SAND2019-11178C

Tailored Polaritons and Nonlinearities in Hybrid Dielectric Metasurfaces

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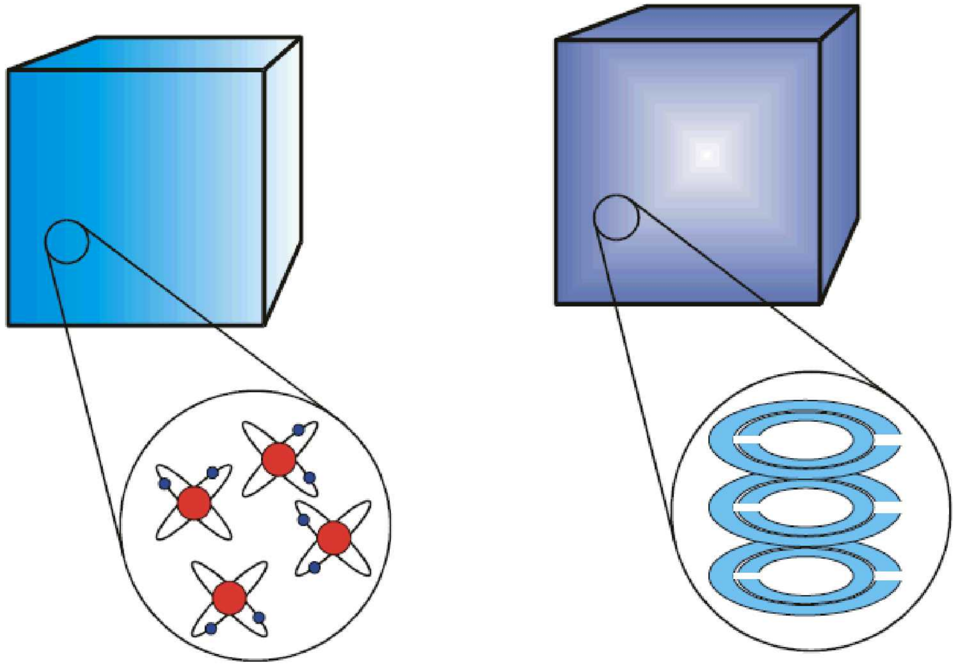
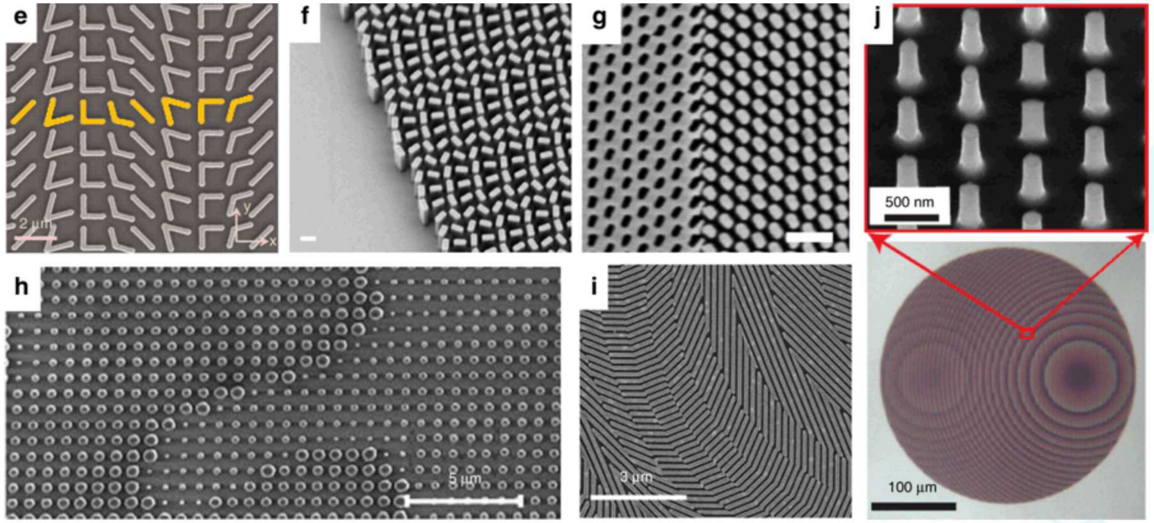
Man-made “atoms” : Metamaterials



John Pendry, Neils Bohr Lecture, Copenhagen 2010

Metasurfaces



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

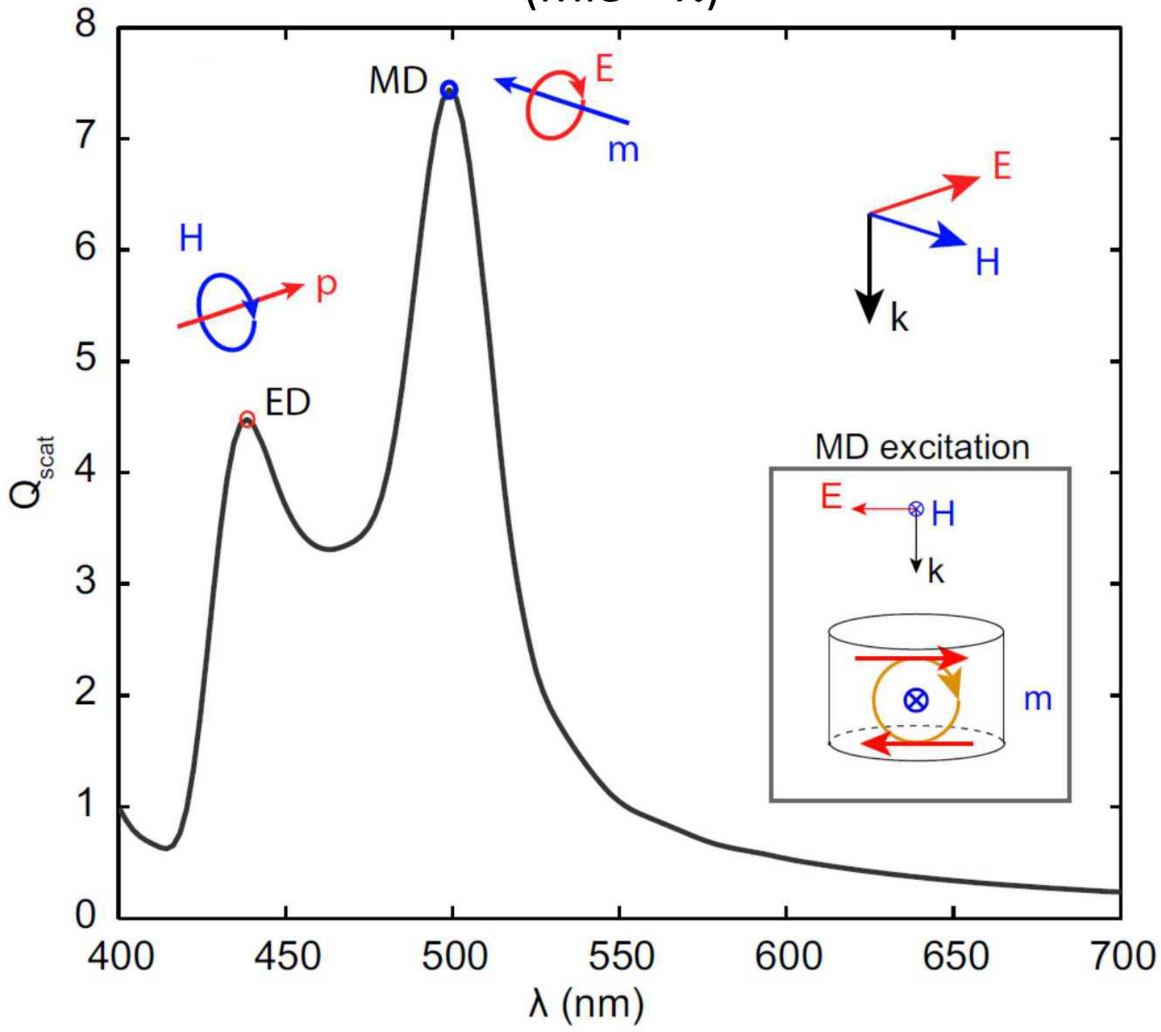
The constituent units need to be much smaller than the wavelength. Metasurfaces are planar (2D) equivalents of metamaterials.

