SAND2021-15790C

Emission Control with Dielectric Metasurfaces

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Acknowledgments

Current postdocs: Prasad Iyer, Sylvain Gennaro

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Jena (Germany): Isabelle Staude, Aleks Vaskin

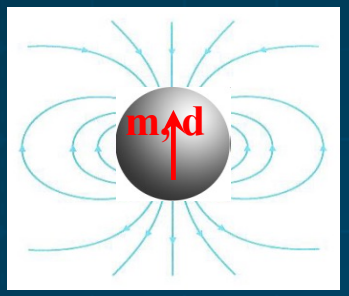
Max Planck (Germany): Tomas Santiago, Maria Chekhova

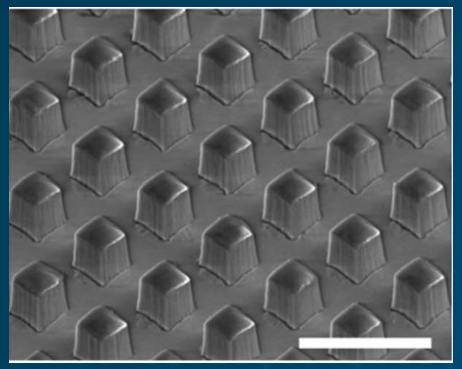
Outline

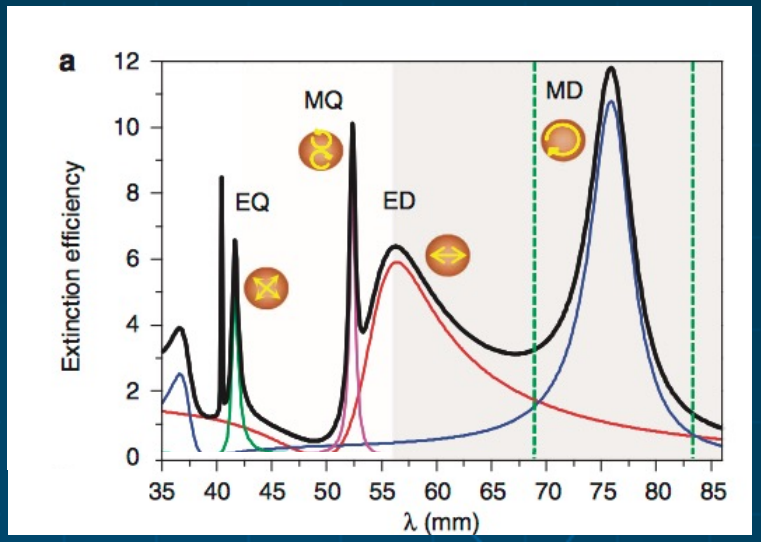
- Background and static emission control using dielectric metasurfaces
- Ultrafast photoluminescence steering
- Control of exciton dynamics in WSe2
- Towards single photon emitters and SPDC

Mie Resonant Dielectric Metasurfaces

Dielectric Resonators



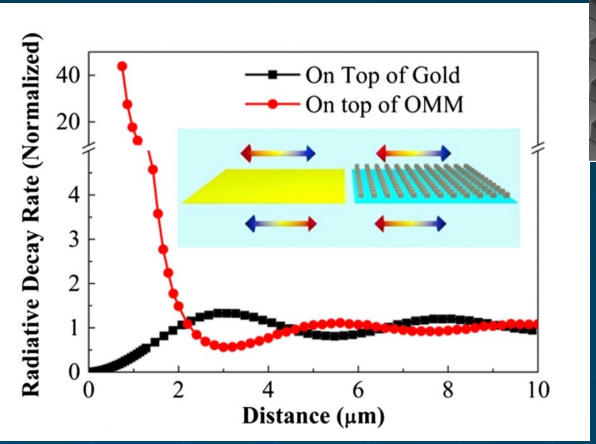


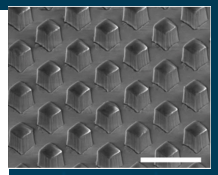


Kuznetsov, Science 2016

Emitters Coupled to Metasurfaces

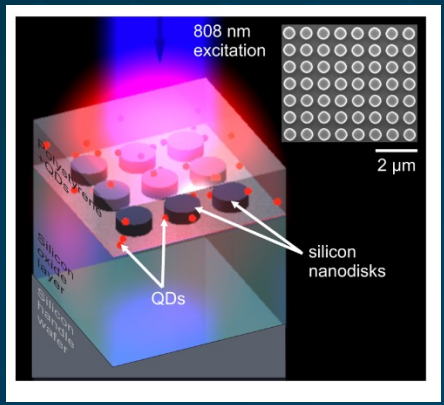
Simulation of emitter very close (~λ) close to dielectric optical mirror showed large radiative enhancement.

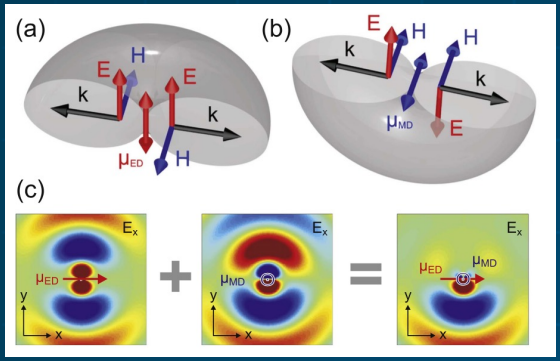




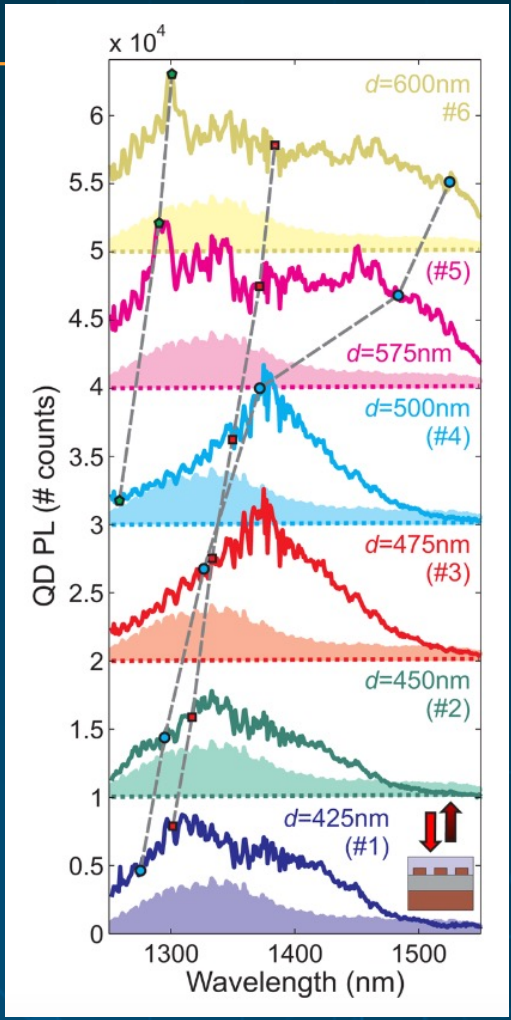
Liu, S. et al. Optica 1, 250–7 (2014)

Colloidal QDs + Metasurfaces



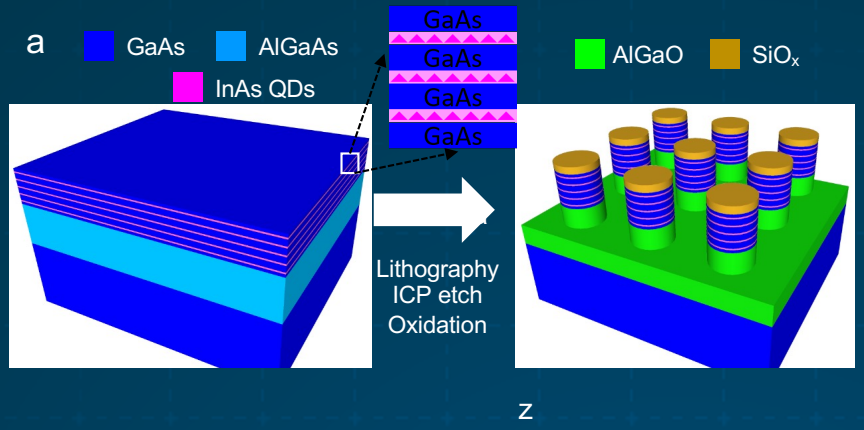


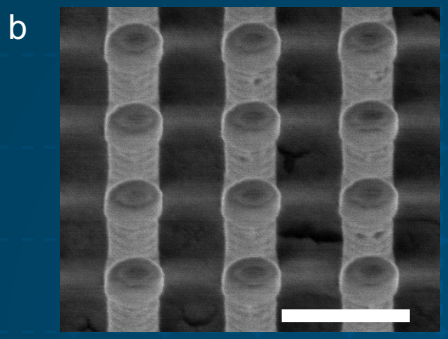
Emitter close to a Huygens metasurfaces could radiate efficiently in one direction

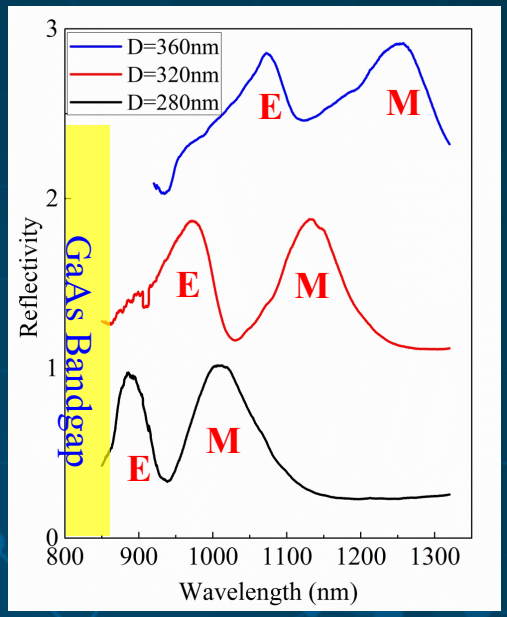


ACS Photonics 2, 172 (2015).

