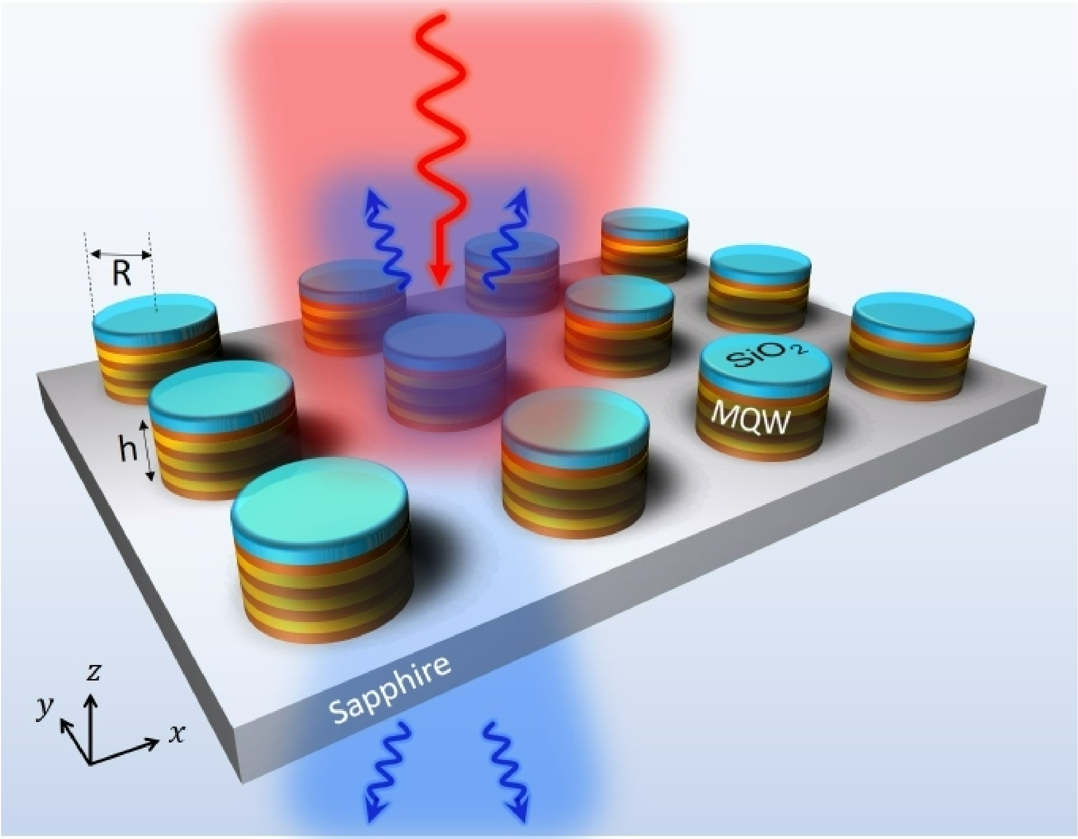
Nano Lett. 16, 5426 (2016)