The All-Dielectric Approach: Mie modes

(Rayleigh << λ)

Wikipedia

(Mie ~ λ)



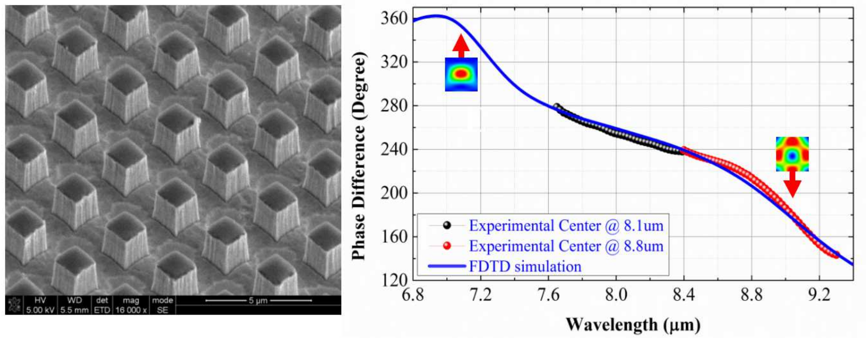
Optics Express 21, 26285 (2013)

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

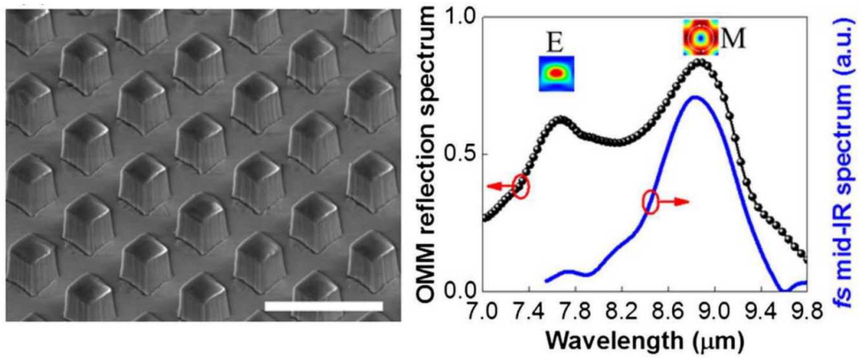
This is not the case for metallic resonators at optical frequencies because of metal losses

Metasurfaces based on Resonant Mie Modes

Magnetic Response

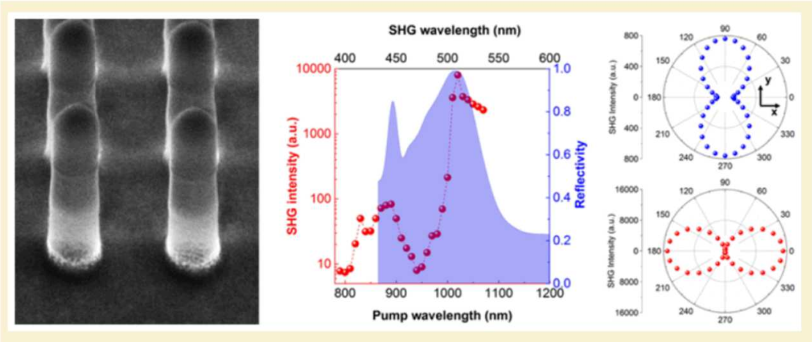


PRL. 108, 097402 (2012)

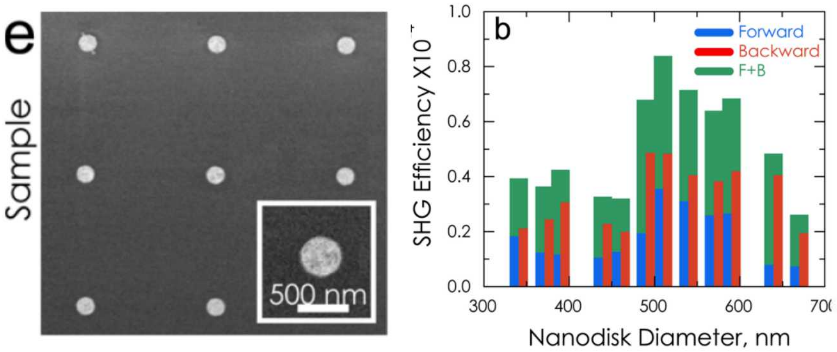


Optica 1, 250 (2014)

Nonlinear Optics

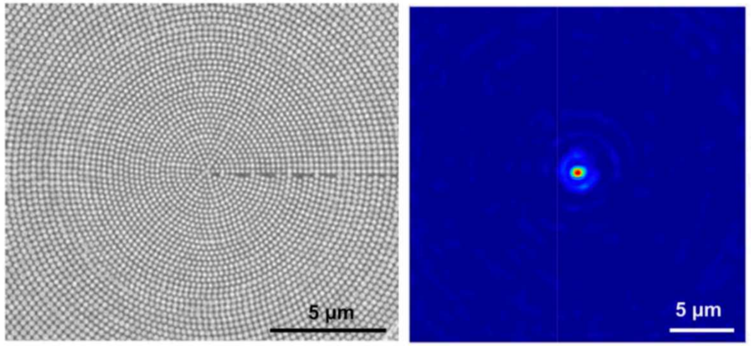


Nano Lett. 16, 5426 (2016)

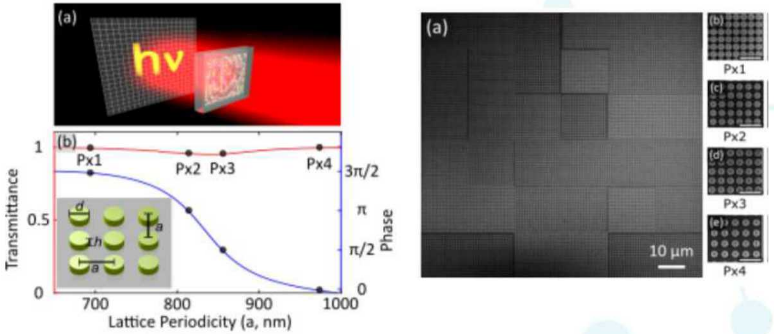


Nano Lett. 16, 7191 (2016)