Embedding Emitters in III-V Semiconductor Metasurfaces

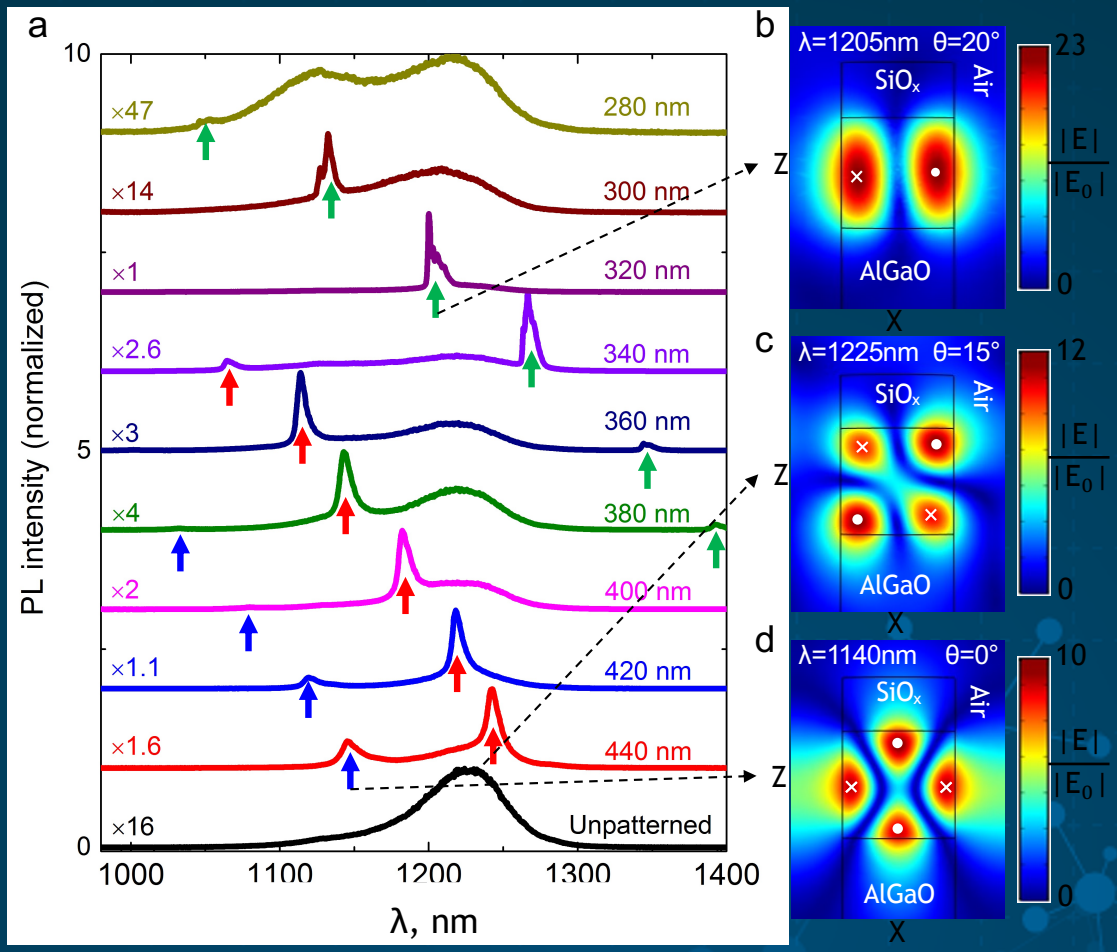




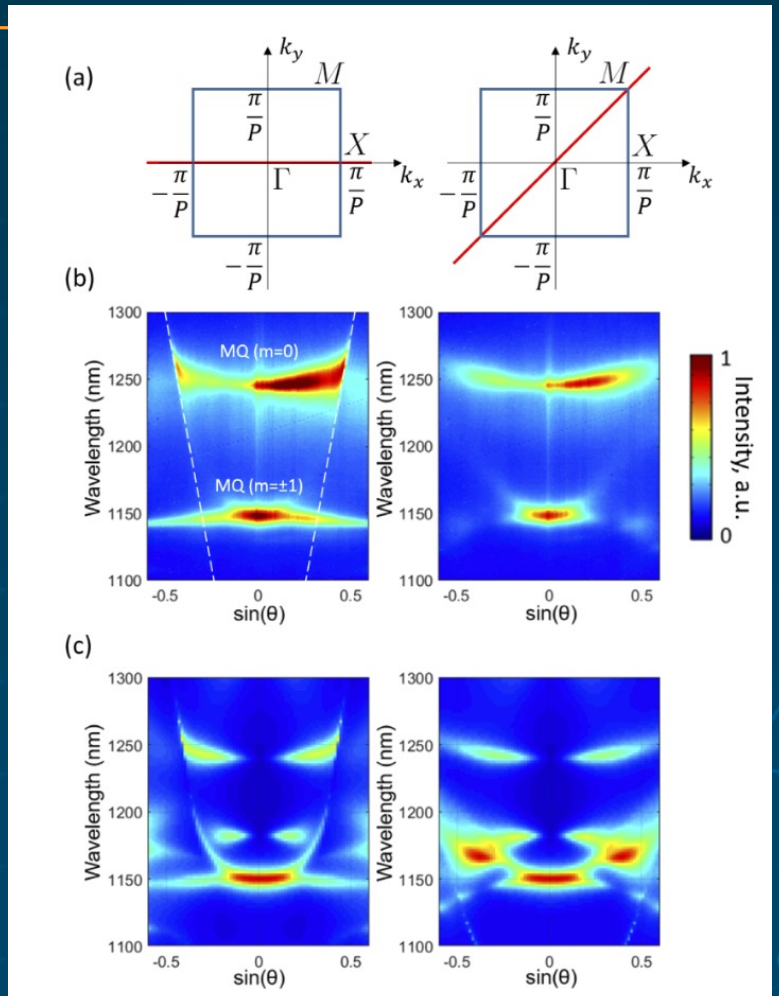


Advanced Optical Materials 4, 1457 (2016).

PL Enhancement: Coupling to Higher Order Mie Modes

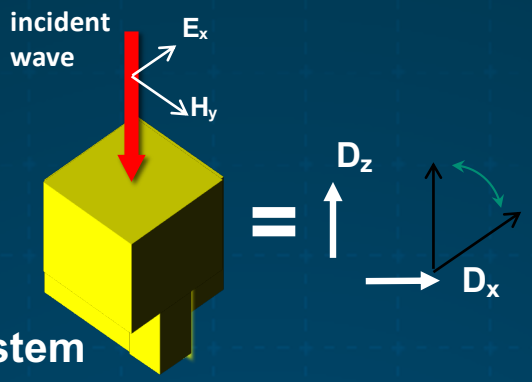


Epitaxial QDs coupled to Quadrupolar Modes



Opt Express 29, 5567 (2021)

High Q modes Using "Broken Symmetry" Resonators (or Bound States in the Continuum - BIC)



Broken symmetry system

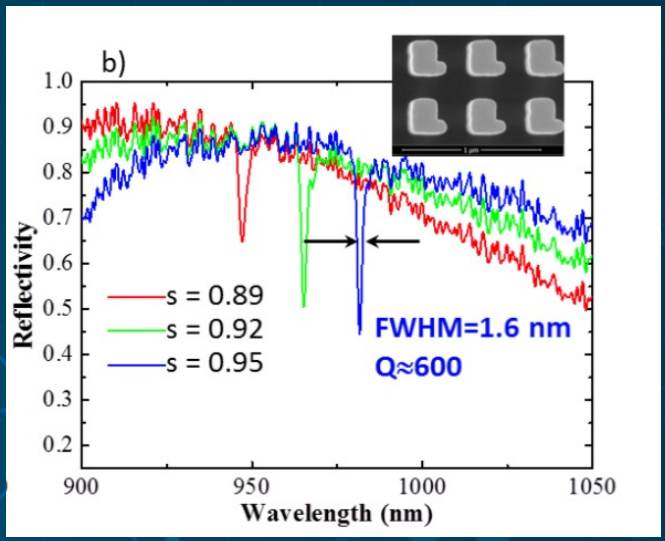
External Wave ⟷ D_x (low Q)

broad dipole resonances

Cavity perturbation

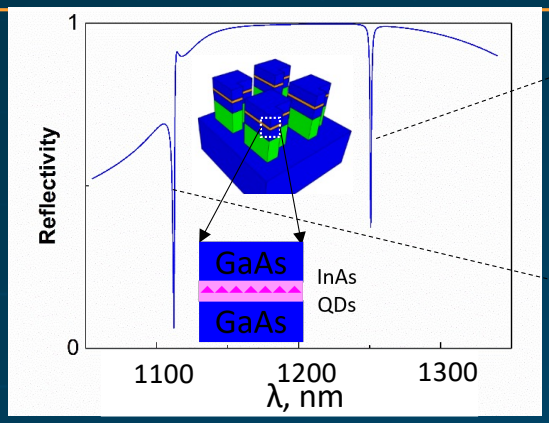
D_z (high Q)