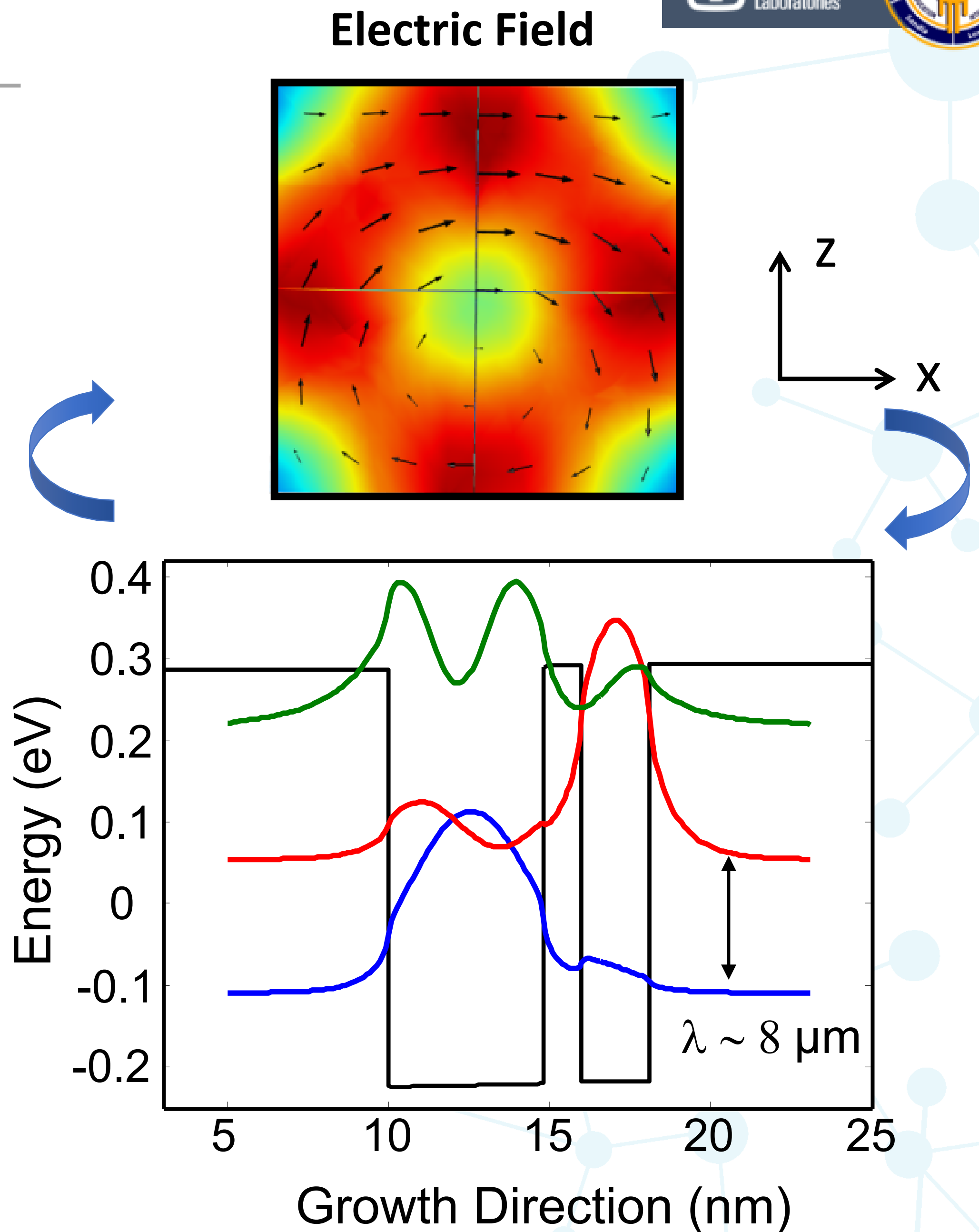


Nano Lett. 16, 7191 (2016)

Advantages of Nonlinear Mie Metasurfaces : **1. Ultrathin (relaxed phase matching) 2. Low loss and high damage thresholds 3. Large mode volume (enhanced light-matter interaction) 4. Ease of fabrication**