Tailoring Linear Transmission



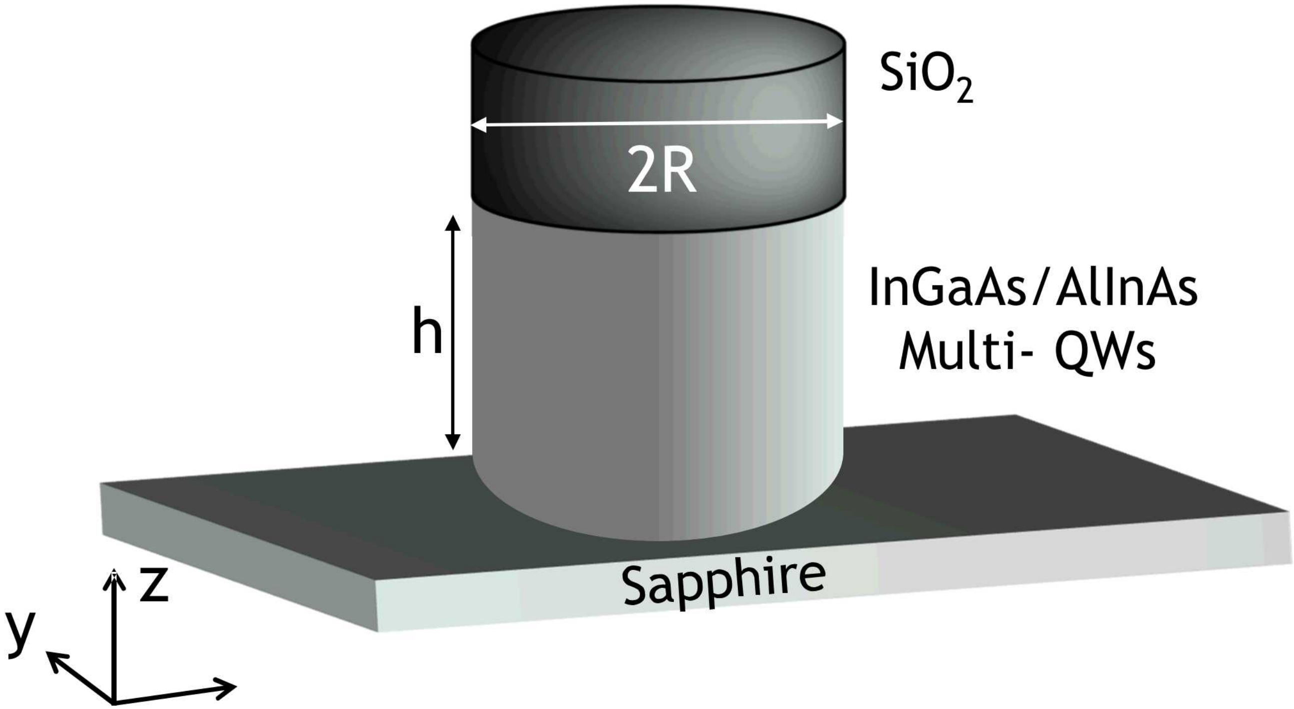
Argonne National Labs

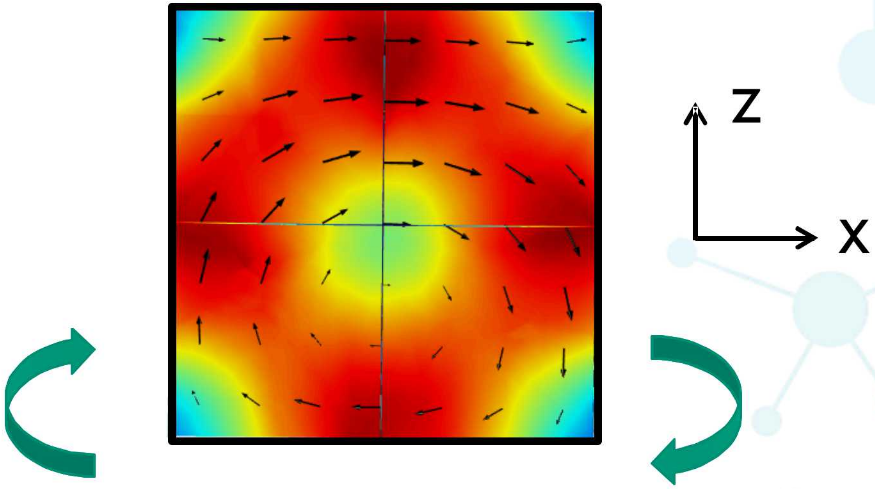


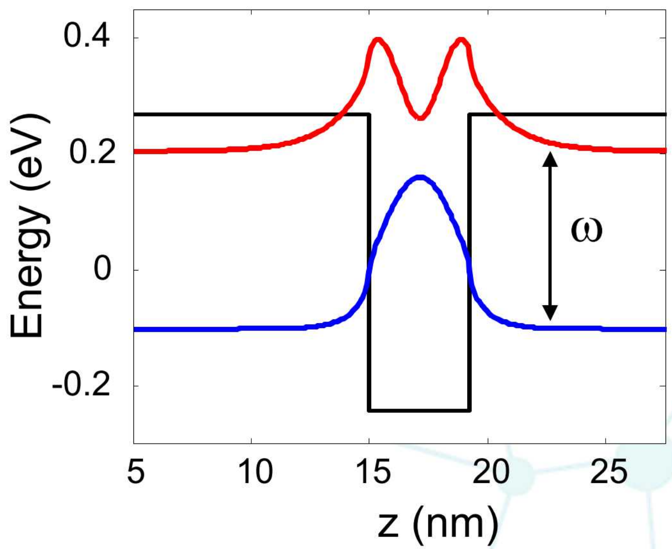
ACS Photonics 3, 514 (2016)

Hybrid Dielectric Metasurfaces : **Integration** of Mie modes **with intersubband transitions** !

