

9/28/2017

Photoluminescence engineering using III-V dielectric metamaterials

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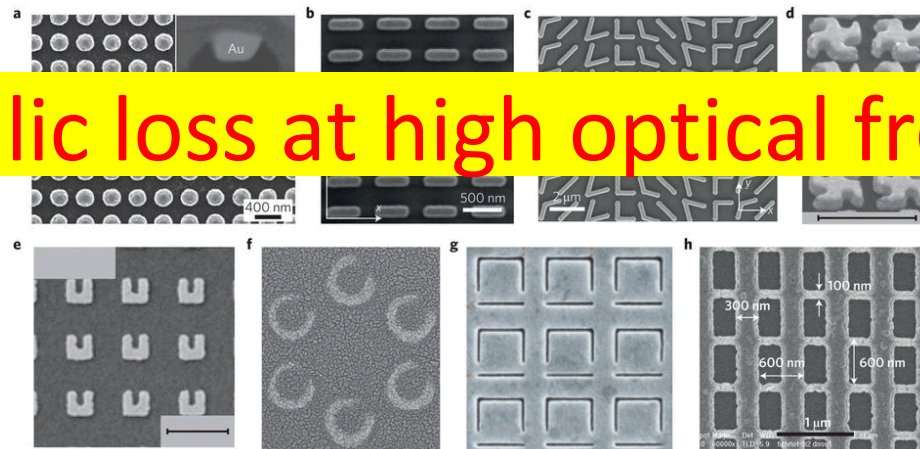
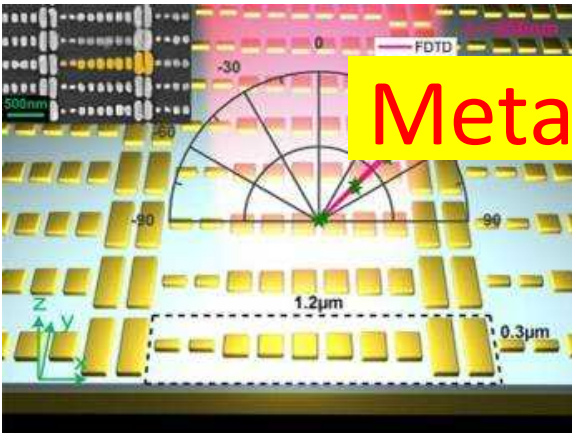
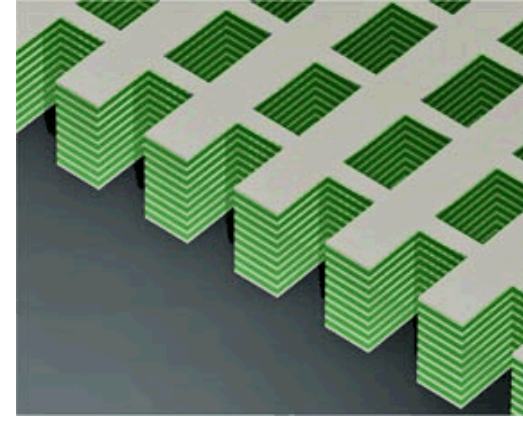
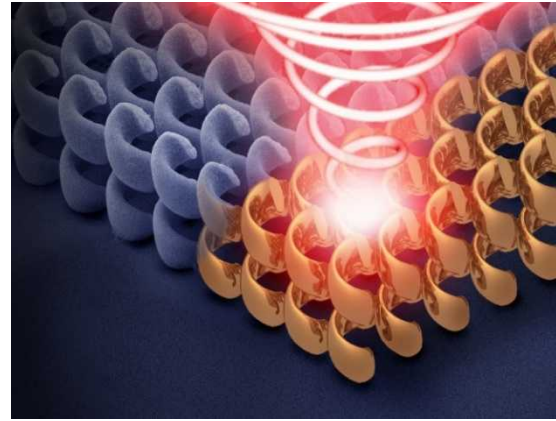
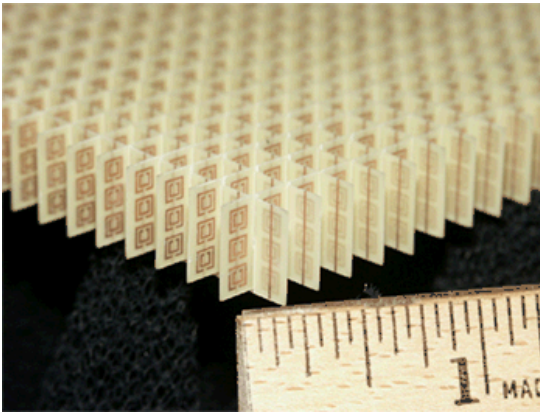
Metamaterials-enhanced light matter interaction

- Fundamental motivation/interest for nanophotonics
- Various platforms: photonic crystal, DBR micro-cavity, microring resonator

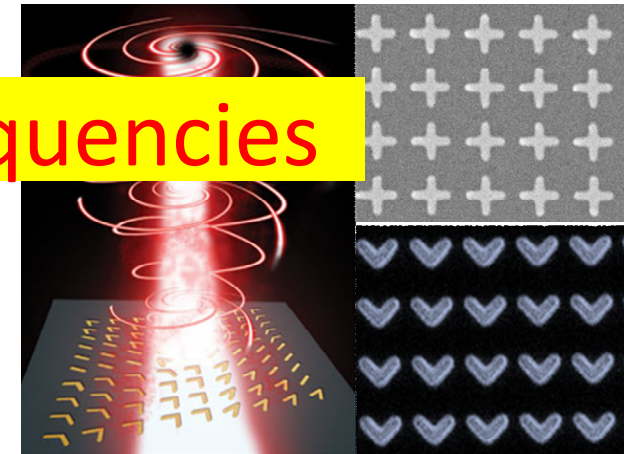
F. Capasso, N. Engheta, V. Shalaev, J. Pendry, D. Smith, M. Brongersma, H. Atwater, A. Alu, M. Belkin, J.

Metamaterials → metasurfaces

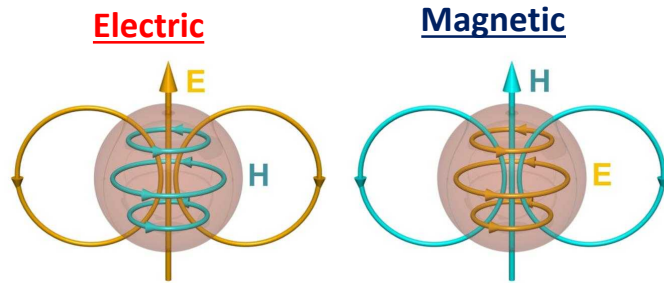
Dionne, HT Chen, X. Zhang, N. Zheludev, J. Valentine, S. Zhang, M. Wegener, E. Hasman, H. Giessen



Metallic loss at high optical frequencies



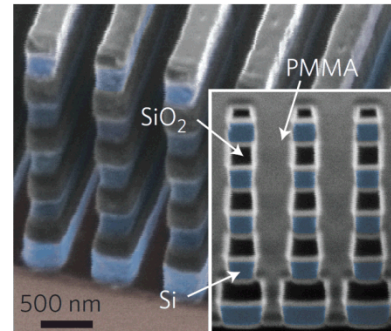
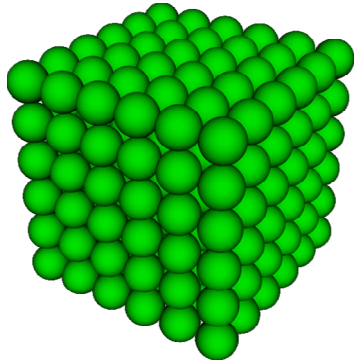
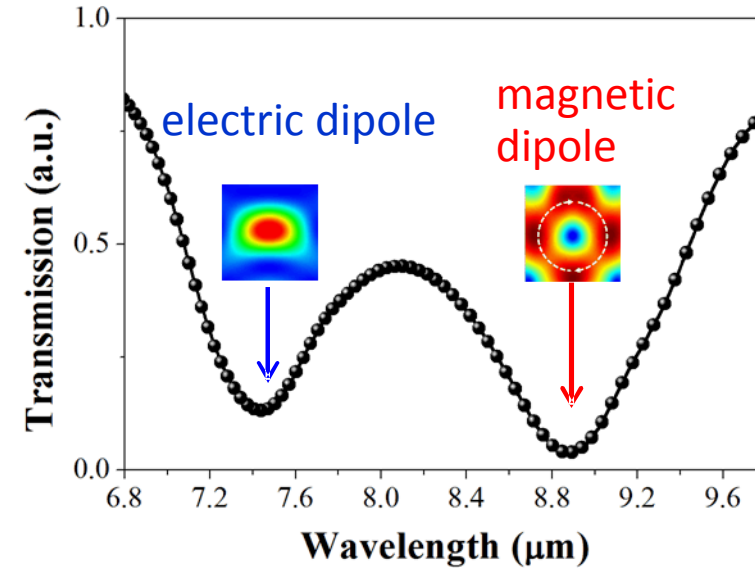
Low loss dielectric metamaterials/resonators