Polaritonic Metasurface : Light-Matter Coupling

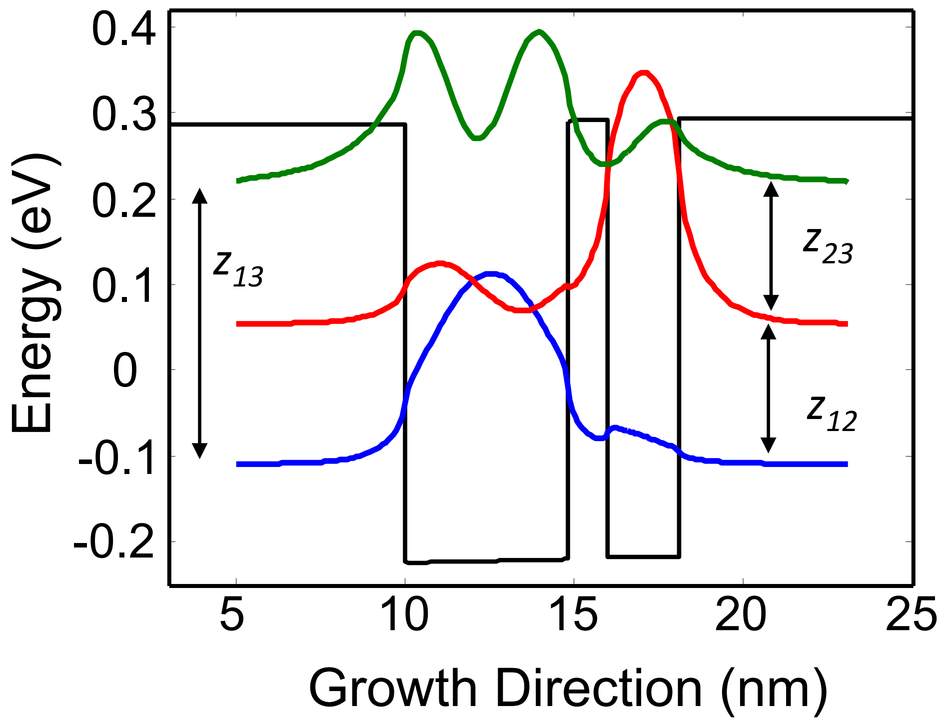


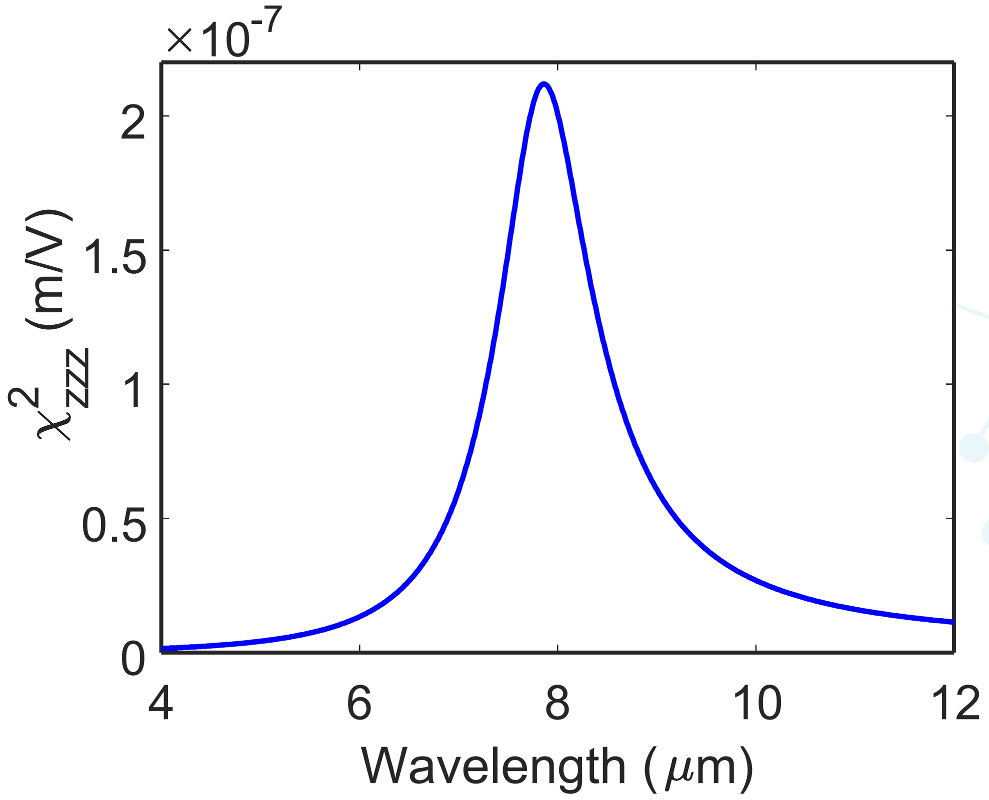


- Light-matter coupling between a MD Mie mode and intersubband electronic excitations.
- MD mode has strong z electric field components, allows for normal incidence, and smallest size of the resonator.

$\chi^{(2)}$ using Intersubband Transitions : Magnitude and Sign Control

InGaAs/AlInAs Quantum Wells $\lambda \sim 8$ μm





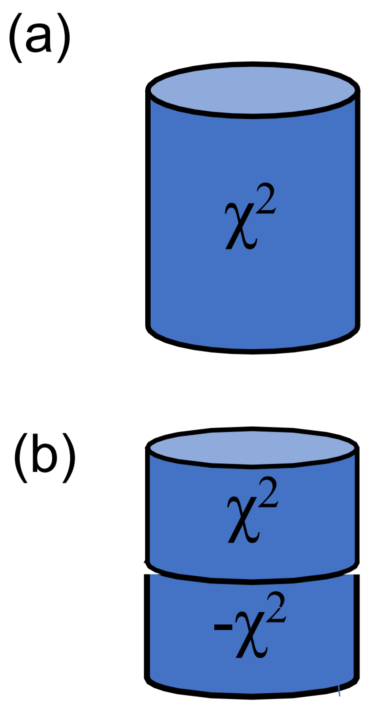
$$\chi^{(2)}(\omega) \propto \frac{N \cdot z_{12} z_{23} z_{13}}{(\omega - \omega_{12} - i\Gamma_{12})(2\omega - \omega_{13} - i\Gamma_{13})}$$