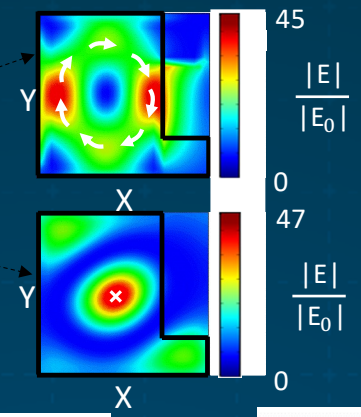
can't radiate in-plane due to local field interactions

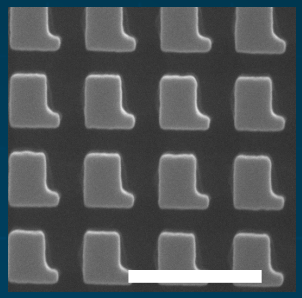


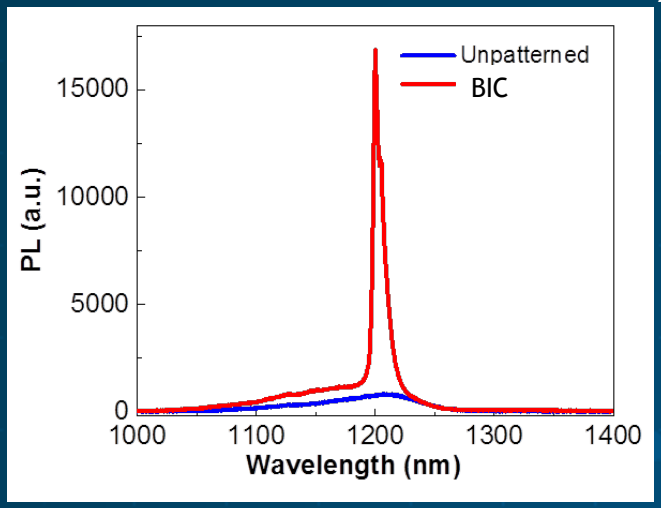
ACS Photonics 3, 2362 (2016)

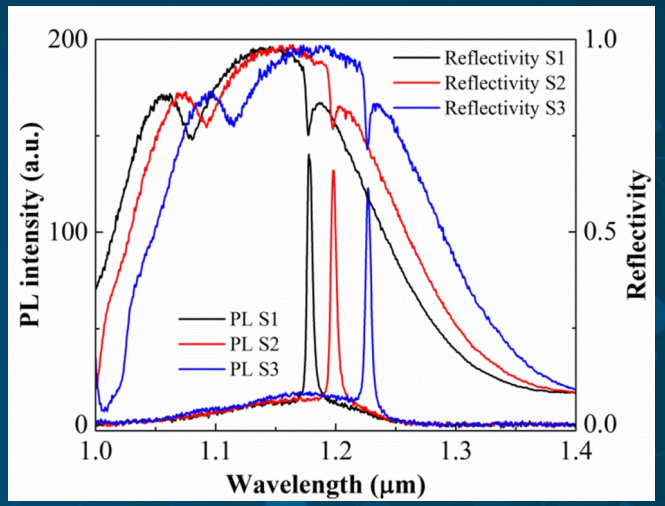
Light Emitting Metasurfaces







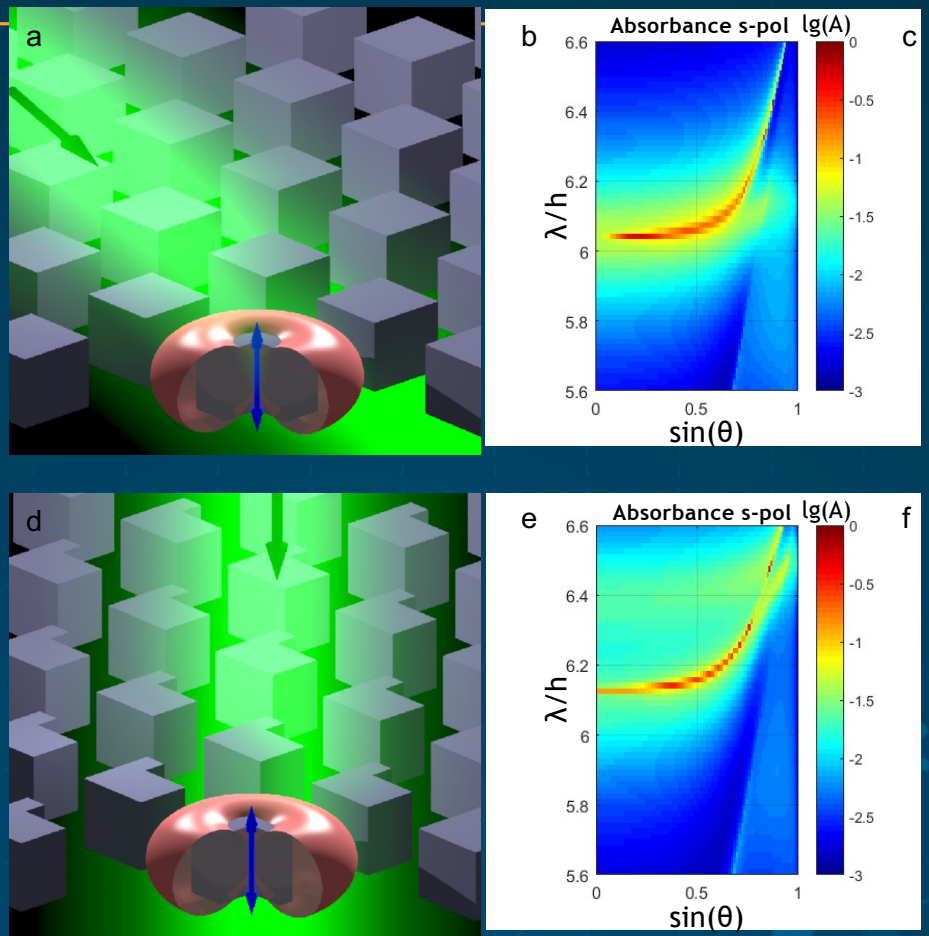




Nano Letters 18, 6906 (2018)

Emission with Out of Plane Dipole Modes

Symmetric Resonators



Broken-symmetry Resonators

Nano Letters 18, 6906 (2018)

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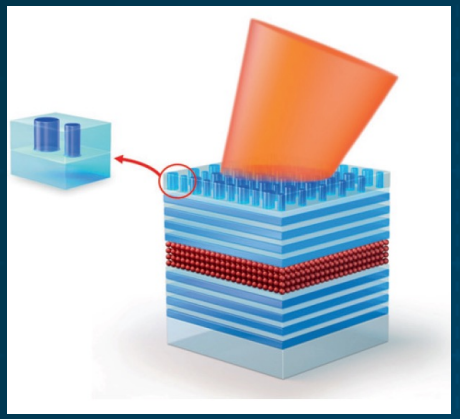
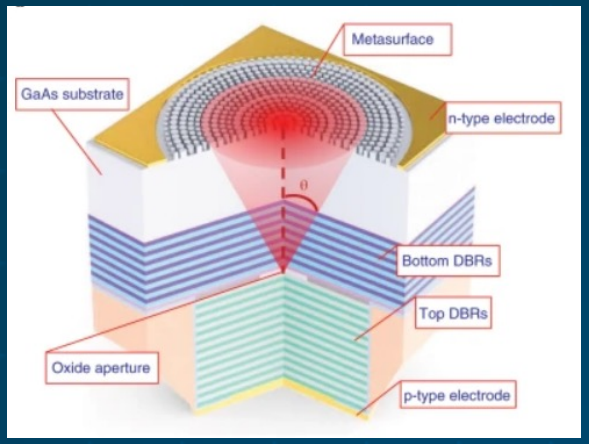
Ultrafast Steering of Photoluminescence

Beam Steering with Static Metasurfaces

Coherent

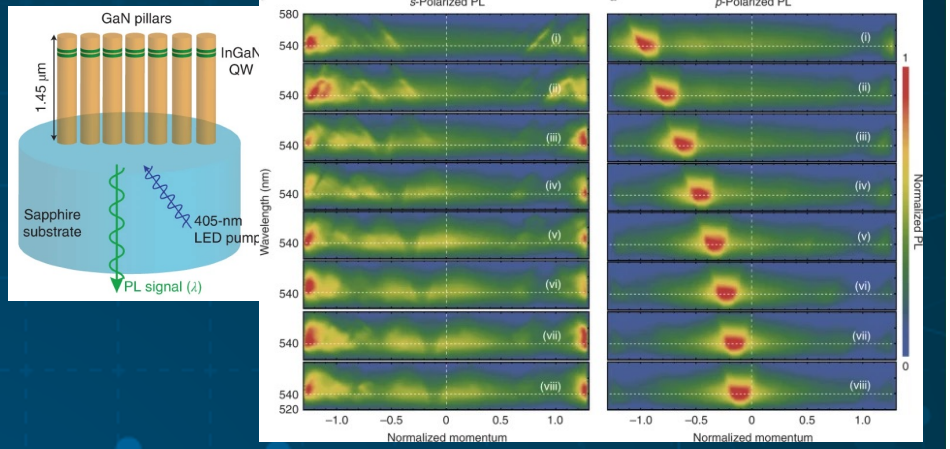




Park, Y.,et.al. (2020). *Nanophotonics*, *9*(5), 1023-1030.