Images: A. Miroshnichenko

Magnetic dipole resonance: tailor μ
Electric dipole resonance: tailor ϵ

- *Much lower loss at optical frequencies*
- *Strong interaction with magnetic field → Huygens's metasurfaces*



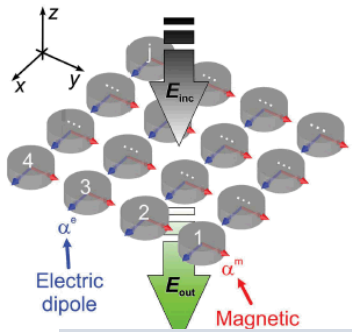
Yuanmu Yang, Jason Valentine

3D structure is possible
Isotropic response can be achieved

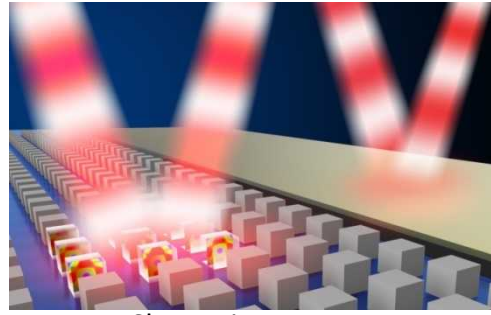
However, still challenging → metasurfaces

Recent progresses of dielectric metasurfaces

Huygens principle:

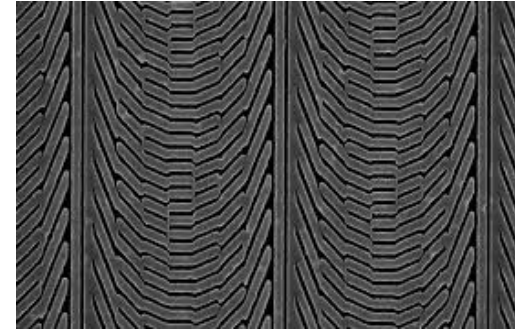


Magnetic mirror



Sheng Liu

Ultrathin gratings, lenses, axicons



Franz Hees, 8, Mark L. Brongersma

REVIEW

APPLIED OPTICS

Optically resonant dielectric nanostructures

Arseniy I. Kuznetsov,¹ Andrey E. Miroshnichenko,² Mark L. Brongersma,^{3*} Yuri S. Kivshar,^{2*} Boris Luk'yanchuk^{1,4*}

nature nanotechnology

PUBLIS

All-dielectric metamaterials

Saman Jahani¹ and Zubin Jacob^{1,2*}

optica

Multipolar nonlinear nanophotonics

DARIA SMIRNOVA AND YURI S. KIVSHAR*

REVIEW ARTICLE

PUBLISHED ONLINE: 28 APRIL 2017 | DOI: 10.1038/NPHOTON.2017.39

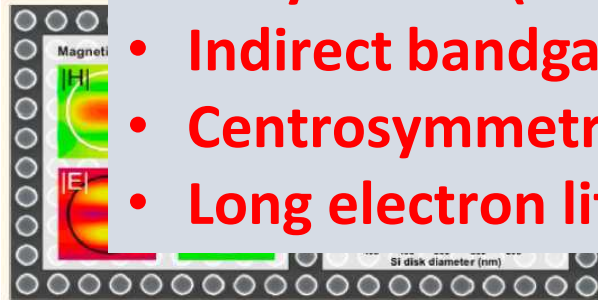
nature photonics

Metamaterial-inspired silicon nanophotonics

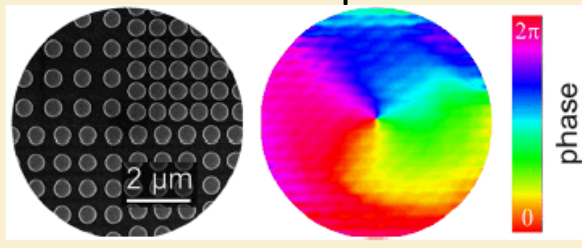
Isabelle Staude¹ and Jörg Schilling^{2*}

Di **Mostly silicon (easy to fabricate)**

- Indirect bandgap: inefficient light emission and absorption
- Centrosymmetric: lack of second-order nonlinearity
- Long electron life time: strong free carrier absorption



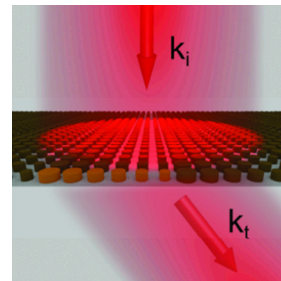
Ultrathin waveplate



Yuri Kivshar

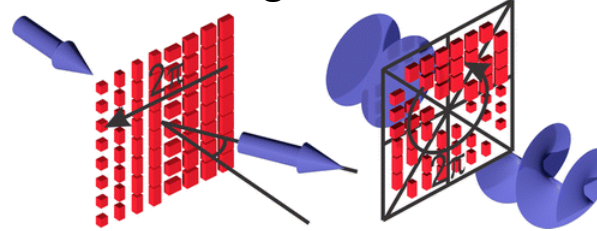
Jason Valentine

Beam deflection



Arseniy I. Kuznetsov

Beam steering, vortex converter



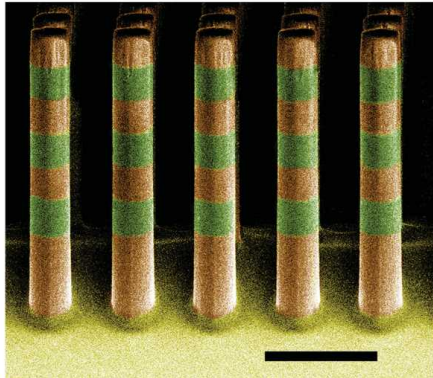
Natalia M. Litchinitser

XXXIInd International Union of Radio Science
General Assembly & Scientific Symposium
August 19-26th, 2017

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& SCIENTIFIC SYMPOSIUM

III-V dielectric metamaterials

- Multilayer structure—MBE/MOCVD growth + monolithic



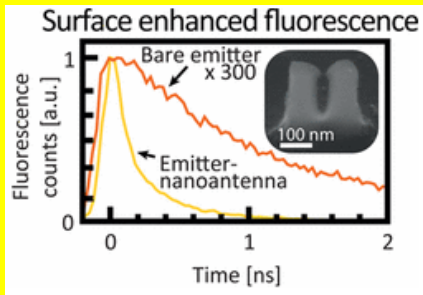
Sheng Liu, et al, Adv. Optical Mater. **4**, 1457, (2016)

- Direct bandgap—

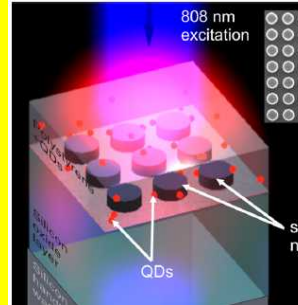
Ultrafast resonance shift $\sim 30\text{nm}$

Maxim, Nature Comm. **8**, article 17, (2017)

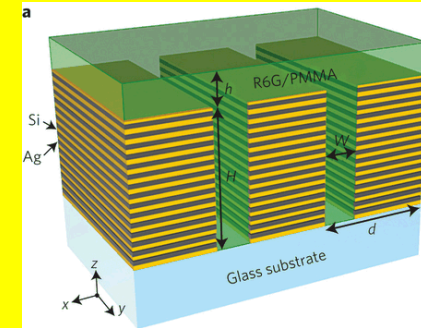
- Enhanced light emission



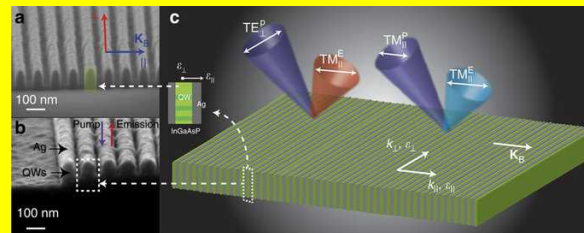
Stefan Maier (2017)



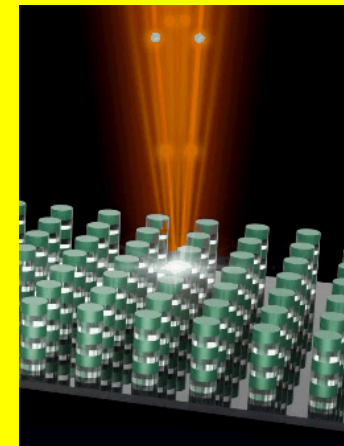
Isabelle (2014)



Zhaowei Liu (2014)