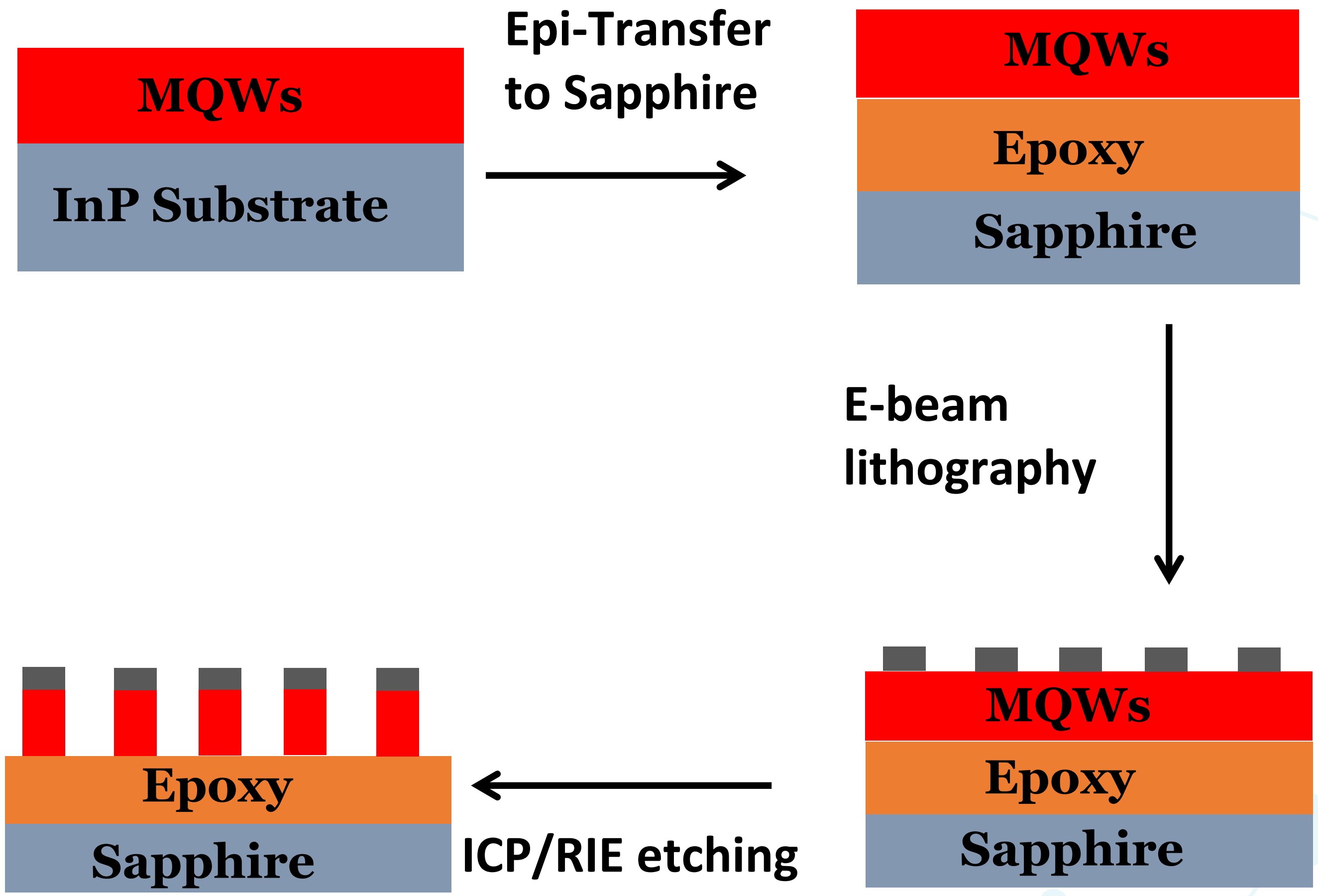
$$z_{ij} \propto \langle \Psi_i | \vec{R} | \Psi_j \rangle$$

Magnitude : Optimization of heterostructure
Sign : Growth sequence of QWs

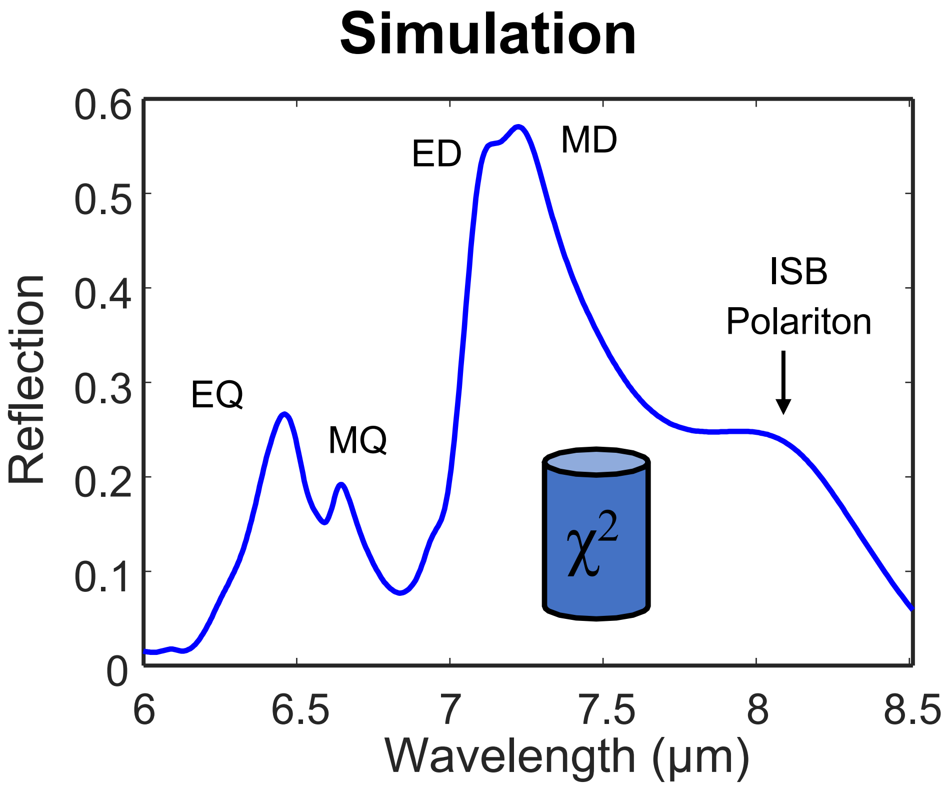
IEEE J. Quantum Electr. 30, 1313 (1994)