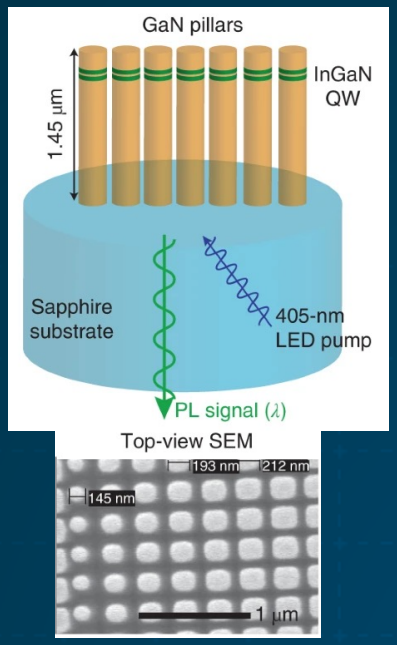
Xie, YY. *et al. Nat. Nanotechnol.* 15, 125–130, 2020

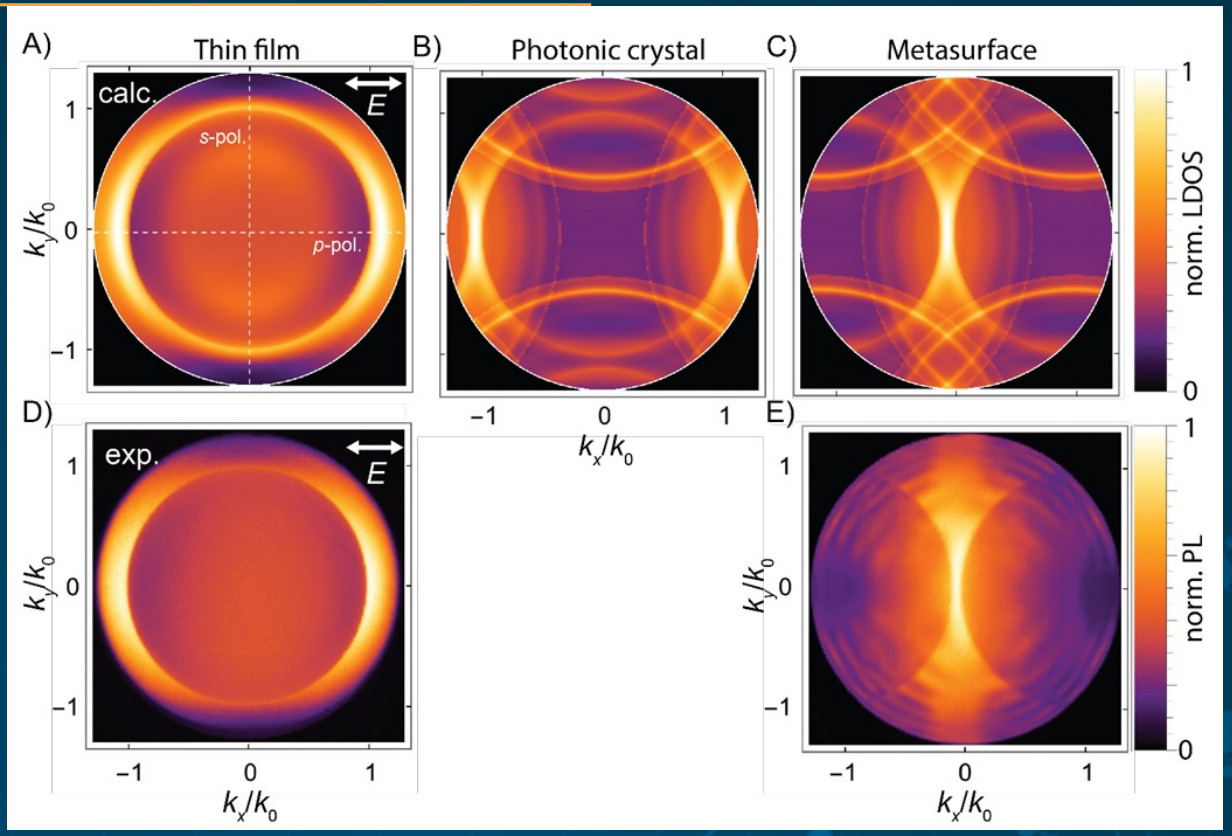
Incoherent



Prasad P. Iyer et.al *Nature Photonics 14, 543-548. 2020*

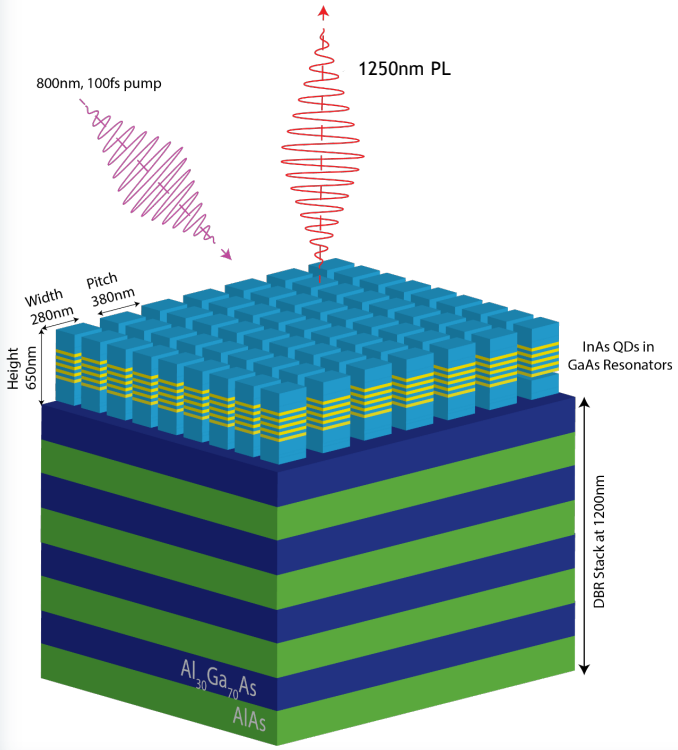
Metasurfaces Can Direct Photoluminescence



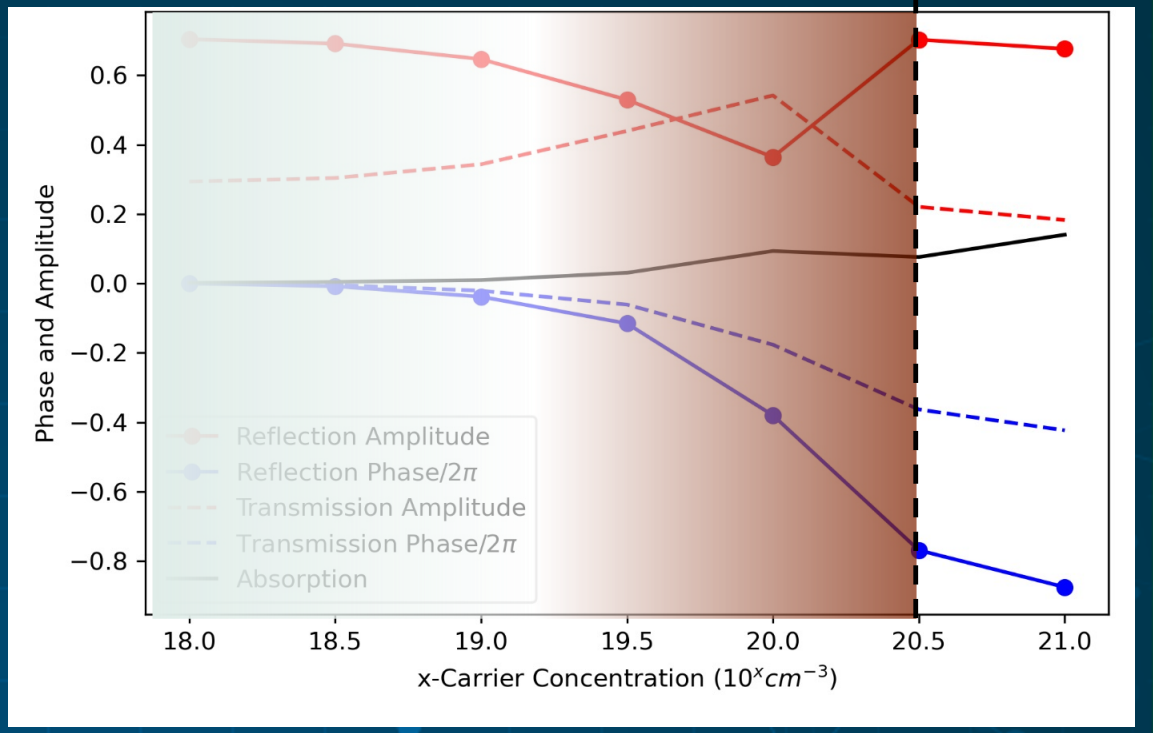


- Metasurface's grating momentum translates the LDOS in momentum space
- This couples trapped modes within the substrate ($k_x/k_0 > \pm 1$) to radiate into free space