Hybrid Mie Metasurface : A Coupled System



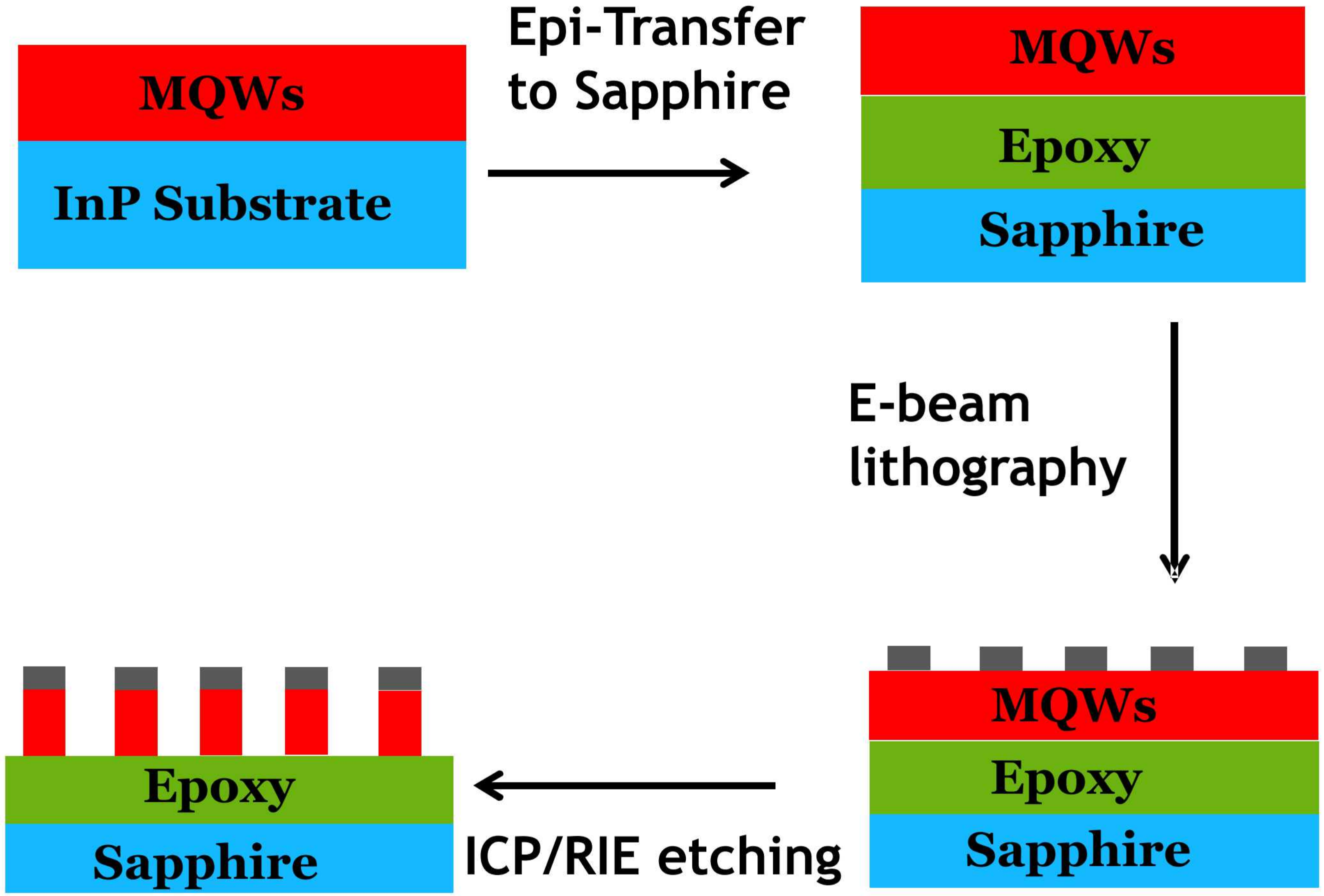


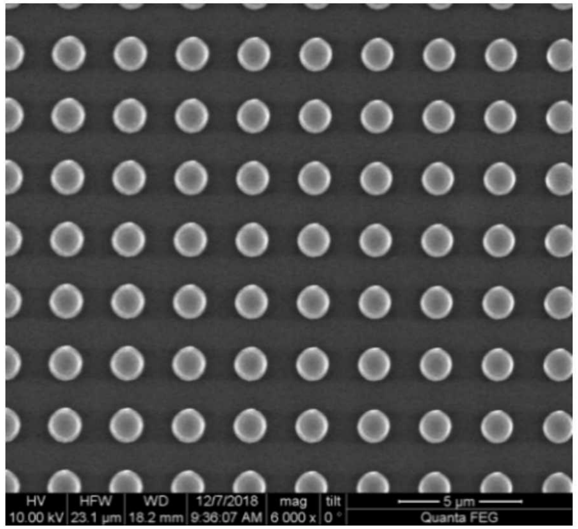


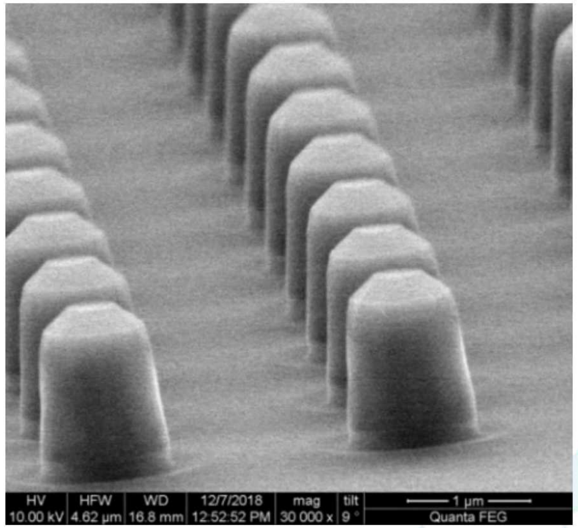
The strength of light-matter interaction depends on :

1. Transition dipole moment of intersubband transitions and number of electrons inside the cavity.
2. Field enhancement of the photonic mode