Luminescent hyperbolic metasurfaces
Joseph Smalley, UCSD



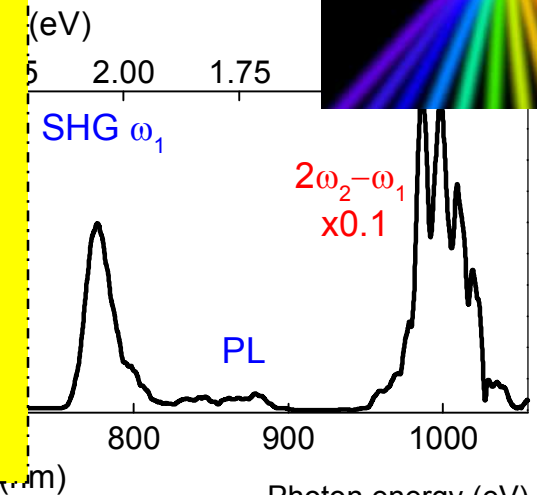
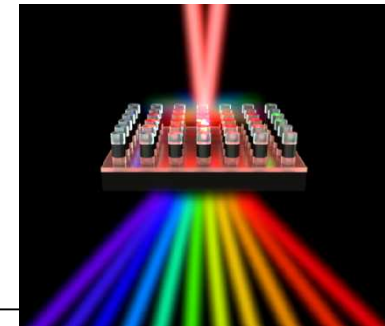
Embedding emitters inside resonators

- Resonantly enhanced second-harmonic generation ($\sim 10^{-5}$)

et al, Nano Letters, **16**, 5426, (2016)

Giuseppe (2016)

Yashar, Dragomir Neshev, Letters (2016)

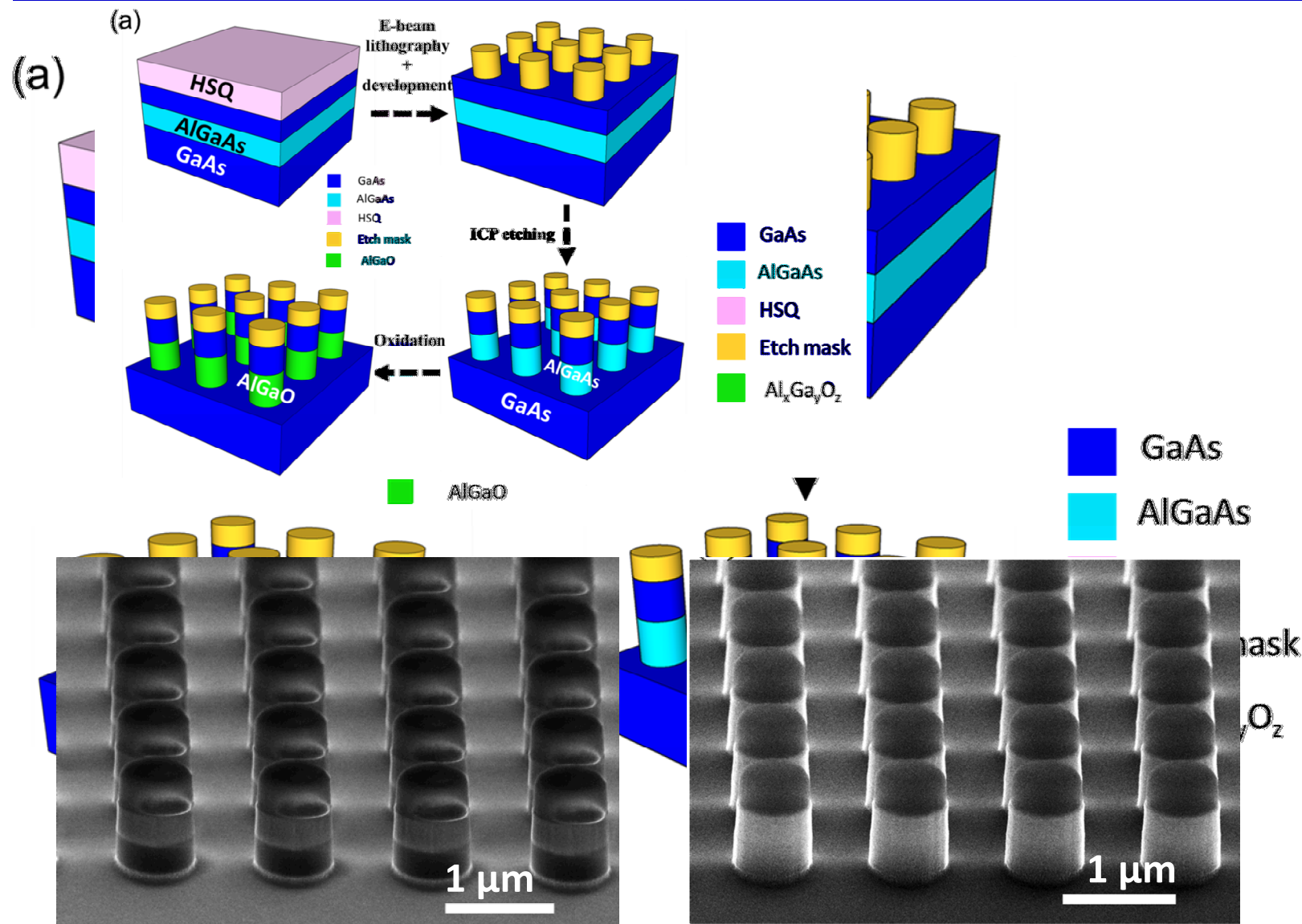


Pump-probe delay (ps)

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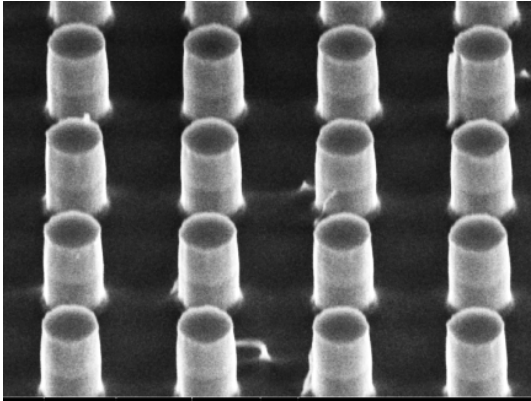
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Fabricate (Al)GaAs Based Dielectric Metasurfaces



- Oxidation:
AlInAs, AlInGaP, etc
- Multilayer structures

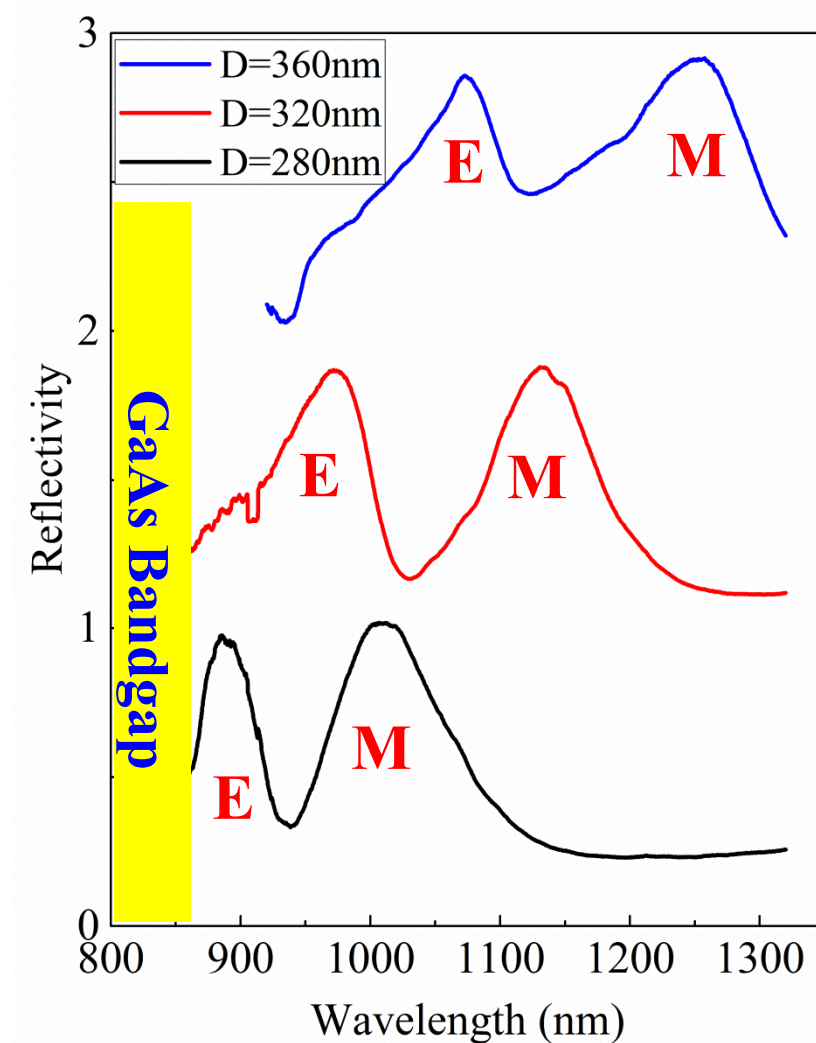
GaAs disk height $\sim 300\text{nm}$
Different diameters