Designing Metasurface for Active PL Steering

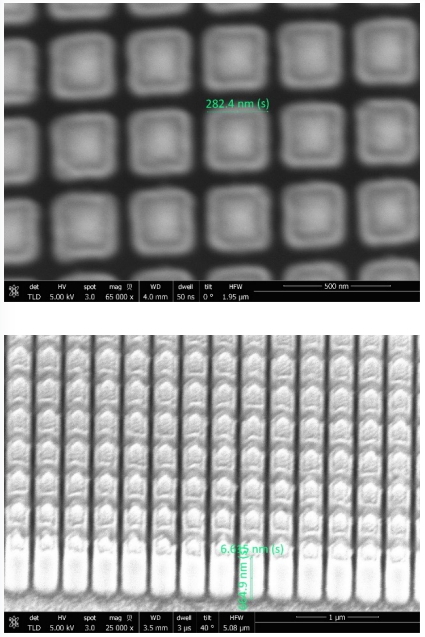


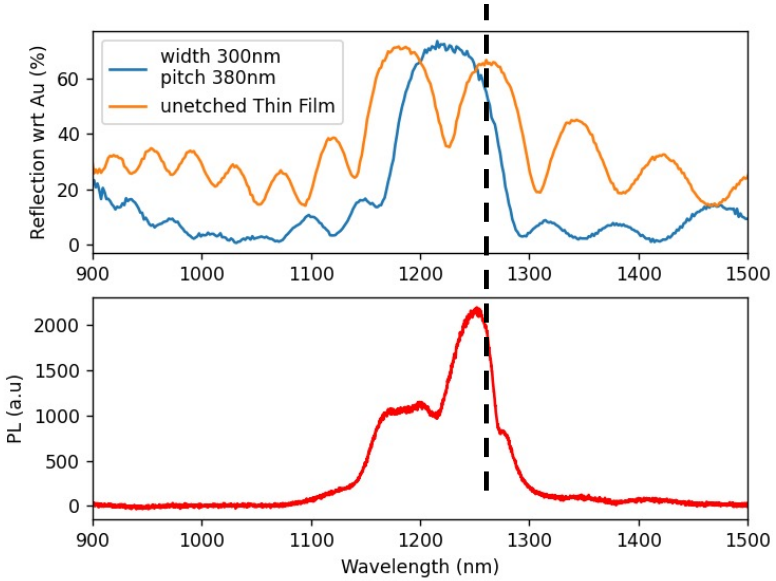
pump Intensity ~ 1mJ/cm^2

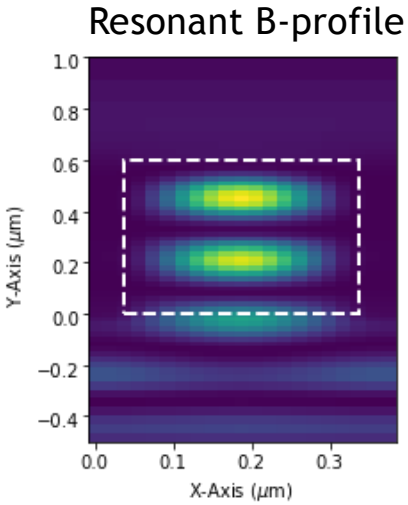


Dynamic 2π phase coverage in the resonators from free carriers excited by the 800nm pump