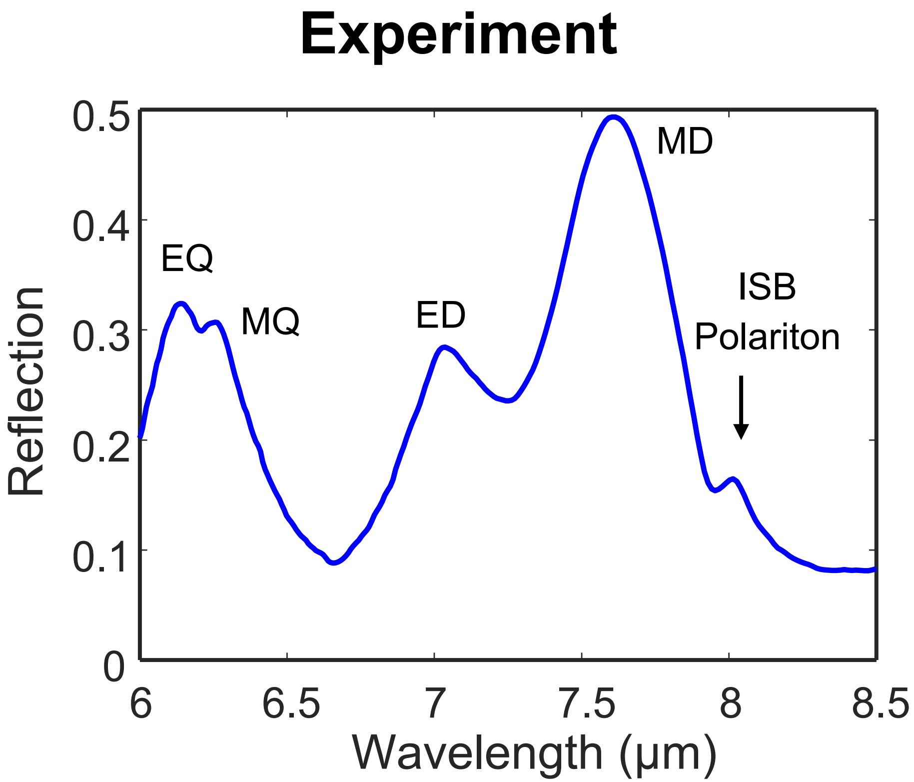
Fabrication of the Polaritonic All-Dielectric Metasurface