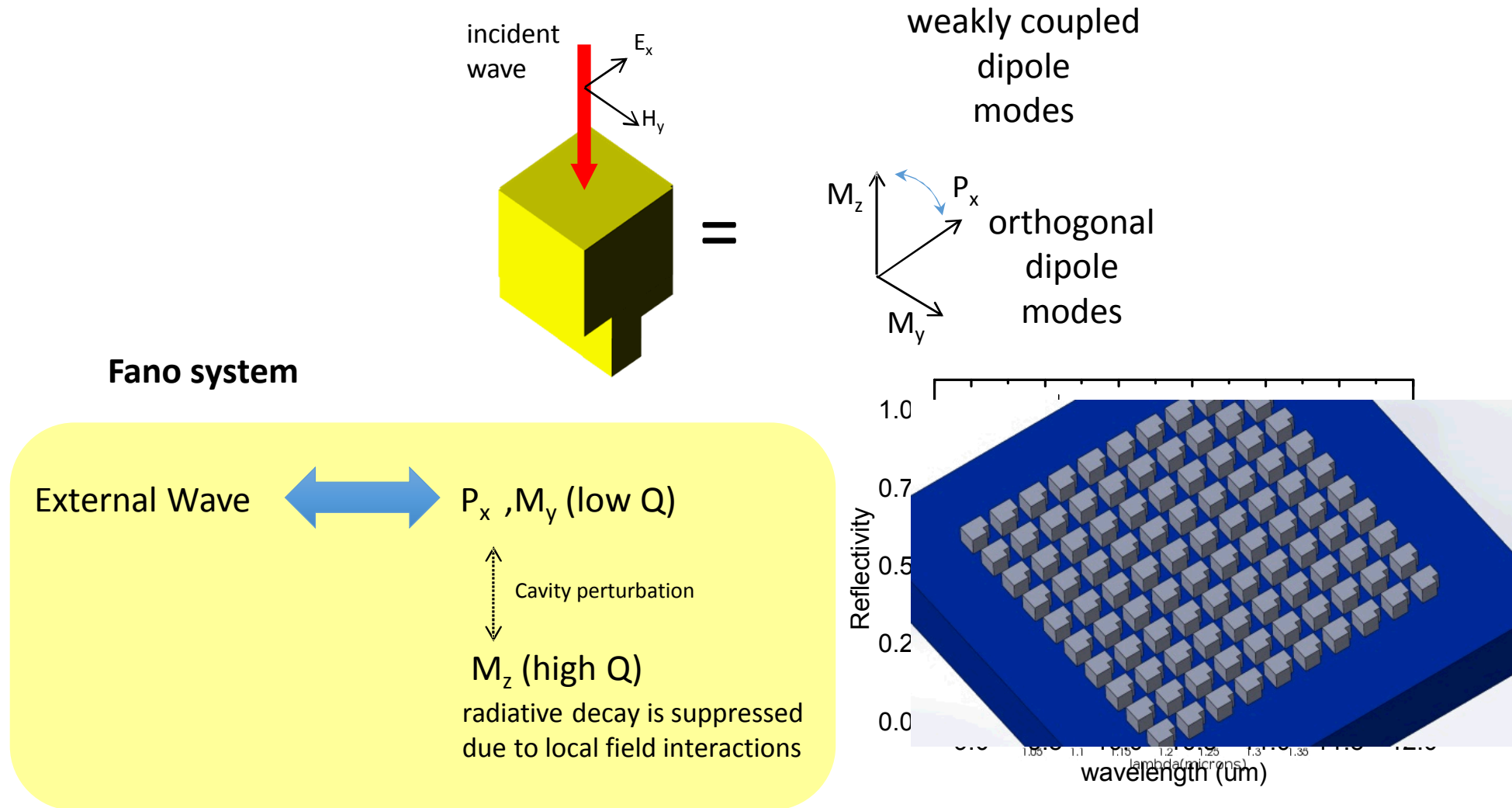
- Extremely low loss below bandgap
- Crystalline

Low quality factor ~ 10

Many applications require narrow,
tunable light emission $\rightarrow$ higher Q



Fano Metasurface: Operating principles

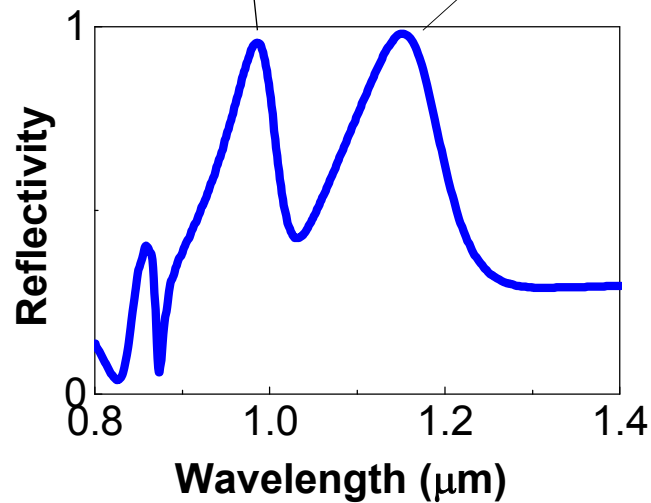
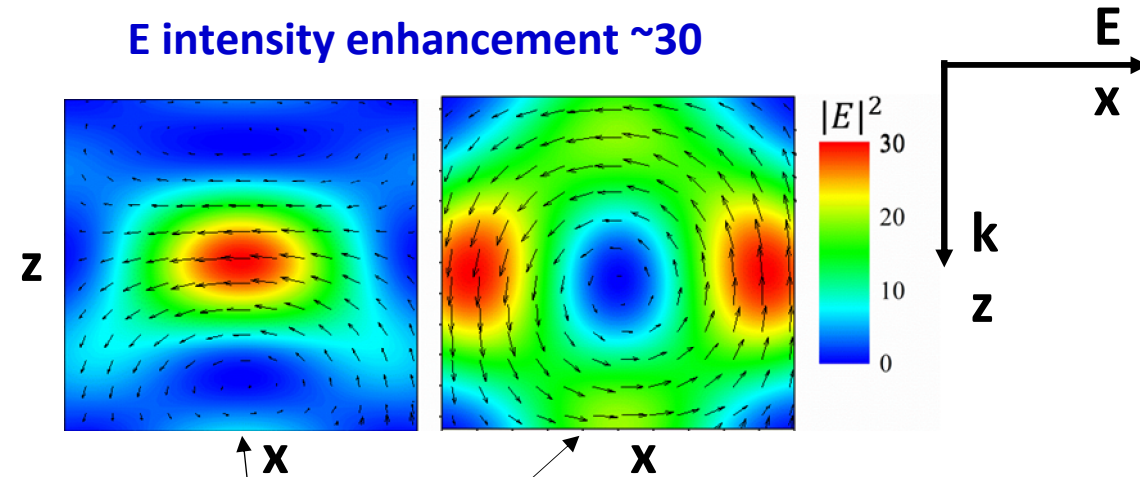