Designing Metasurface for Active PL Steering

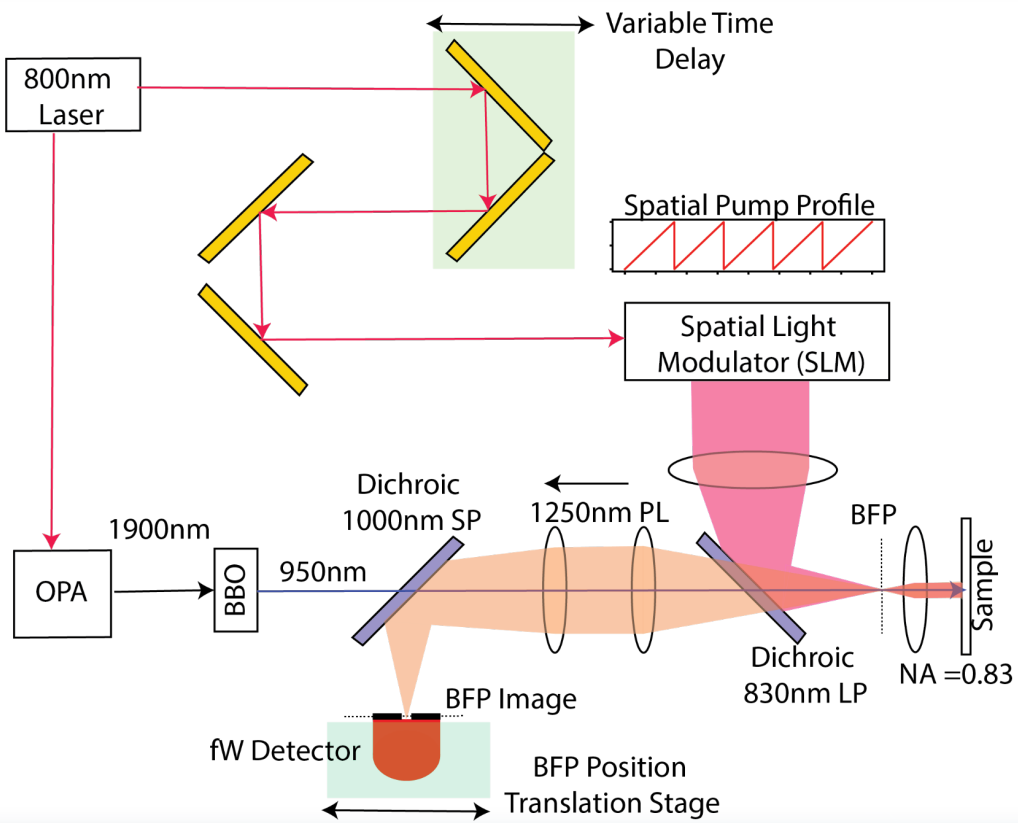


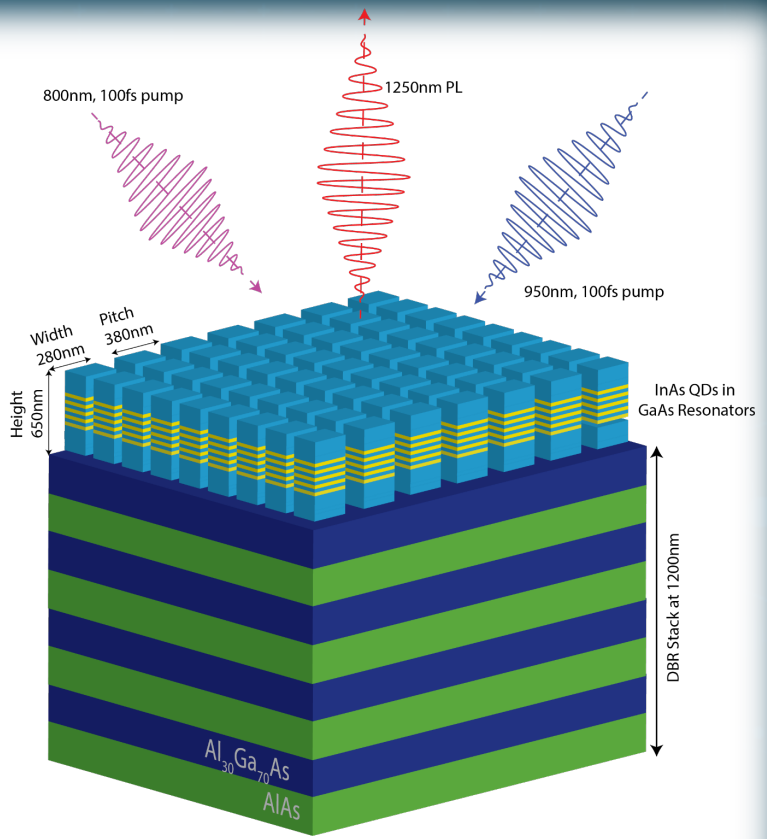




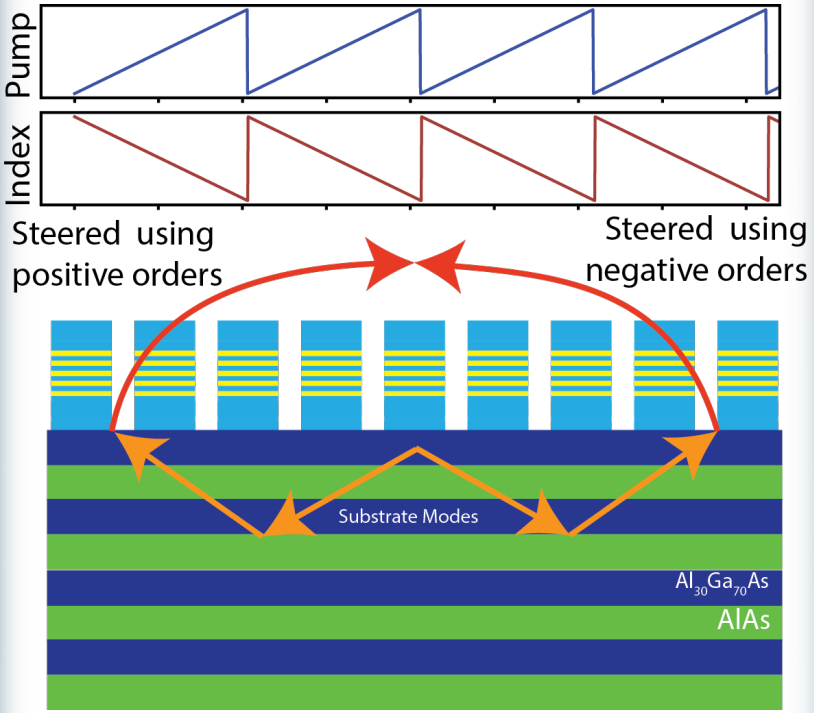
- The PL peak of the metasurface at the right edge of the DBR stack in reflection
- This allows for PL to couple to substrate modes at off-normal angles

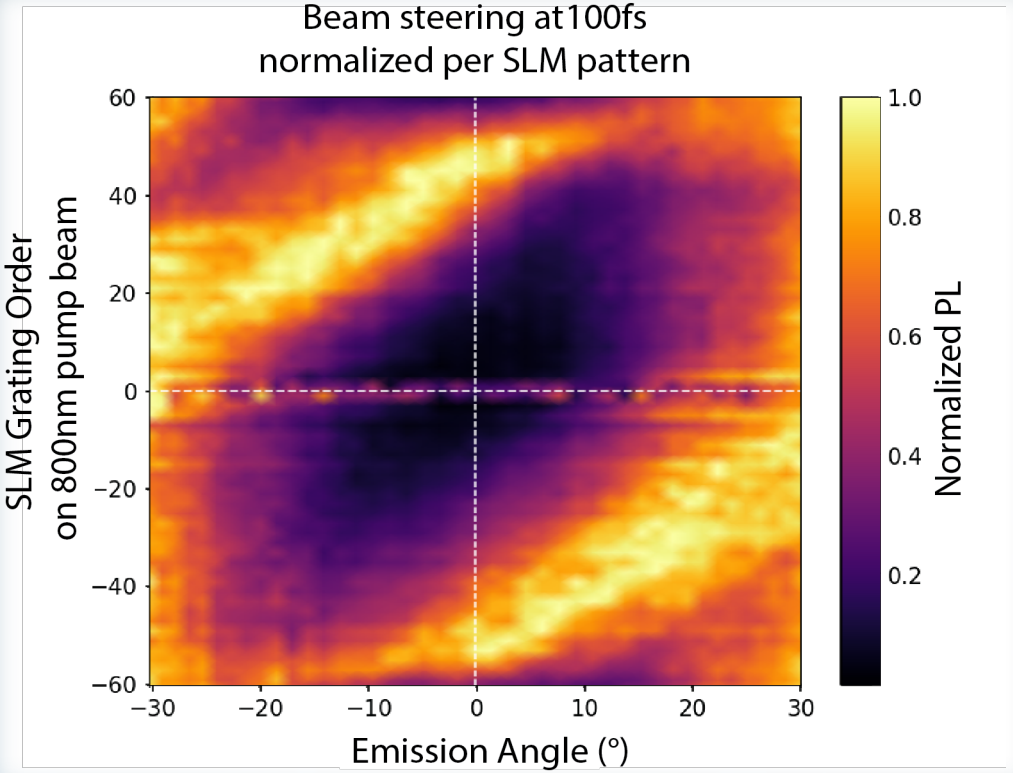
Experimental Setup Active Beam Steering



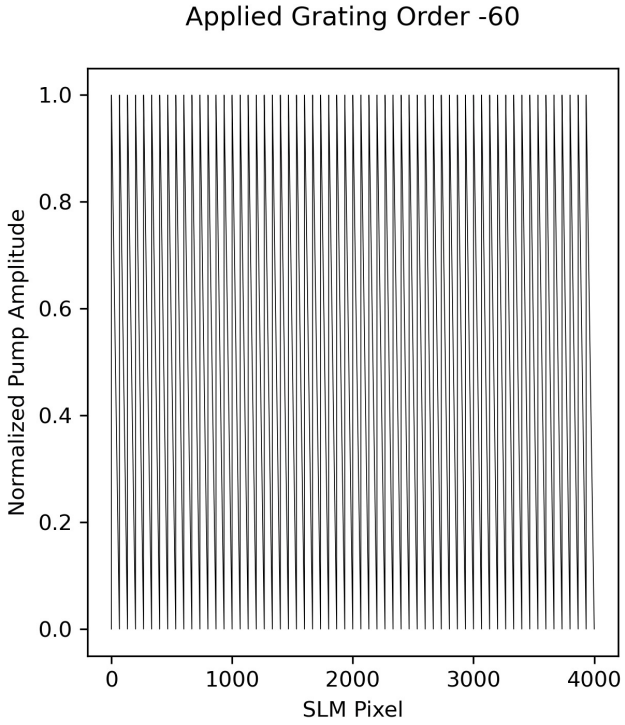


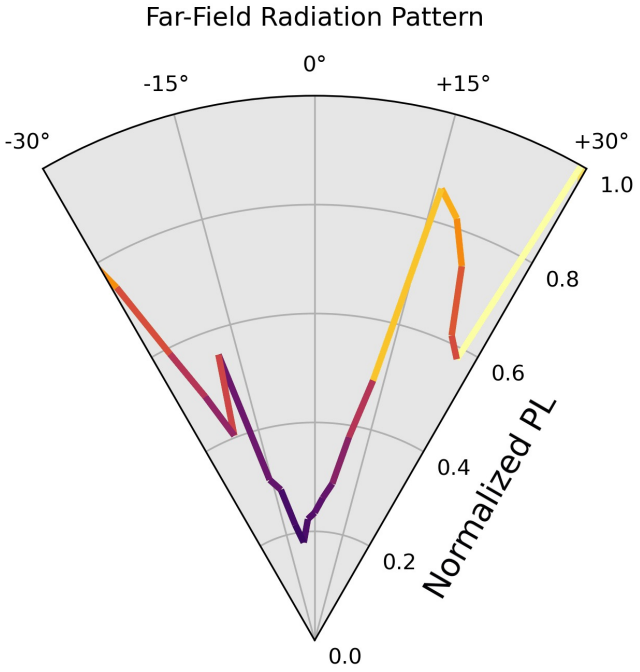
Unidirectional PL steering over 60° Field of View