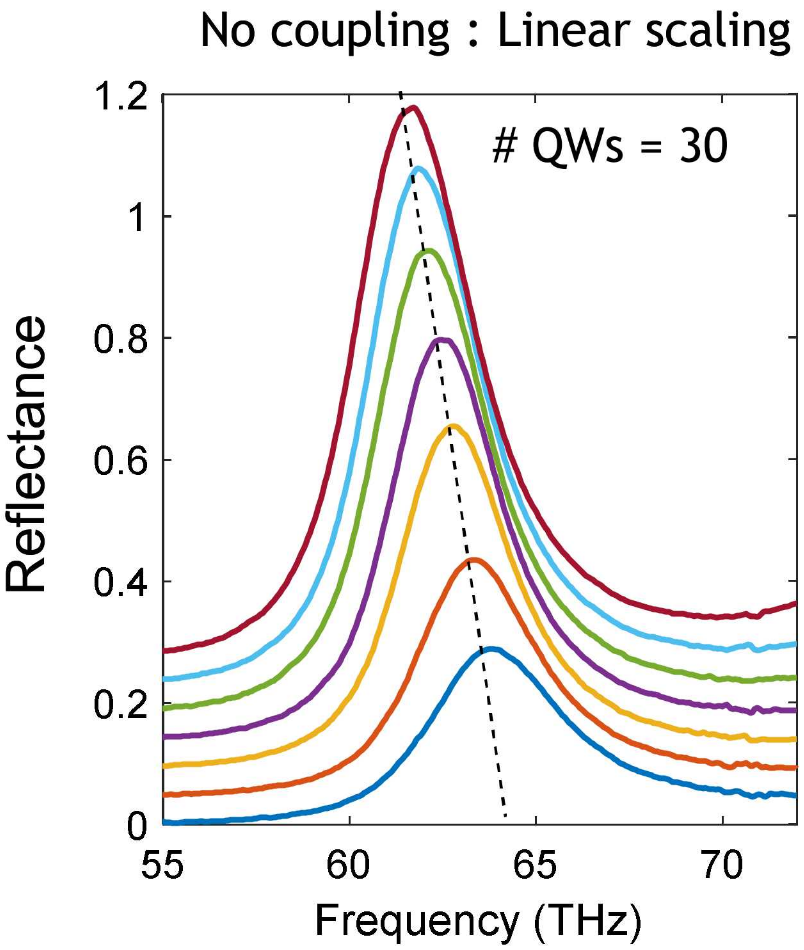
Fabrication of a Hybrid Metasurface

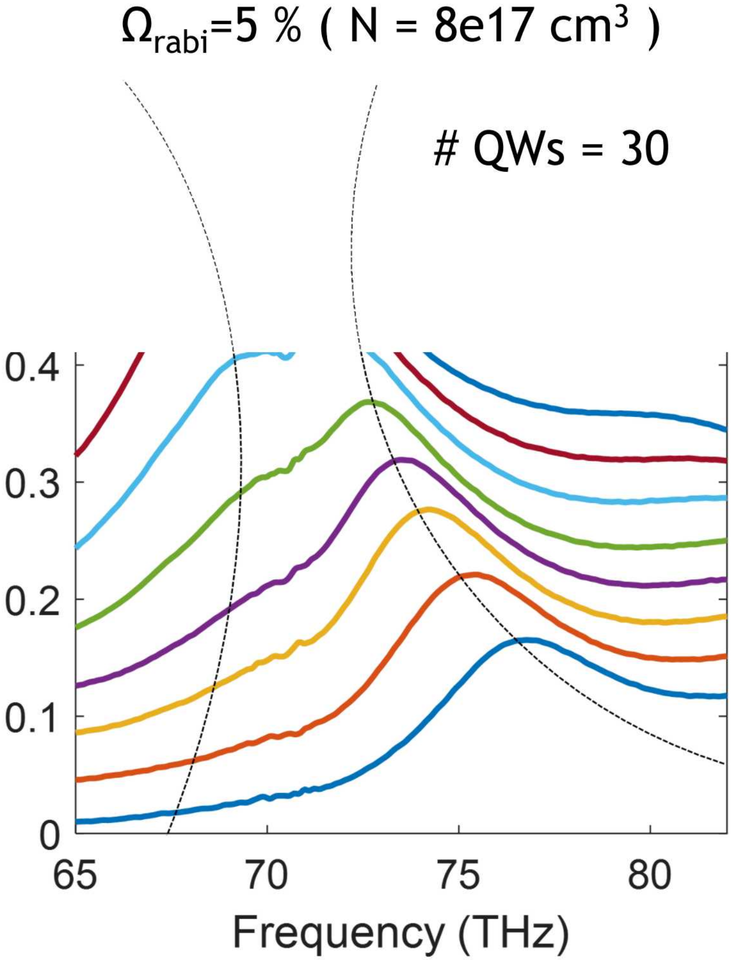


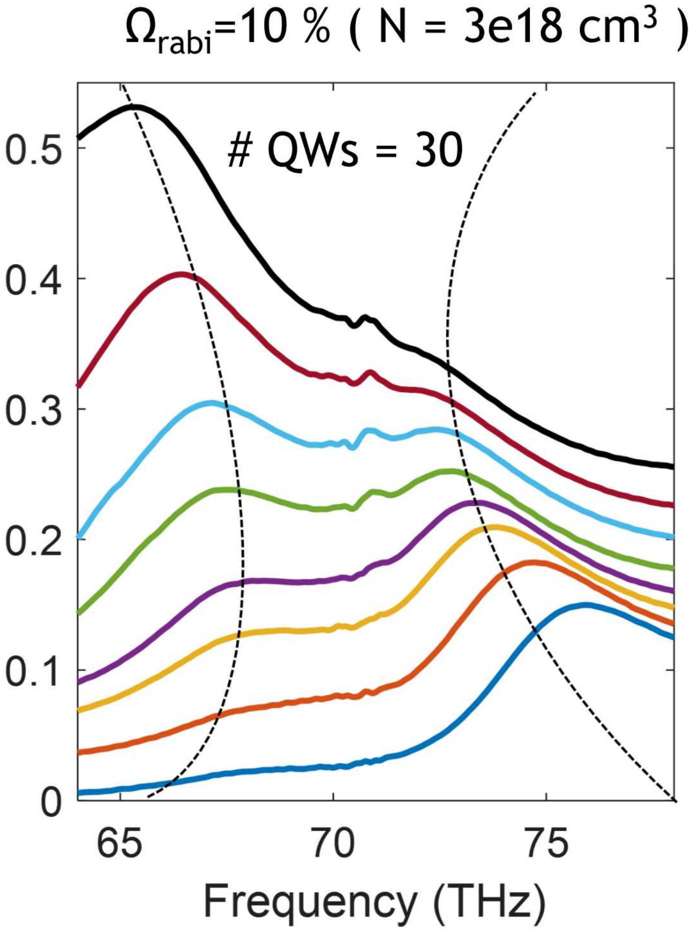




Experimental Demonstration of Strong Light-Matter Interactions

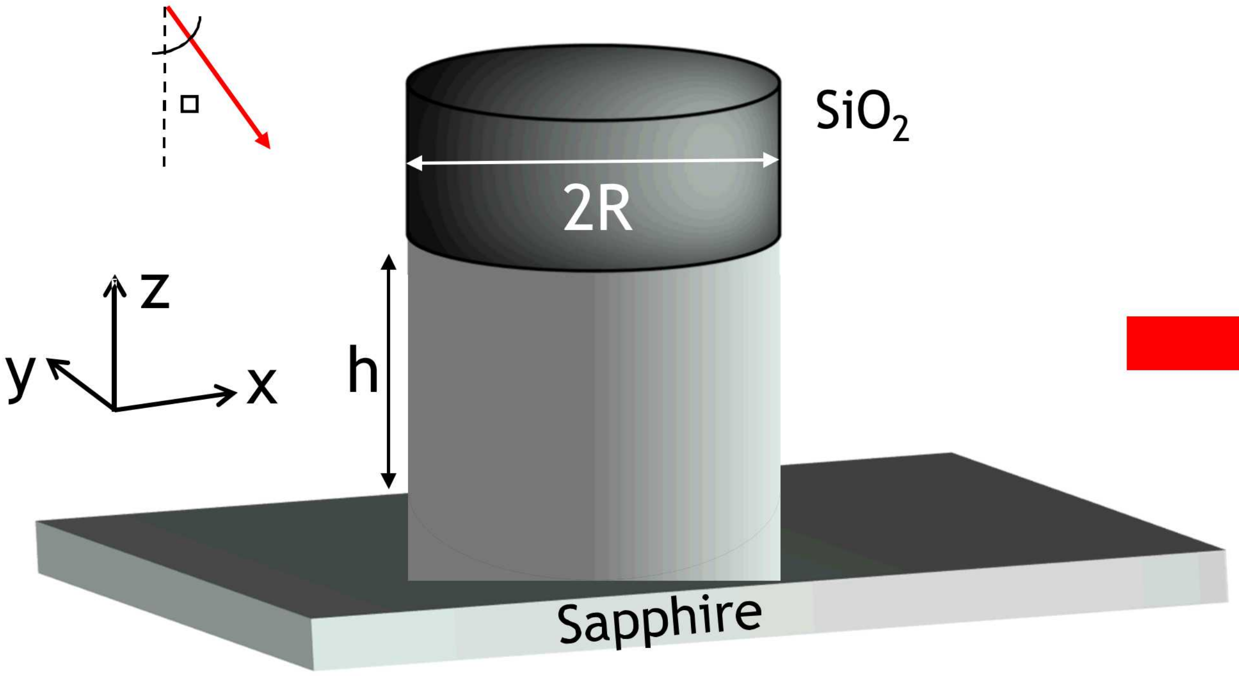


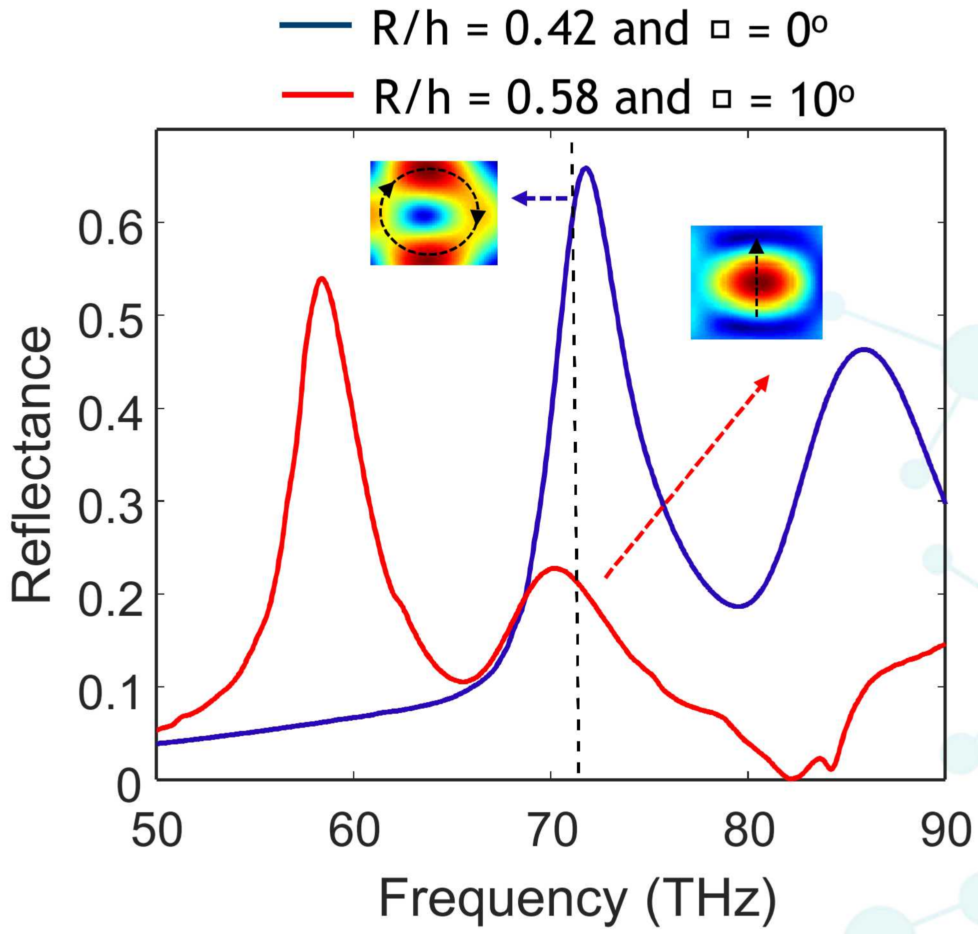




The strength of light matter interactions can be engineered by engineering heterostructure!