Linear Reflectance Spectra : Simulation and Experiment

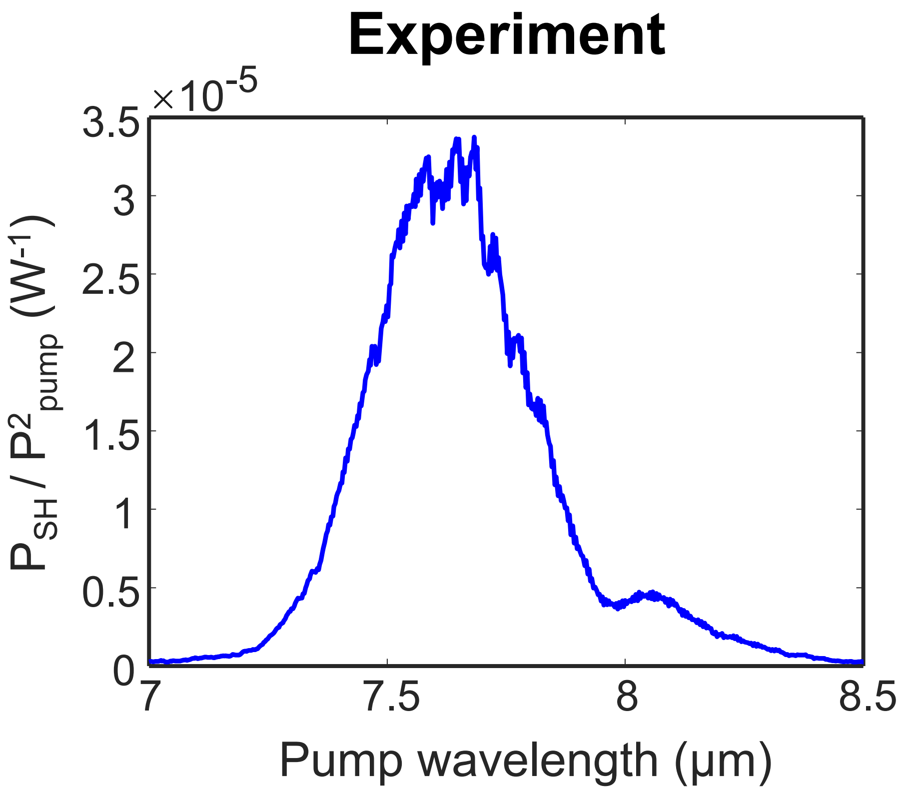


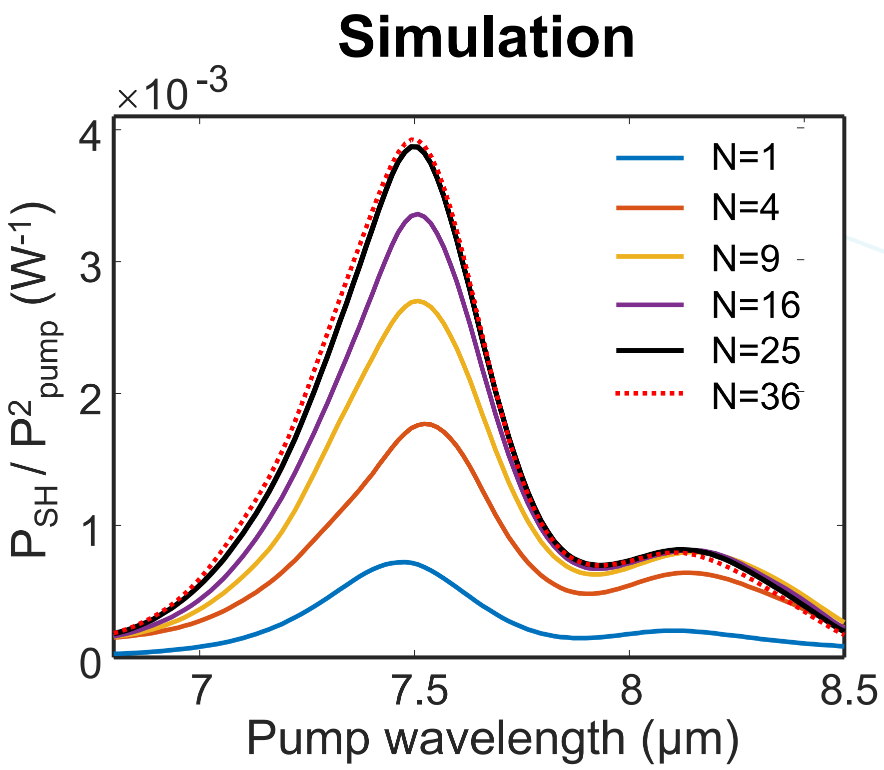


MD

Splitting of Photonic Resonance due to Strong Coupling !

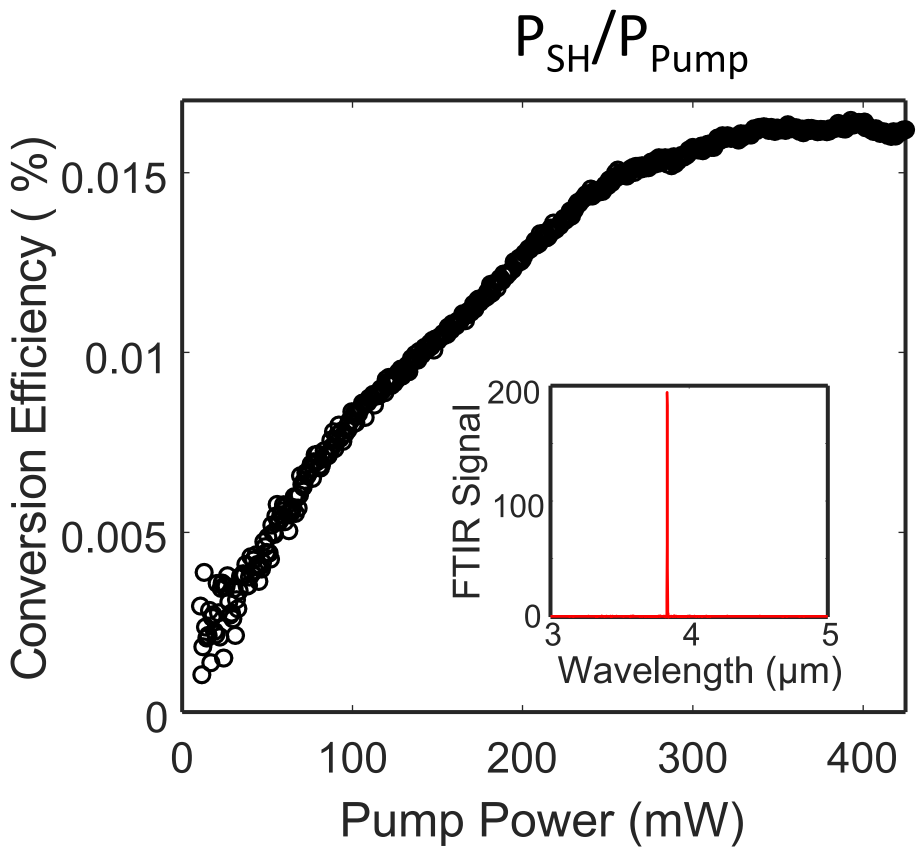
Second-Harmonic Generation : Experiment and Simulations