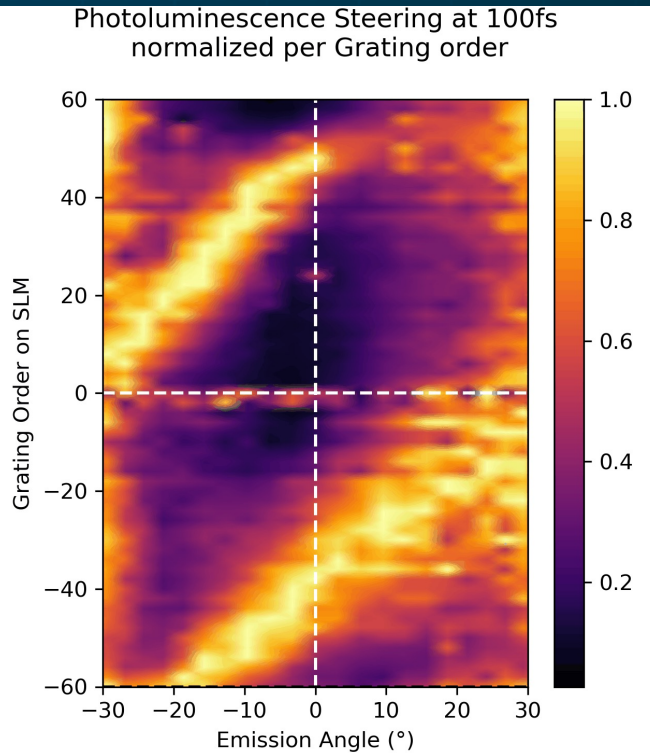




Dynamic Steering of Photoluminescence







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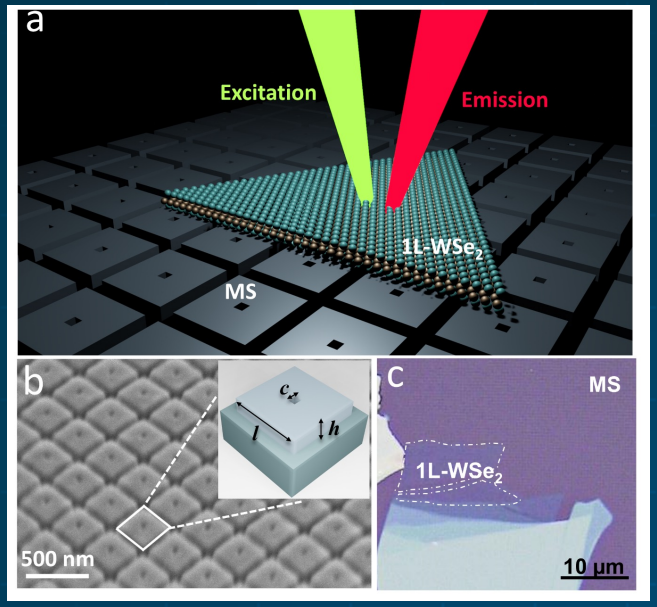
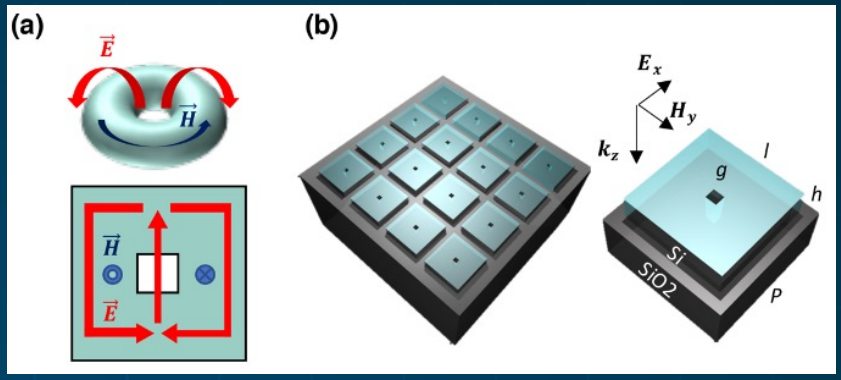
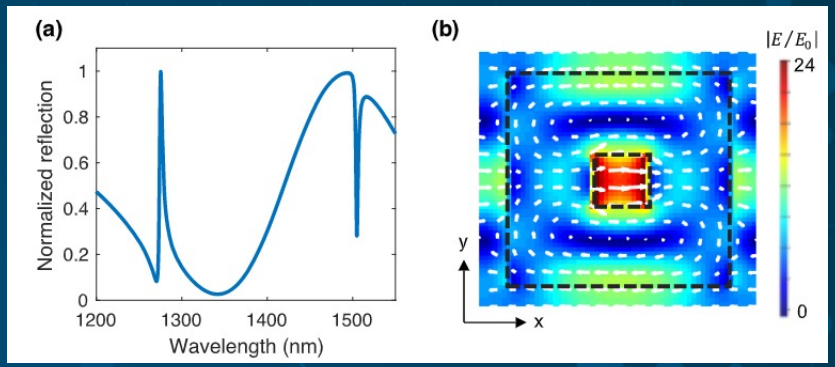
Emission control: Excitons in WSe_2

Excitons in WSe_2 Coupled to TiO2 Metasurface (Toroidal Resonances)



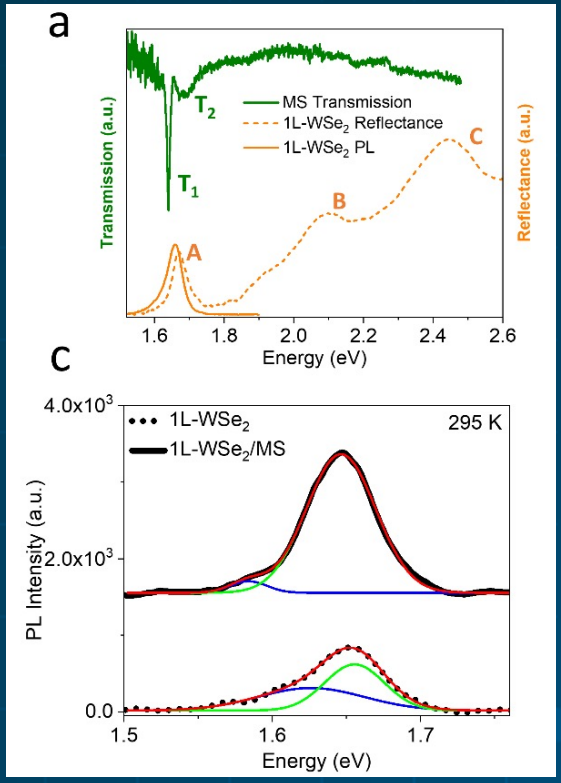




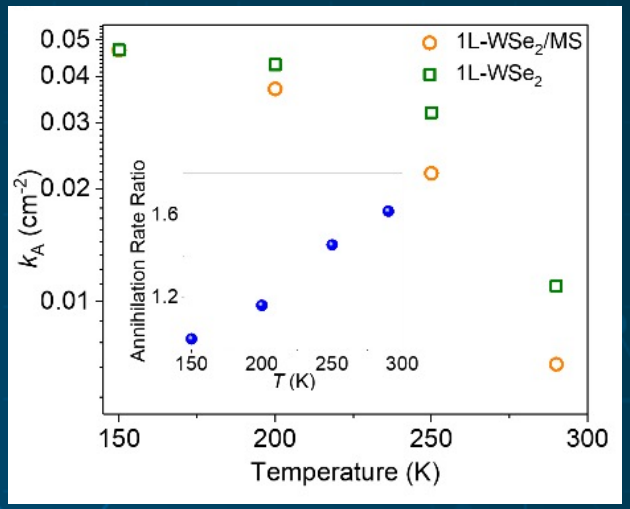
ACS Photonics 7, 1699 (2020).

Modification of Exciton Dynamics in WSE2 Using Toroidal Metasurfaces

Enhanced PL in 1L-WSe2+Metasurface: Purcell effect



Reduction of exciton annihilation rate



Changes in *annihilation rates*
Nano Letters 2021, in press.

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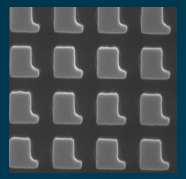
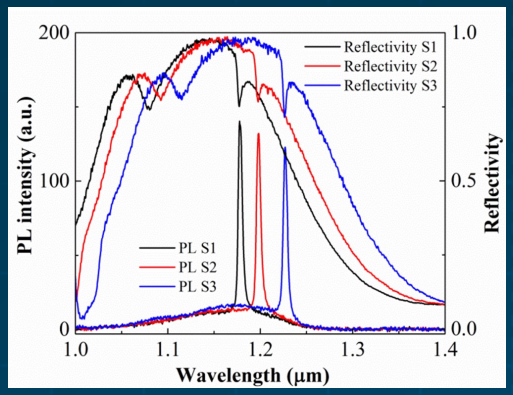
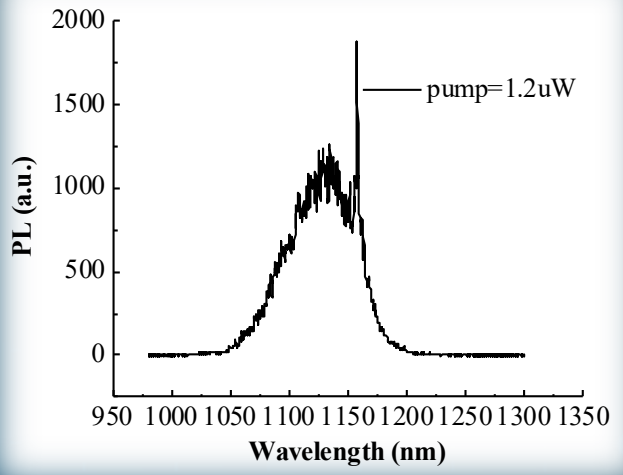
Control of Single-Photon Emission and Spontaneous Parametric Down-Conversion (SPDC) using Metasurfaces