ACS Photonics 2016, 3, 2362–2367

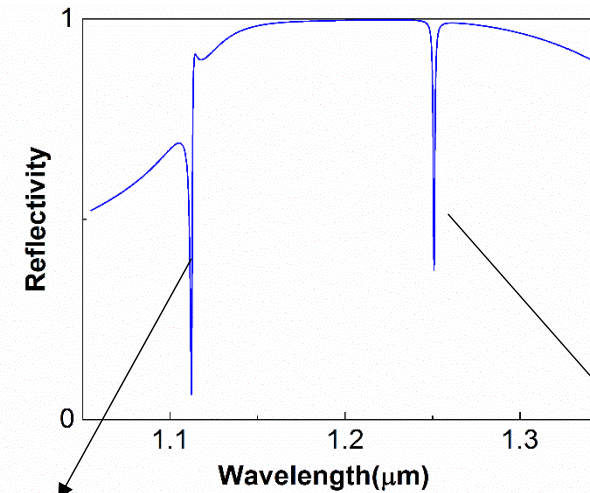
High Q Fano resonators

- Regular nano-cylinder resonators

E intensity enhancement ~ 30

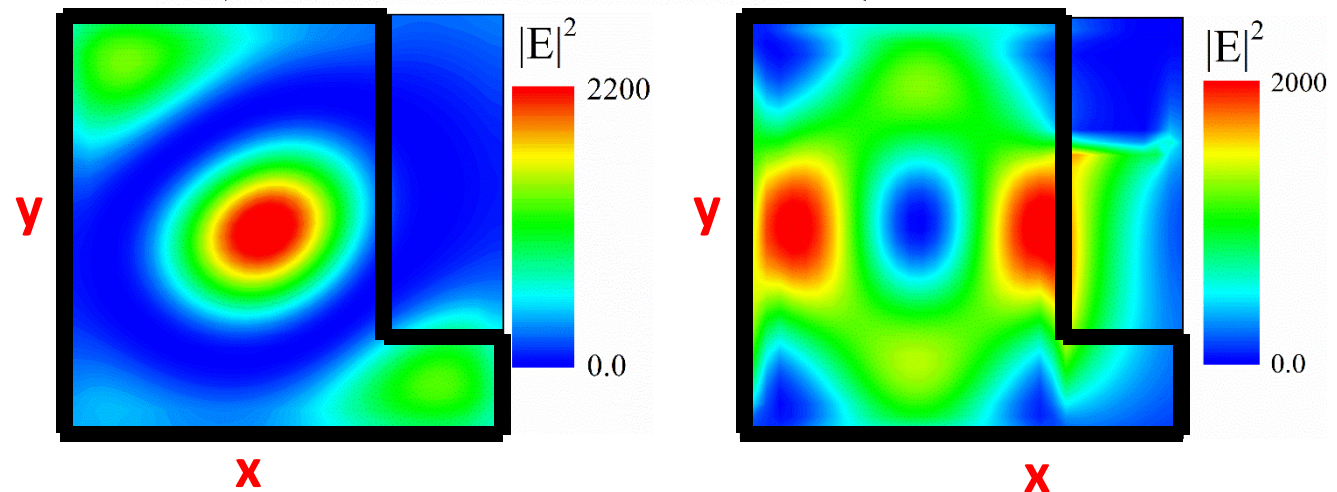


- Broken symmetry design
- Single unit cell

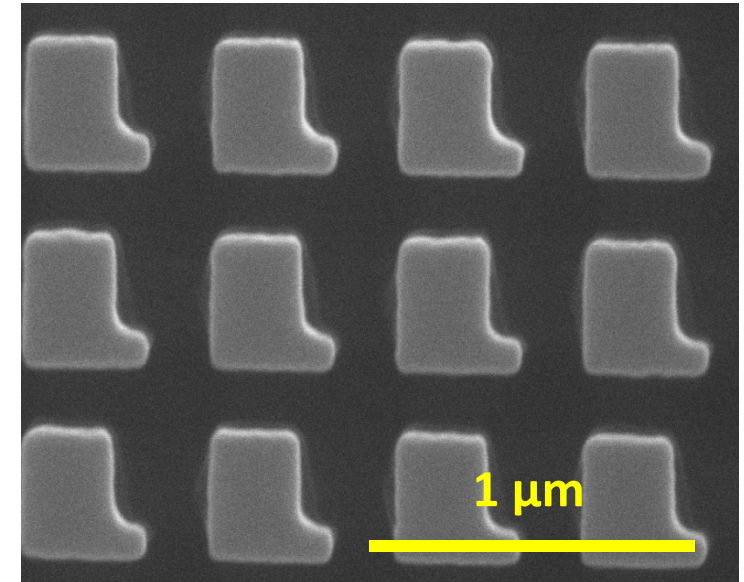
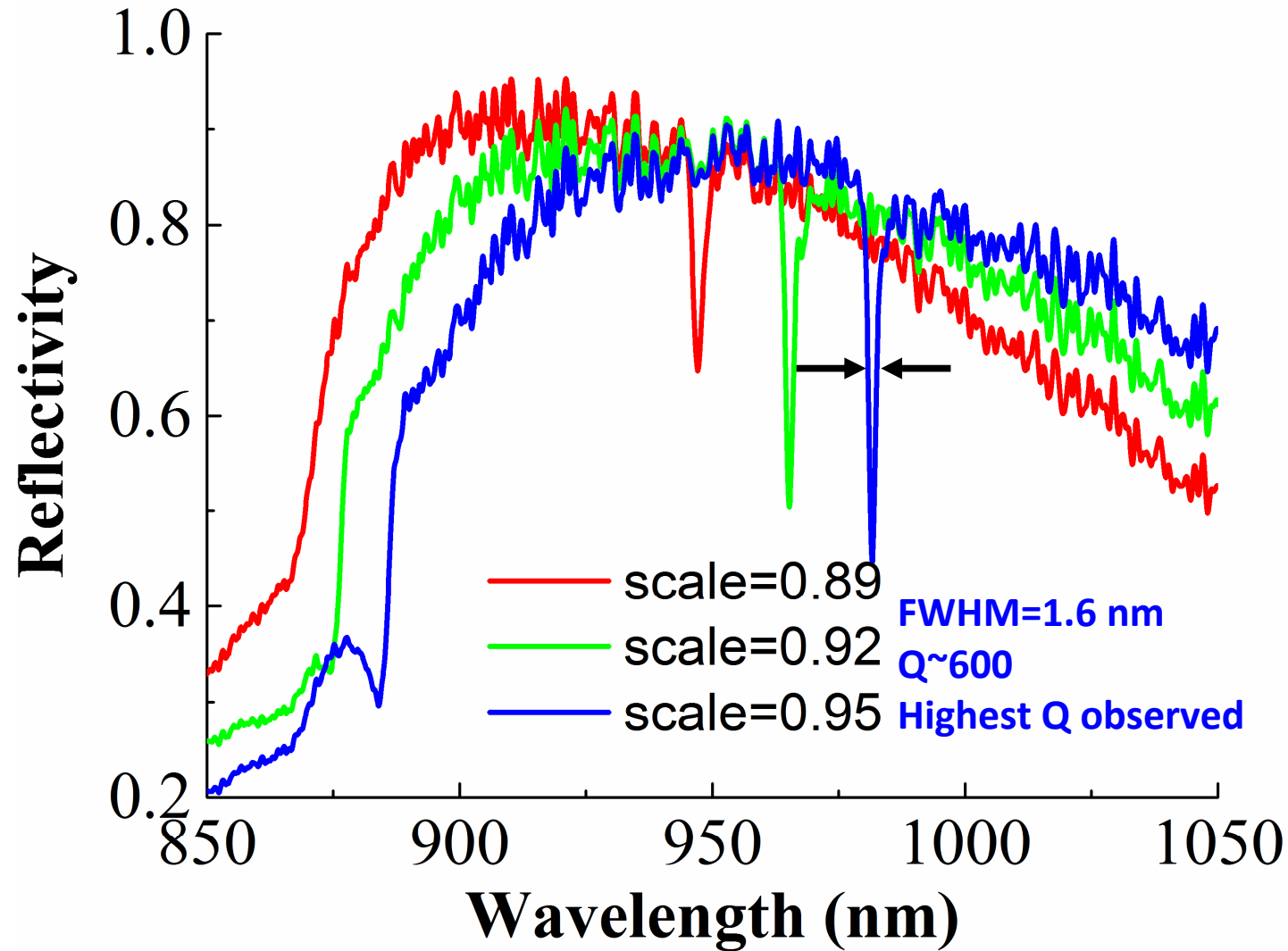