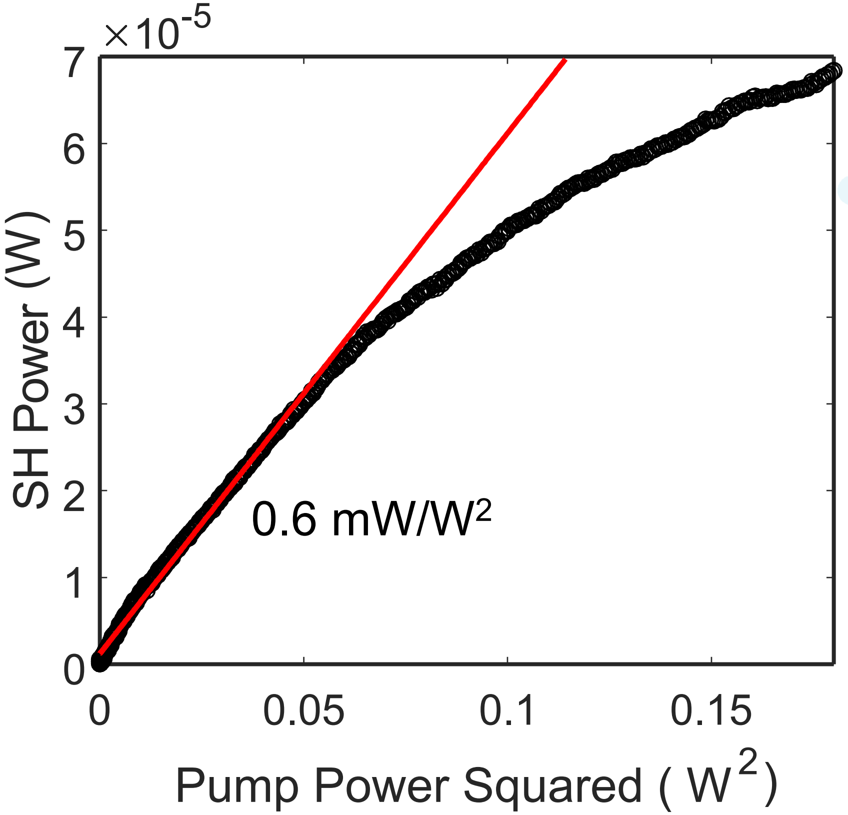




Excellent agreement between experiments and simulations can be seen !

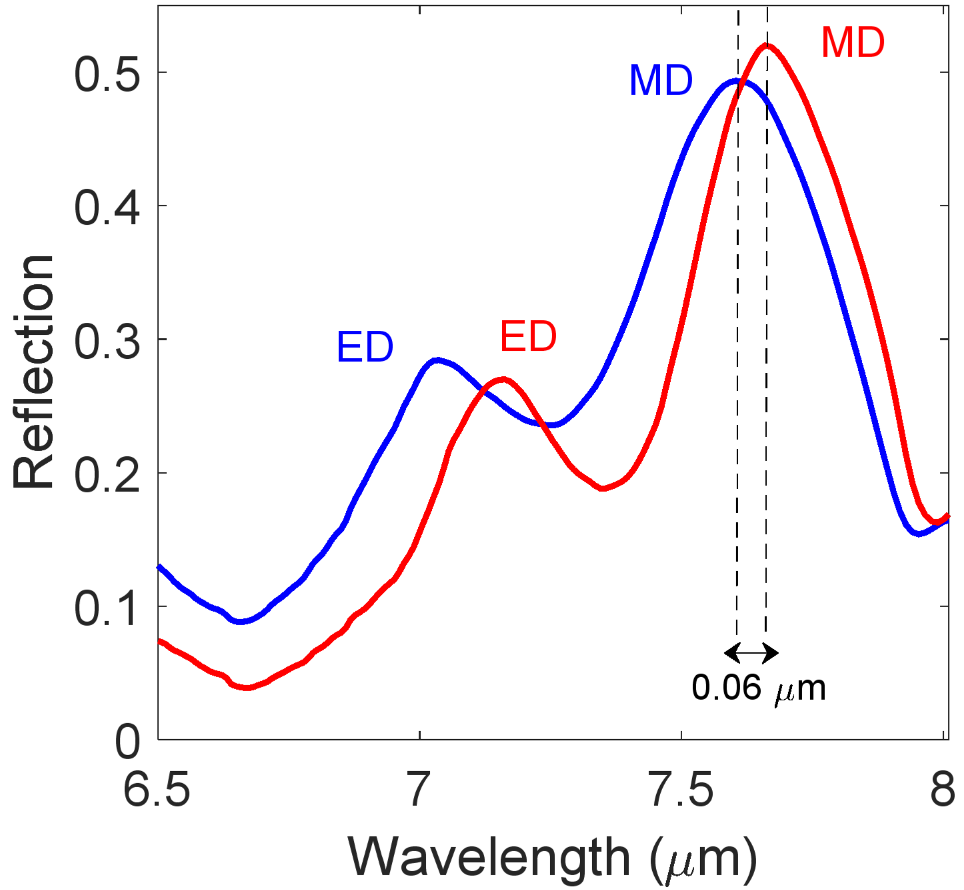
Experimentally Measured SHG Efficiencies