Single-Photon Emission + MEtasurfaces



Epitaxial QDs

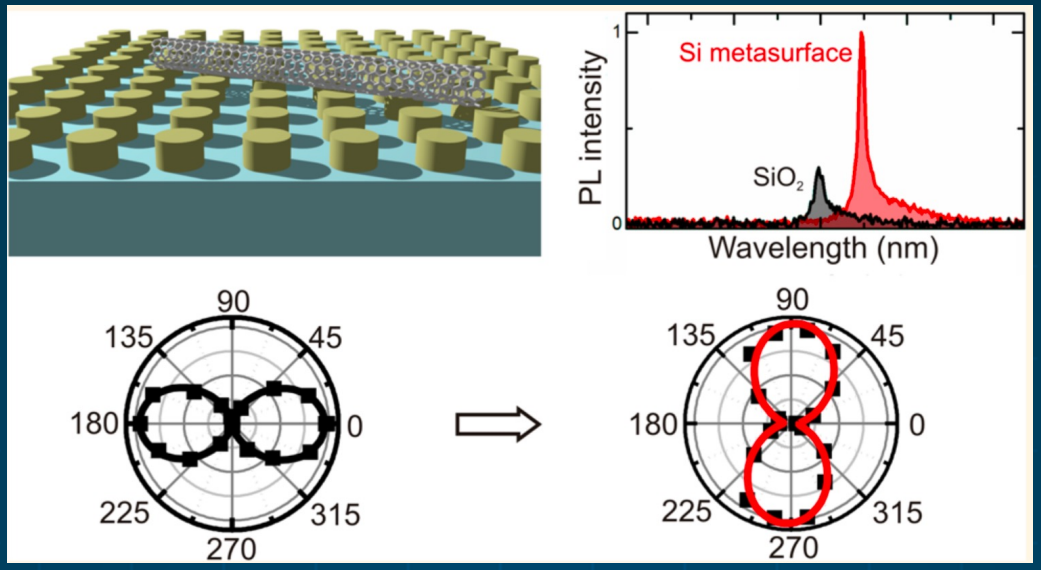




Other approaches for single-photon sources:

- Colloidal QDs
- Color centers in high bandgap materials
- Single dopants in Carbon nanotubes

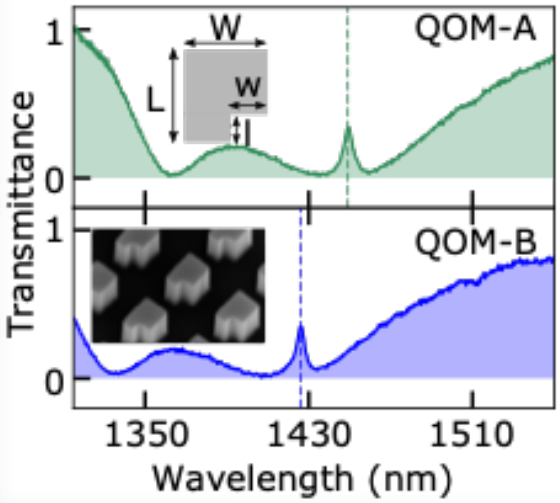
Single-dopant emitter in Carbon-Nanotube coupled to Si metasurface

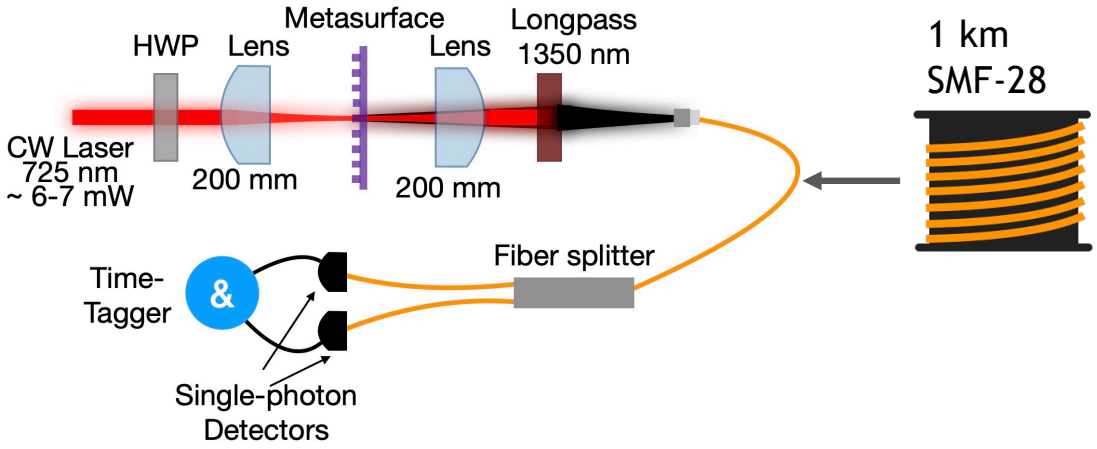


ACS Nano 11, 6431 (2017)

The challenge in these approaches is localization of single-photon emitter

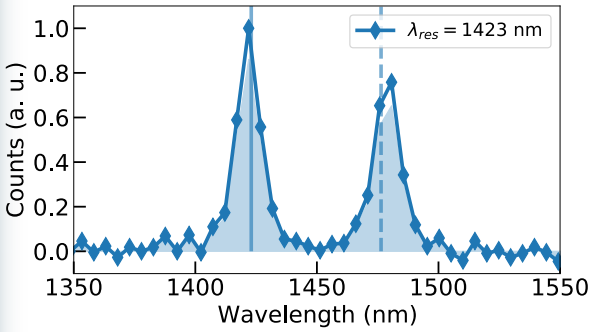
Spontaneous Parametric Down-Conversion from GaAs Metasurfaces



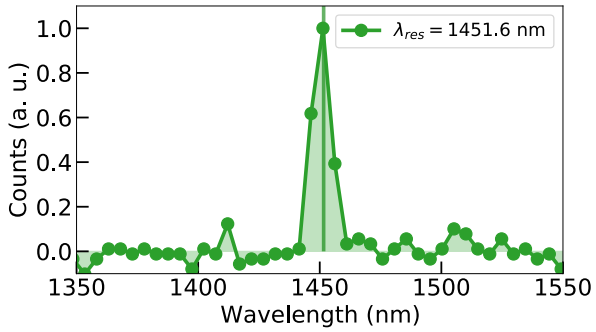


Bi-photon Spectra

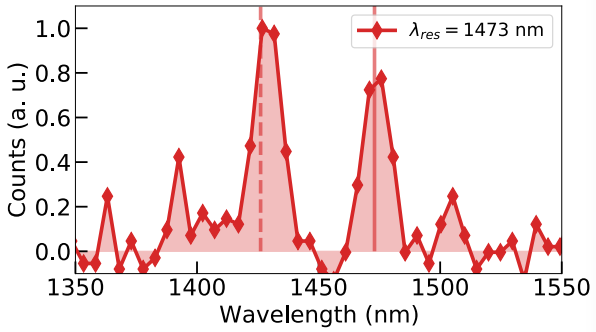
Blue-shifted resonance



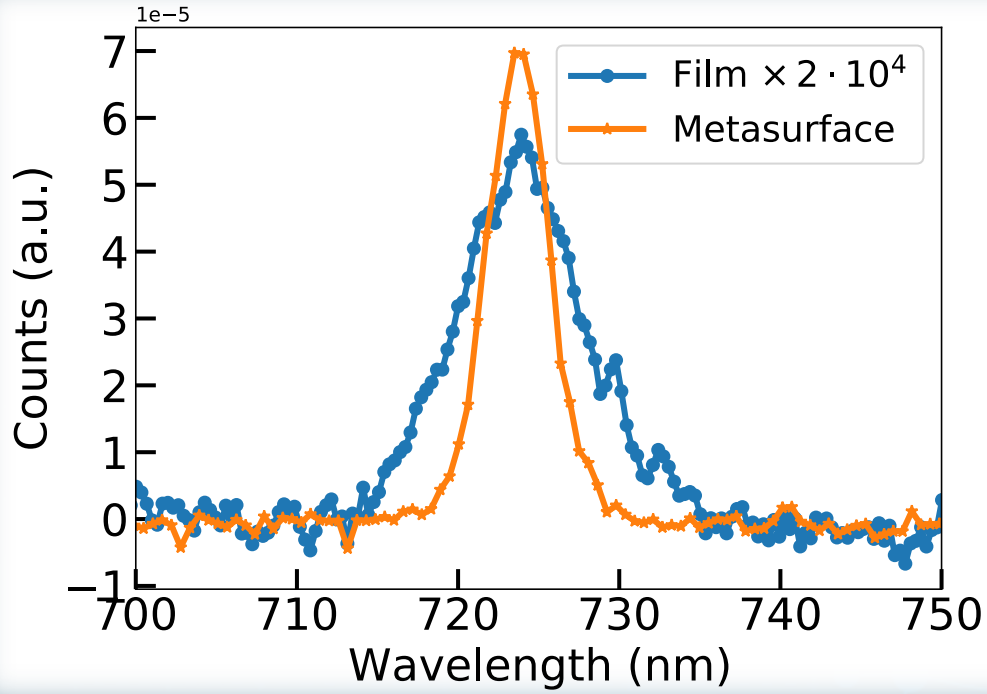
degenerate resonance



Red-shifted resonance



SPDC from Metasurface: Comparison to Film



4 orders of magnitude enhancement in biphoton rate!

Outline

- Background and static emission control using dielectric metasurfaces
- Ultrafast photoluminescence steering
- Control of exciton dynamics in WSe2
- Towards single photon emitters and SPDC