Intensity enhancement
 >1000

Out of plane dipoles



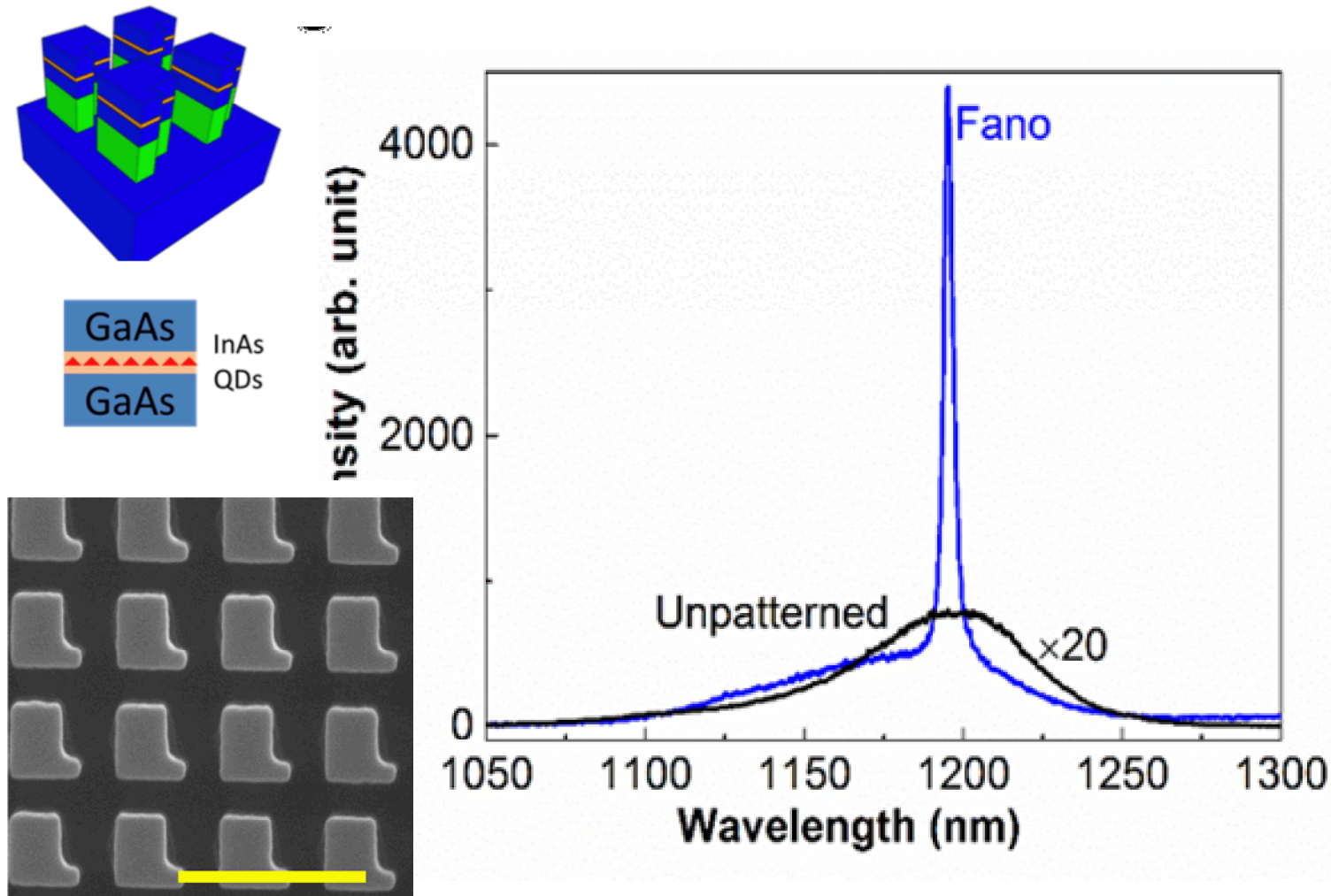
GaAs Fano metasurface samples



ACS Photonics 2016, 3, 2362–2367

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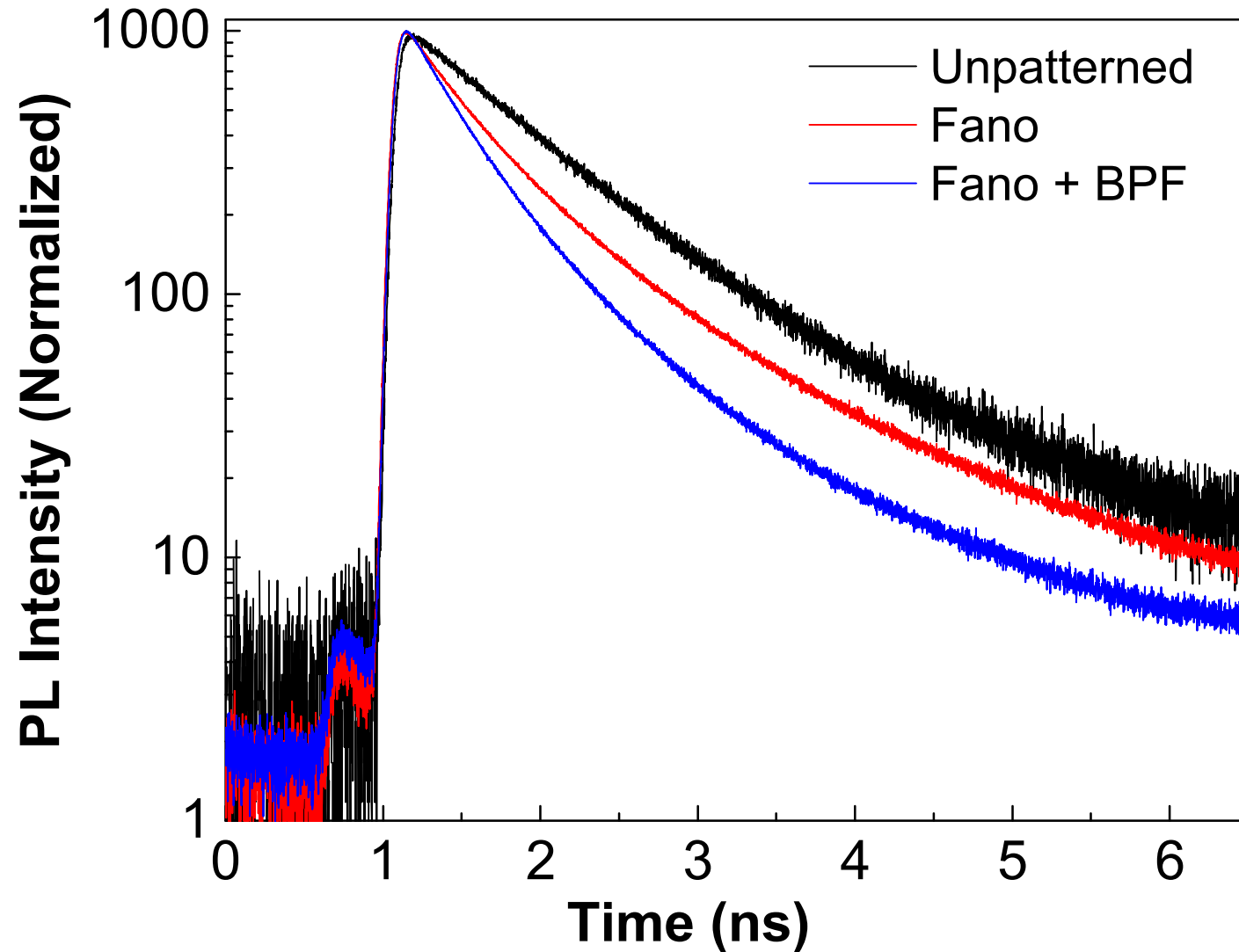
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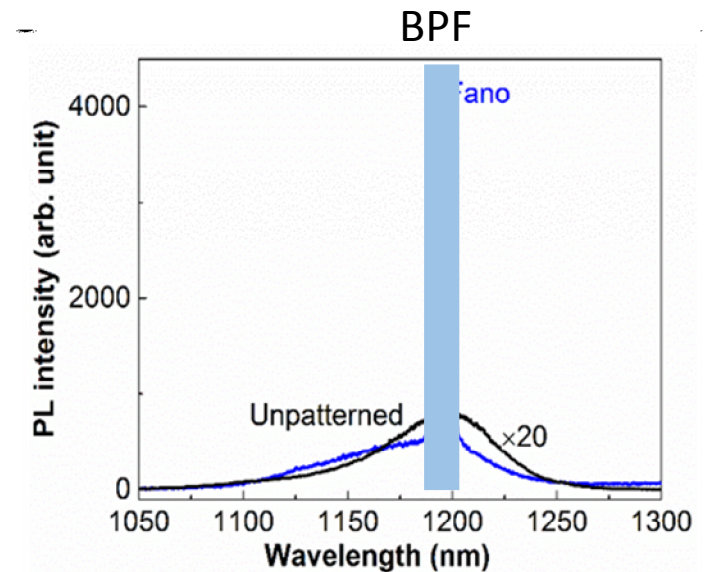
- PL linewidth narrowing
- Large enhancement of PL peak intensity

Questions:

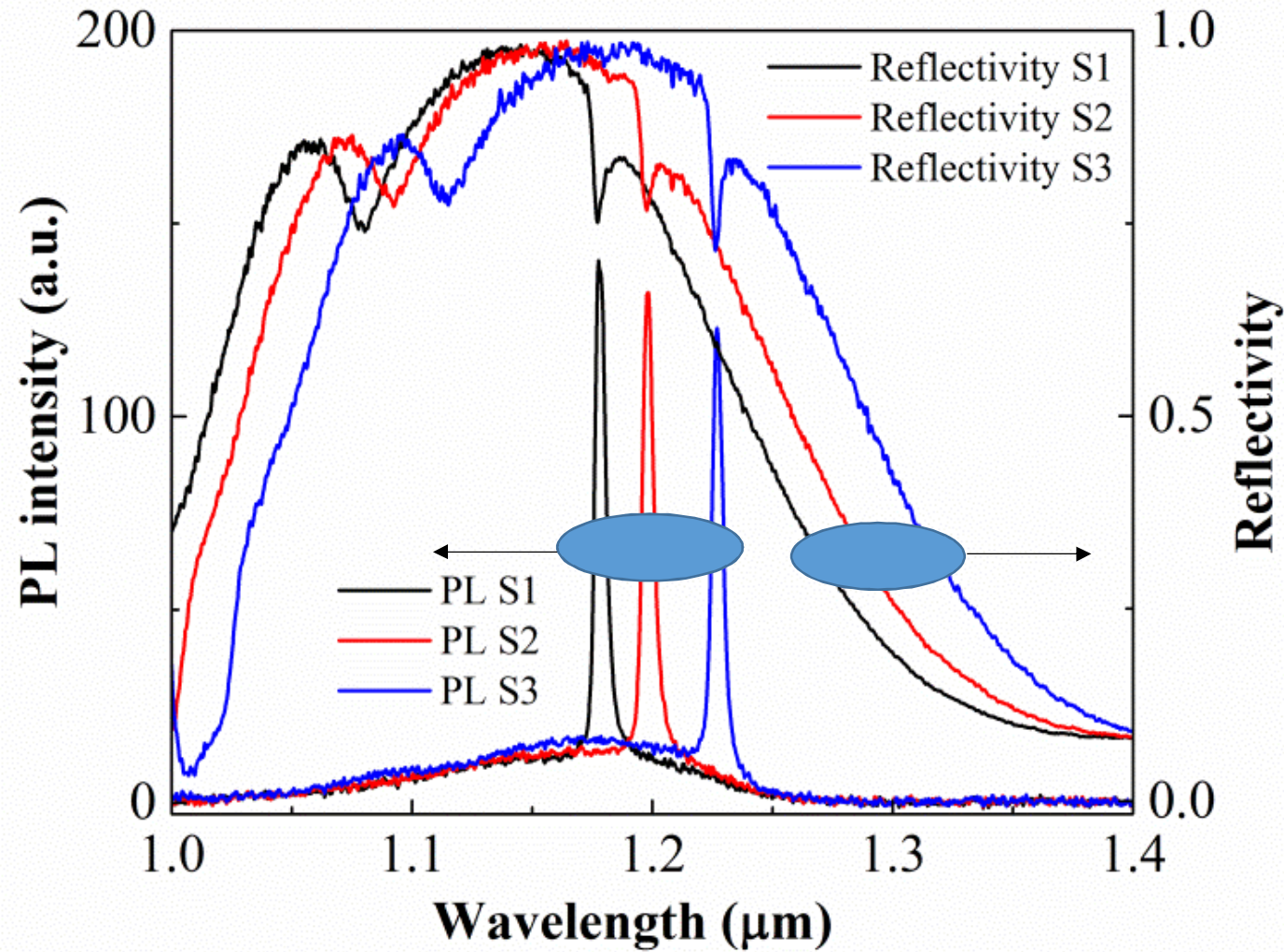
- Purcell enhancement (lifetime measurement)
- Spectral tuning + peak wavelength