Tailoring Strong Light-Matter Interactions using Different Mie modes

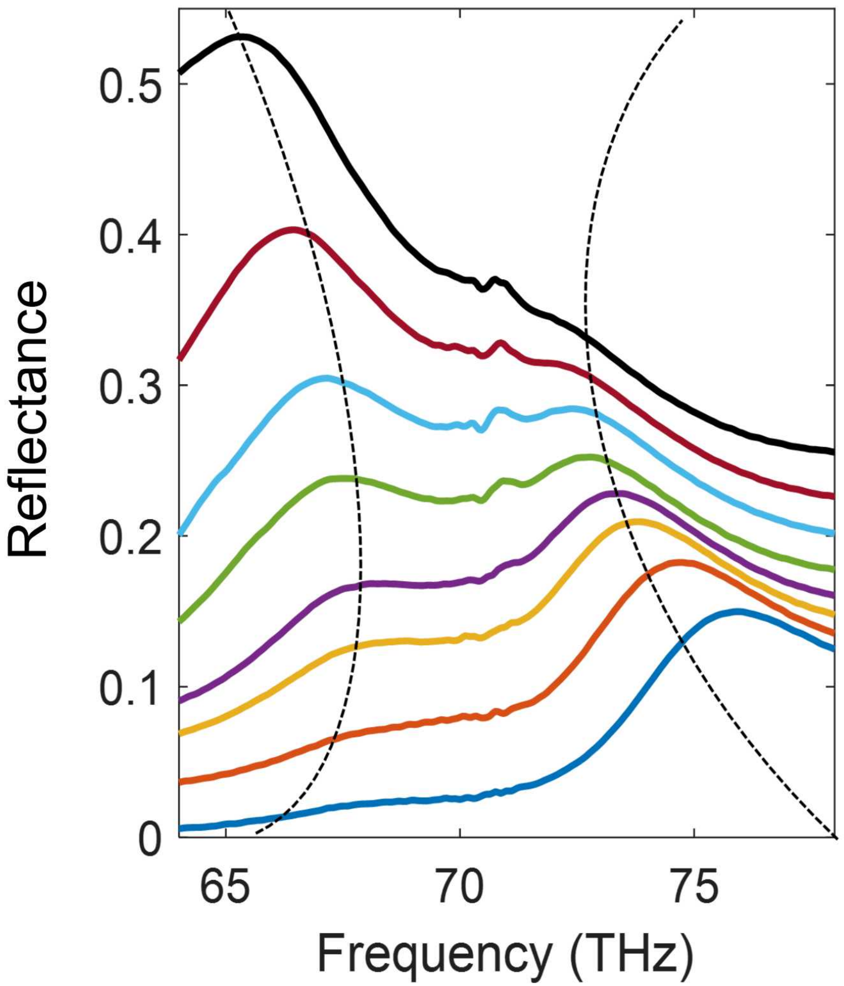




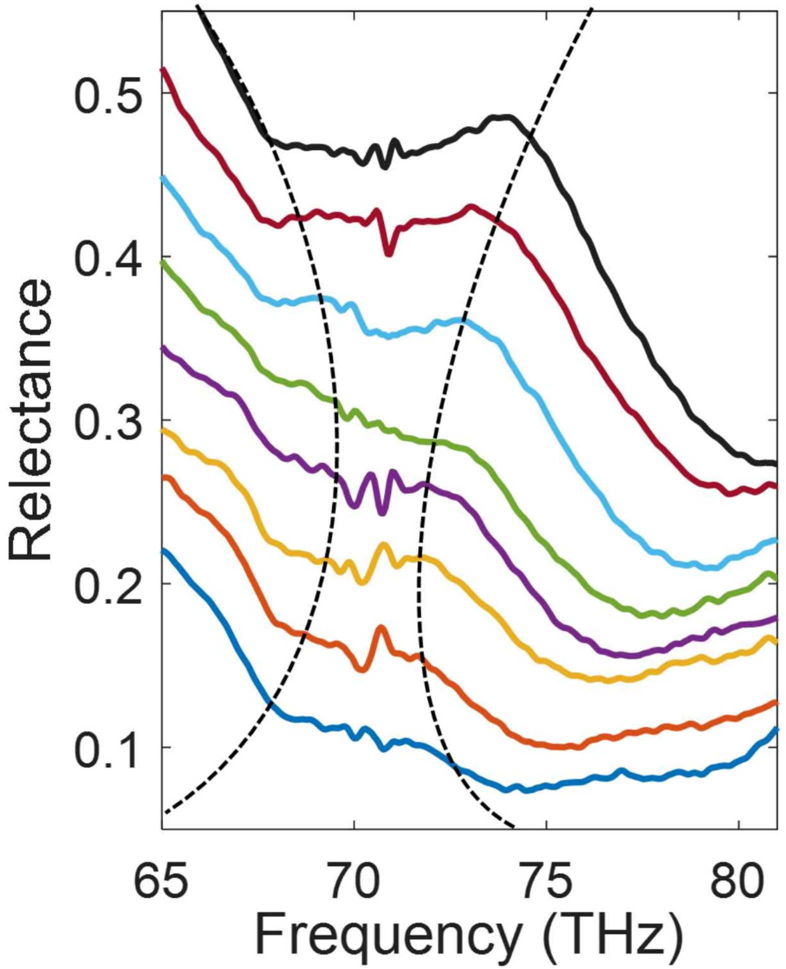
Since different Mie modes have different mode volumes and field enhancements, we can modify light-matter interaction by modifying the resonator (without modifying the heterostructure) !

Experimental Demonstration of Strong Light-Matter Interactions

Magnetic Dipole



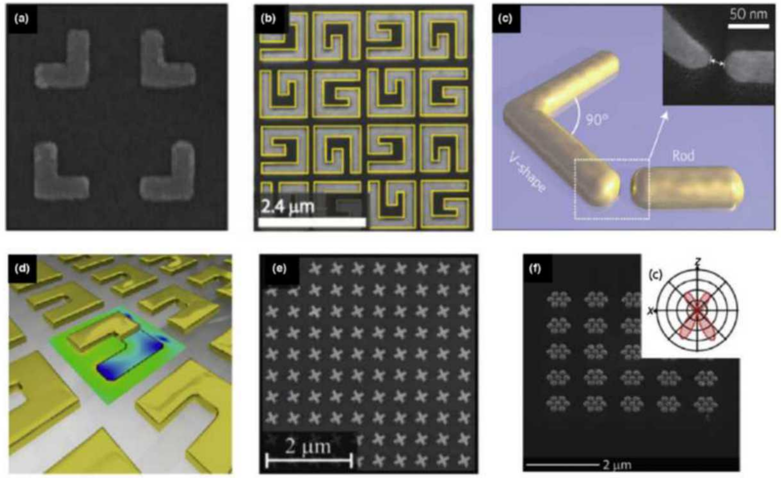
Electric Dipole



The magnetic dipole modes show stronger light-matter interaction !

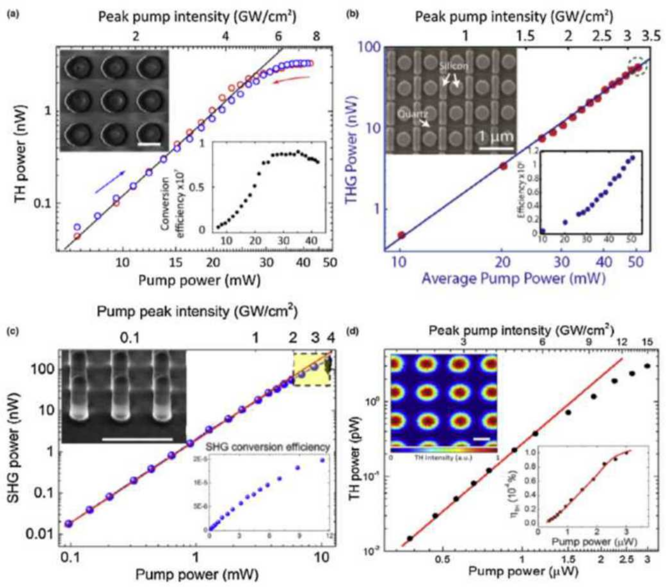
Nonlinear Metasurface Approaches

Plasmonic Metasurface



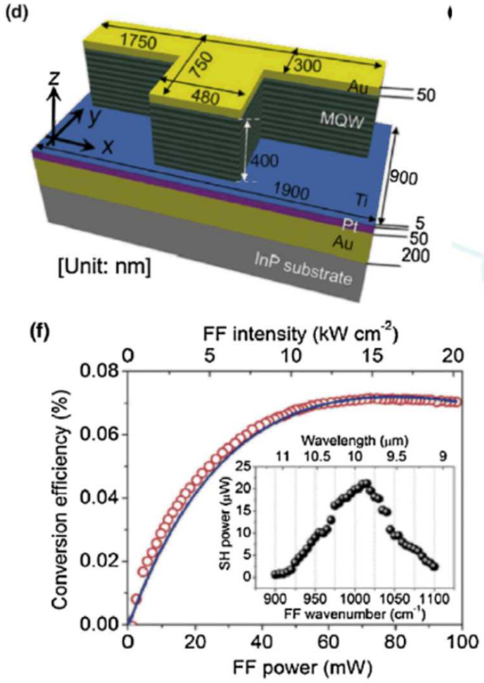
Max. Efficiency 6 x10^{-5} at ~ 0.5 GW/cm^2