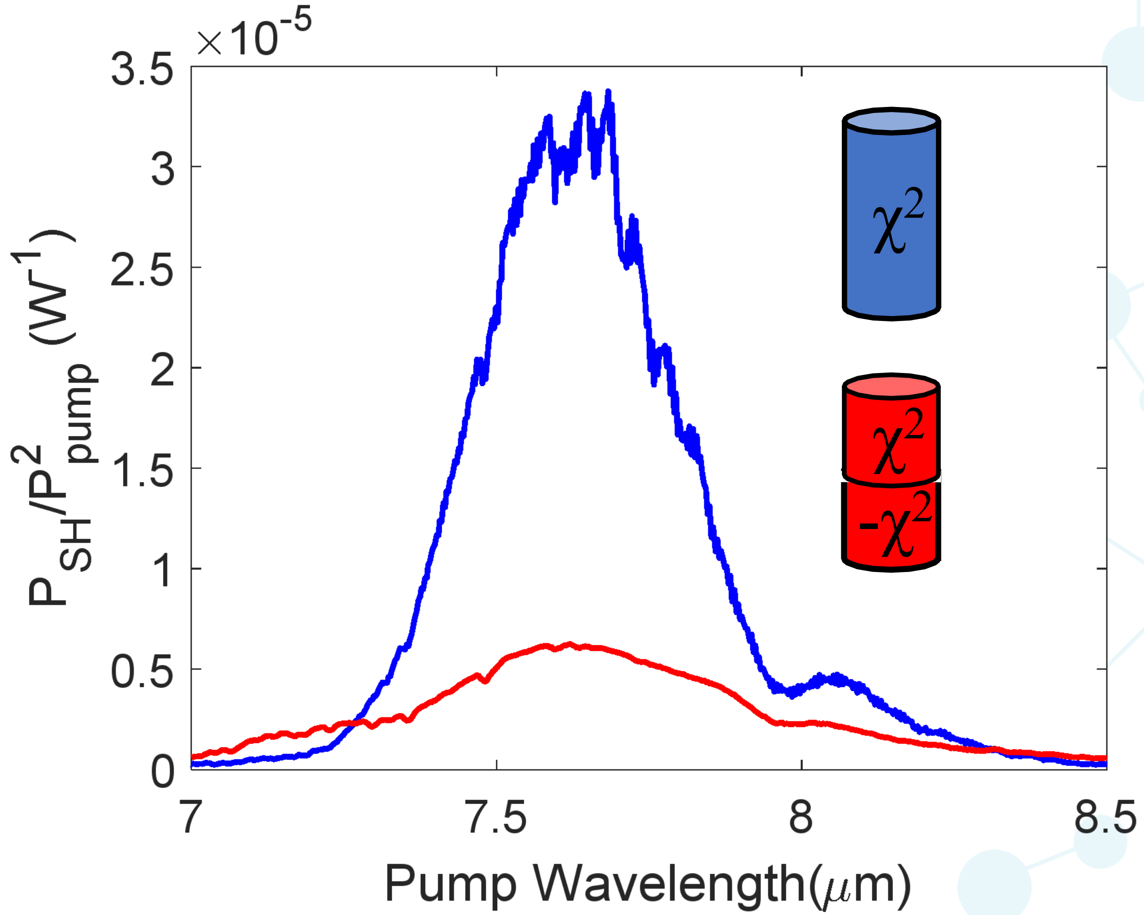




Large magnitude of $\chi^{(2)}$ gives SHG efficiency ~ 0.016 % at 11 kW/cm^2 and conversion factor ~ 0.6 mW/W^2.

Polarity Switching of $\chi^{(2)}$





The SHG efficiency can be controlled by controlling the sign of $\chi^{(2)}$ inside the Mie resonator

Summary

- We demonstrate giant second-order nonlinearities in polaritonic all-dielectric metasurfaces which can be controlled via microscopic control of magnitude and sign of the material nonlinearity.

- Our results are proof-of-concept and the efficiencies can be improved by optimizing the heterostructure, field overlaps, and interplay between field enhancement and nonlinearity.

- Our approach although demonstrated for a particular wavelength, in principle, can be scaled to other wavelengths from visible to near-IR.