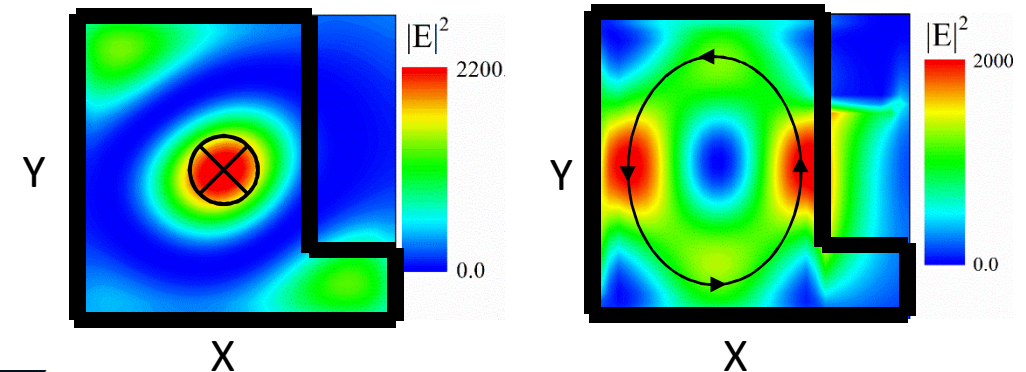
- Purcell enhancement ($\sim 100\%$ quantum efficiency emitter)
- Low emission quantum efficiency from epitaxially grown InAs QDs
- Possible non-radiative decay rate (+strong surface recombination, passivation) $\tau_{PL}^{-1} = \tau_r^{-1} + \tau_{nr}^{-1}$



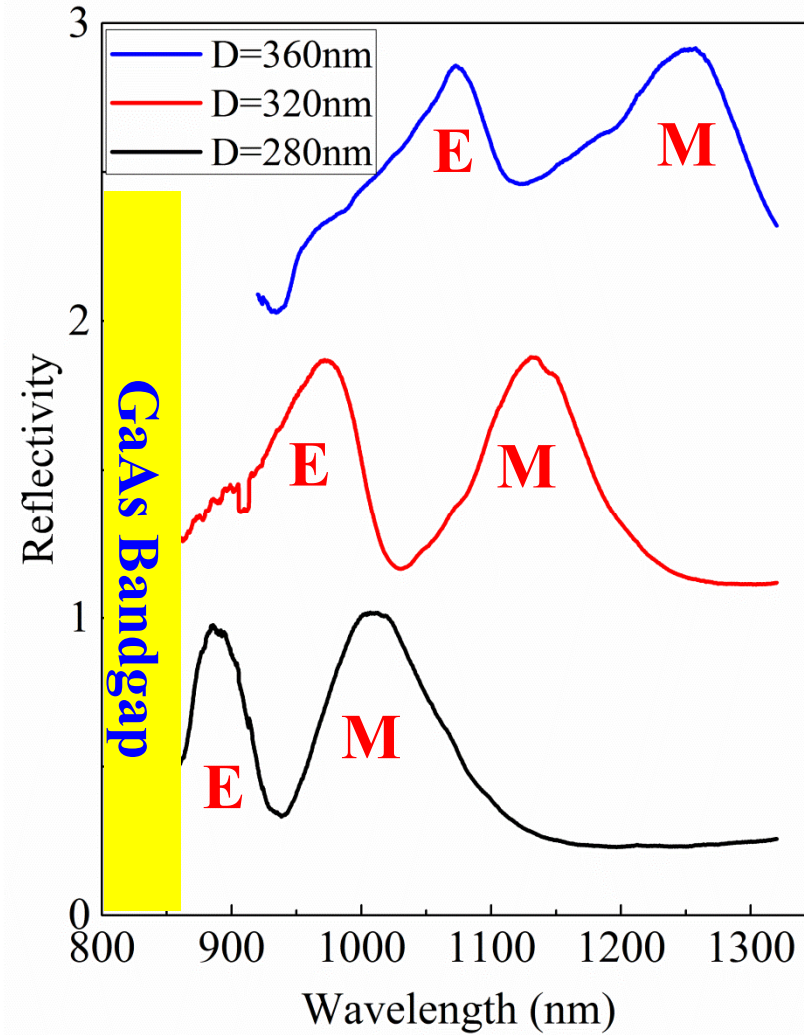
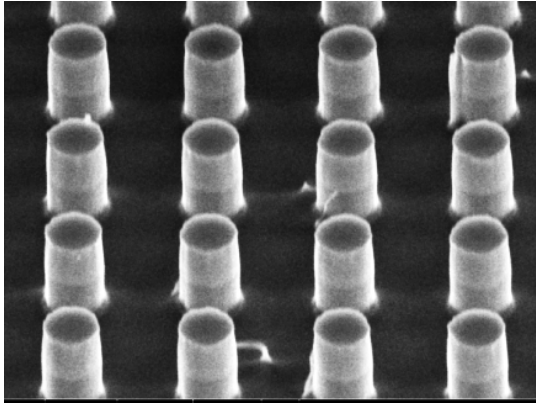
BPF: band pass filter



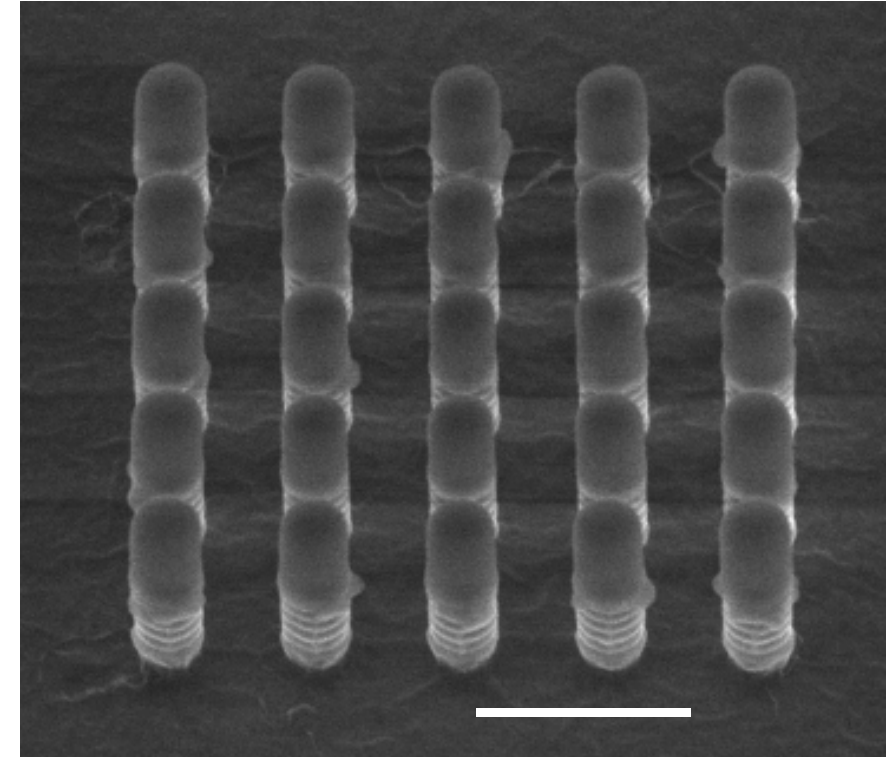
- Spectral tuning of the Fano resonances by changing the sizes
- PL peaks agree well with the reflectivity dips
- PL enhancement only occurs at one of the two resonances
 - Higher Q (fabrication, absorption)
 - Out of plane emission vs in-plane emission (NA)



PL enhancement by cylinder sample ???