All Dielectric Metasurface



Max. Efficiency ~ 10^{-4} -10^{-5} at ~ 5 GW/cm^2

IST-Plasmonic Metasurface



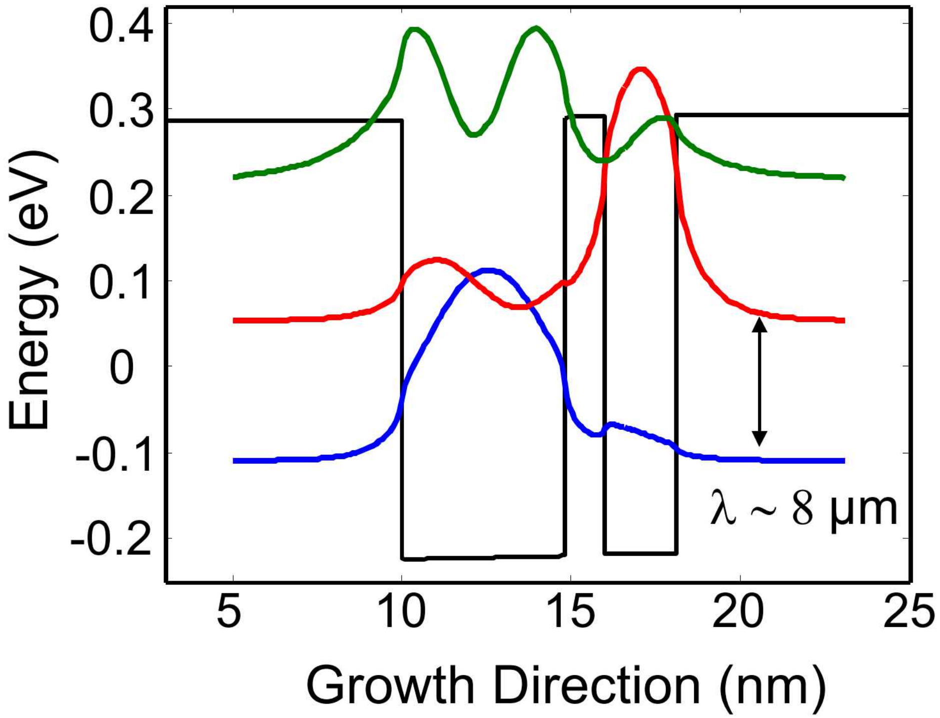
Max. Efficiency ~ 7 x 10^{-4} at 15 kW/cm^2

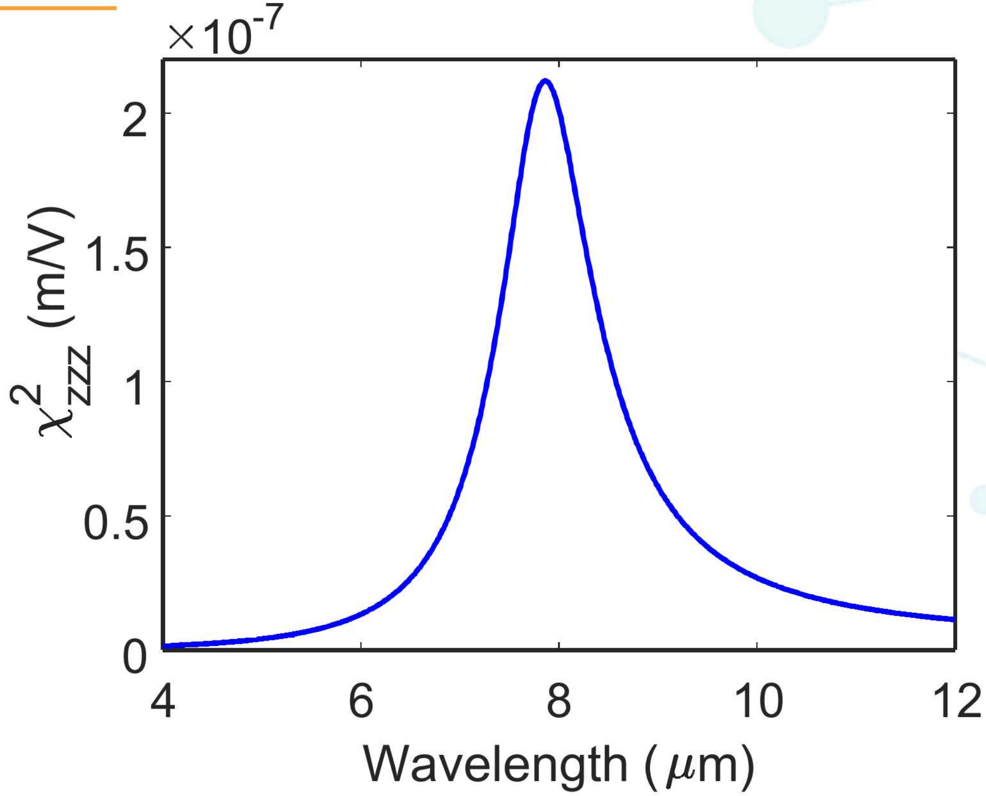
Ref. : A. Krasnok, M. Tymchenko, A. Alu, Materials Today 21, 8-21 (2018).

Comparison of SHG efficiencies (normalized by spot size)

Nonlinear Metasurface Approaches	Maximum Normalized Conversion Efficiency ($W/W^2/cm^2$)
IST + Plasmonic Resonator + Metal Backplane + Etching of QWs	1746 (Experimental)
IST+ Leaky Mode Resonance	101 (Experimental)
IST + Plasmonic Resonator	29 (Experimental)
GaAs/AlGaAs nonlinear Mie metasurfaces	0.05 (Experimental)
IST + Mie Resonator (Not optimized !)	**3250 (14 micron spot size)**

Generation of Resonant □(2) using Intersubband Transitions



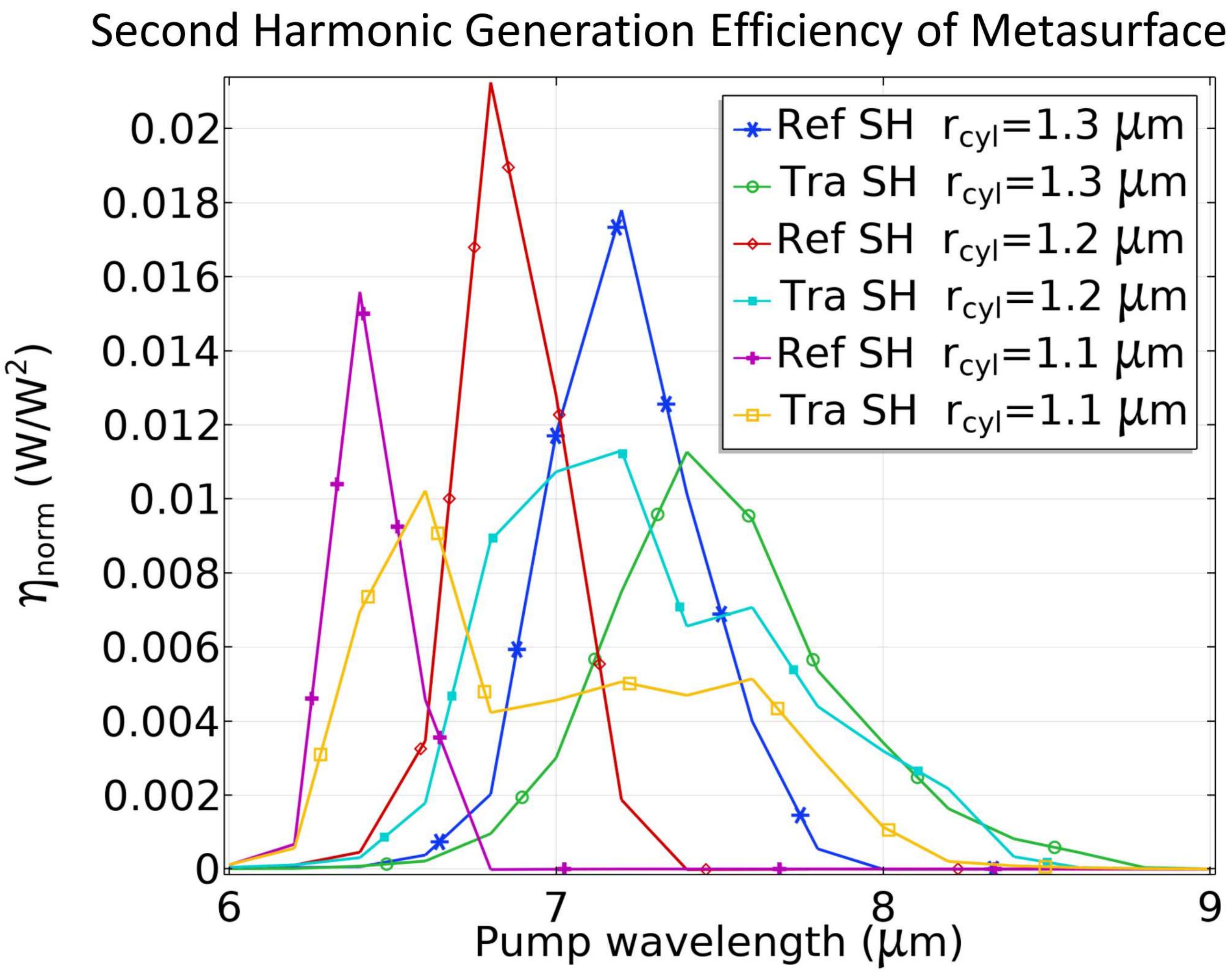


$$\chi^{(2)}(\omega) \propto \frac{N \cdot z_{12} z_{23} z_{13}}{(\omega - \omega_{12} - i\Gamma_{12})(2\omega - \omega_{13} - i\Gamma_{13})}$$

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

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

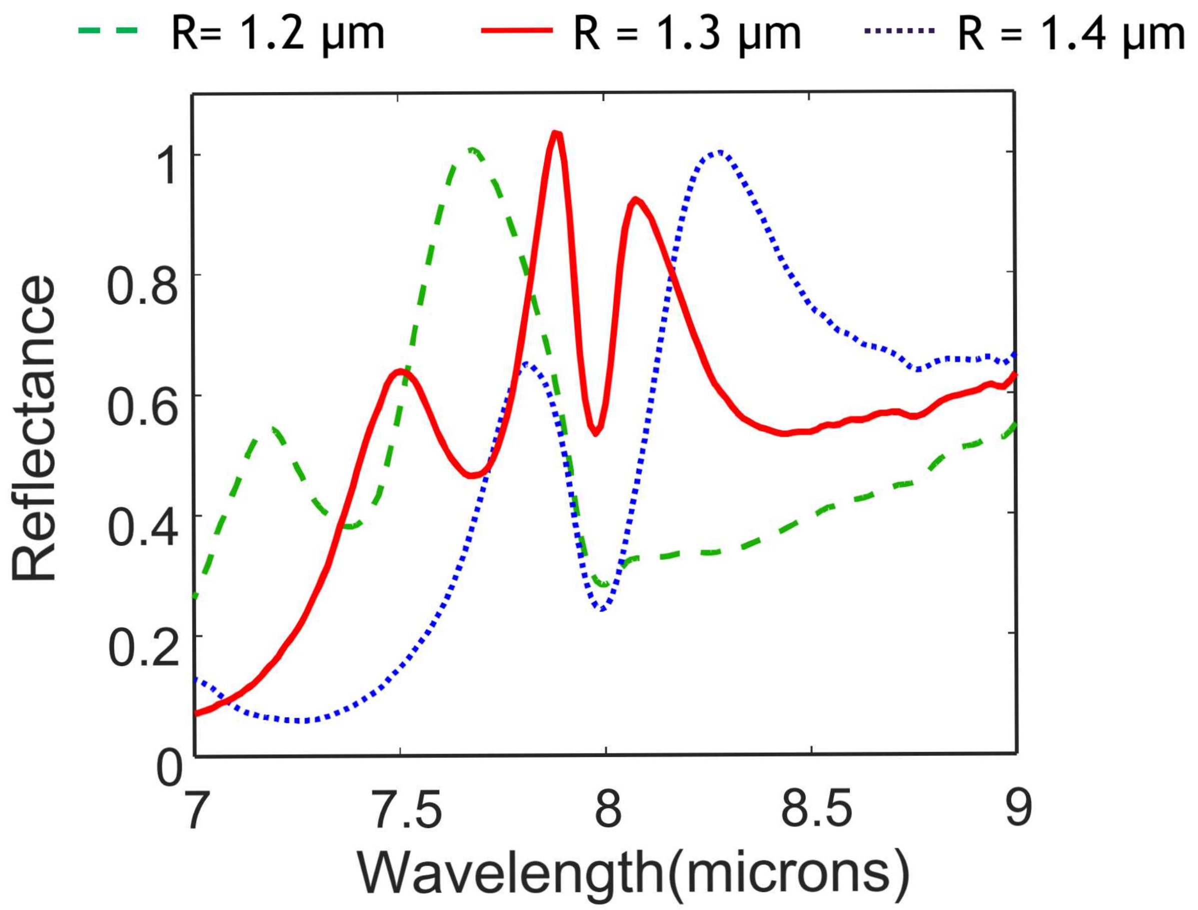
Second Harmonic Generation (SHG) : Simulations



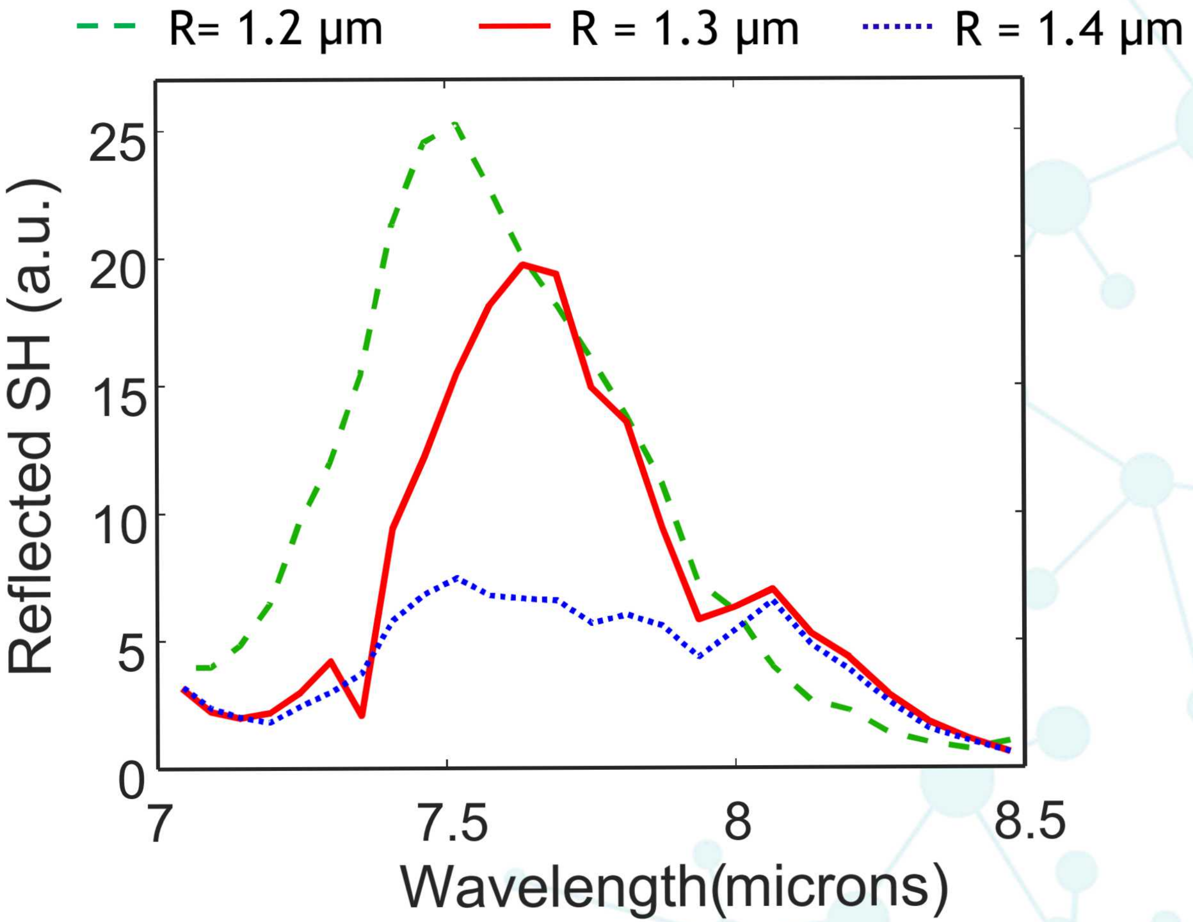
Extremely high efficiencies can be obtained. Maximum SHG is at shorter wavelengths due to larger field enhancements !

Second Harmonic Generation (SHG) : Experimental Data

Linear Reflectance of Metasurface



Reflected Second Harmonic



Similar to simulations, max SHG is at shorter wavelengths. Experimental measurements are ongoing.

Summary

- We demonstrate tailored light-matter interactions and nonlinearities in hybrid dielectic metasurfaces.

- Hybrid dielectric metasurfaces offer an efficient and flexible platform for both fundamental studies of light-matter interaction and for realizing efficient new light sources and nonlinear devices.

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