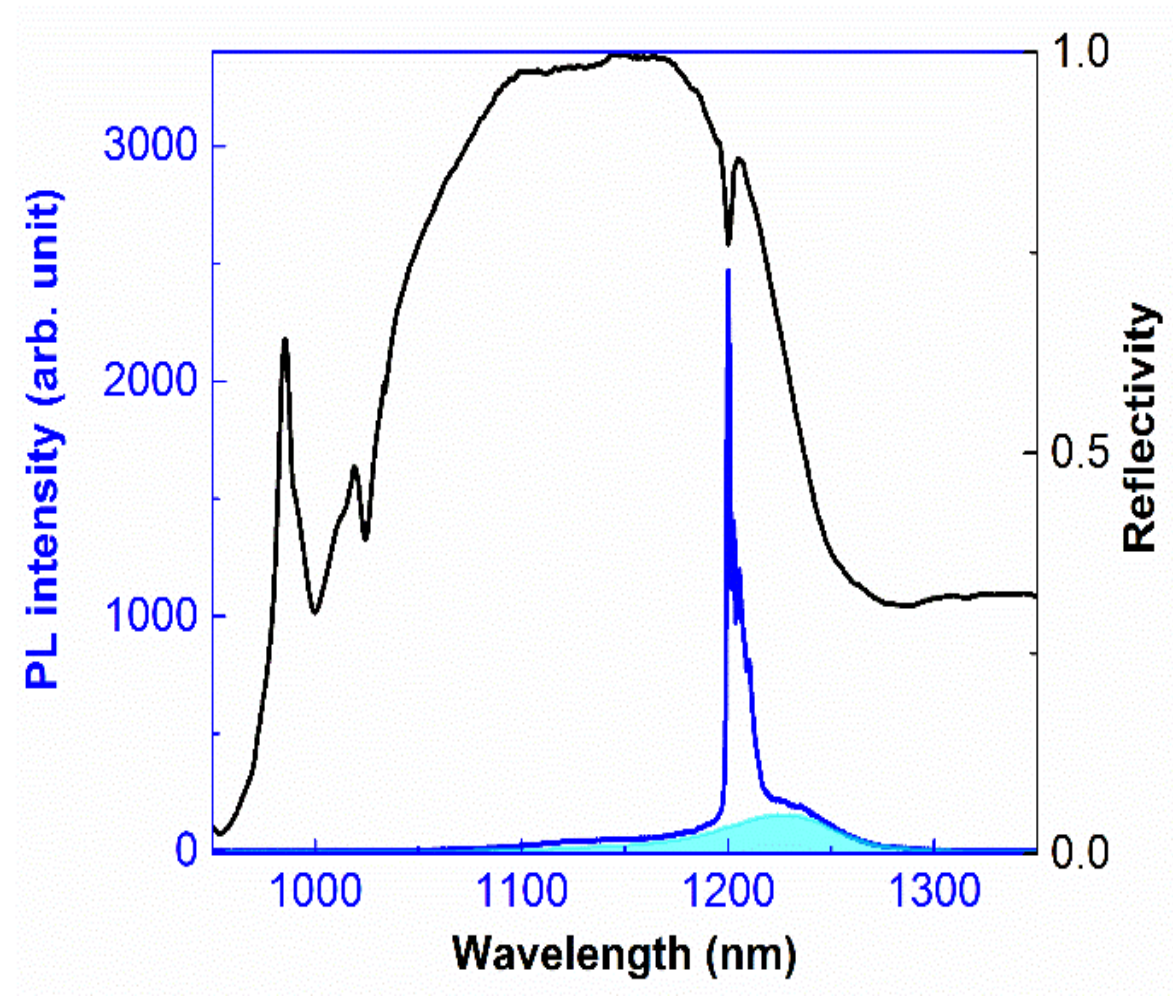
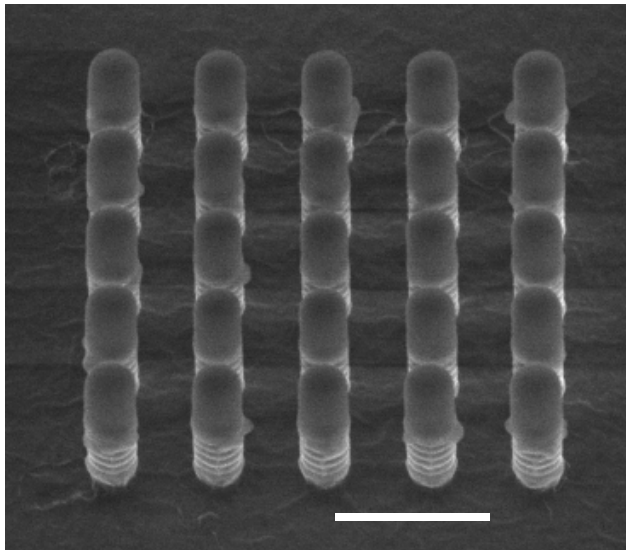


Embedding QDs emitters

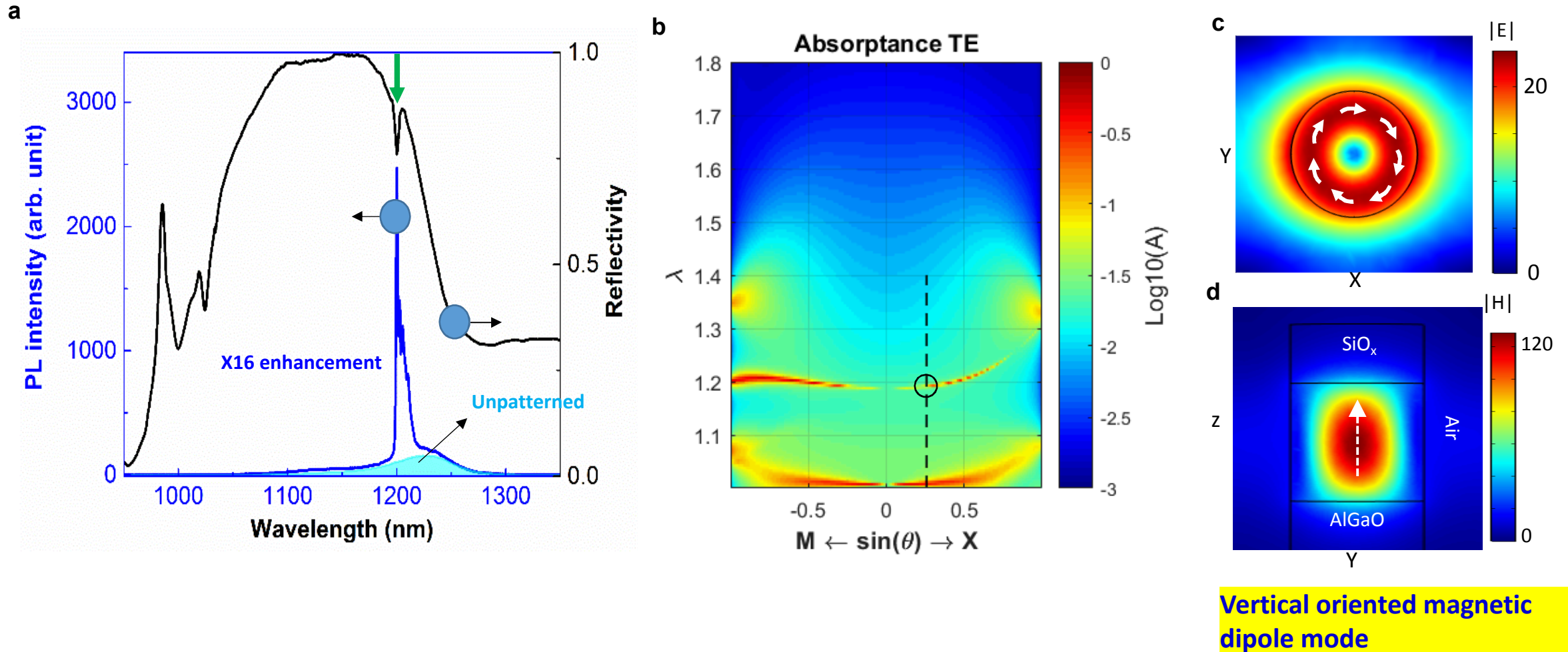


Sharp PL enhancement by cylinder sample

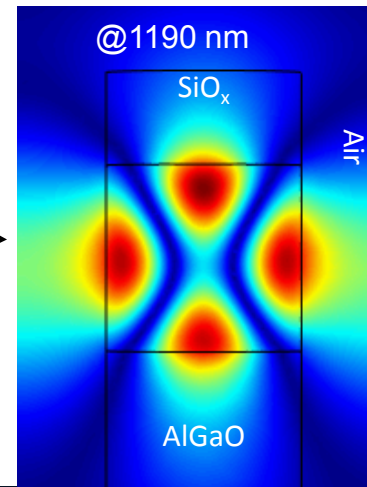
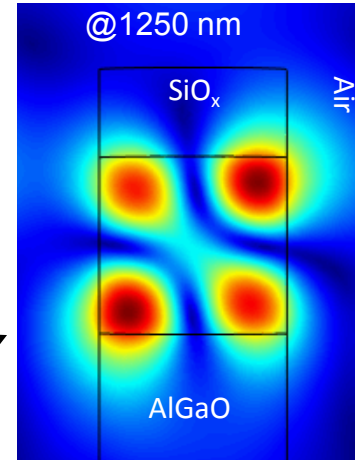
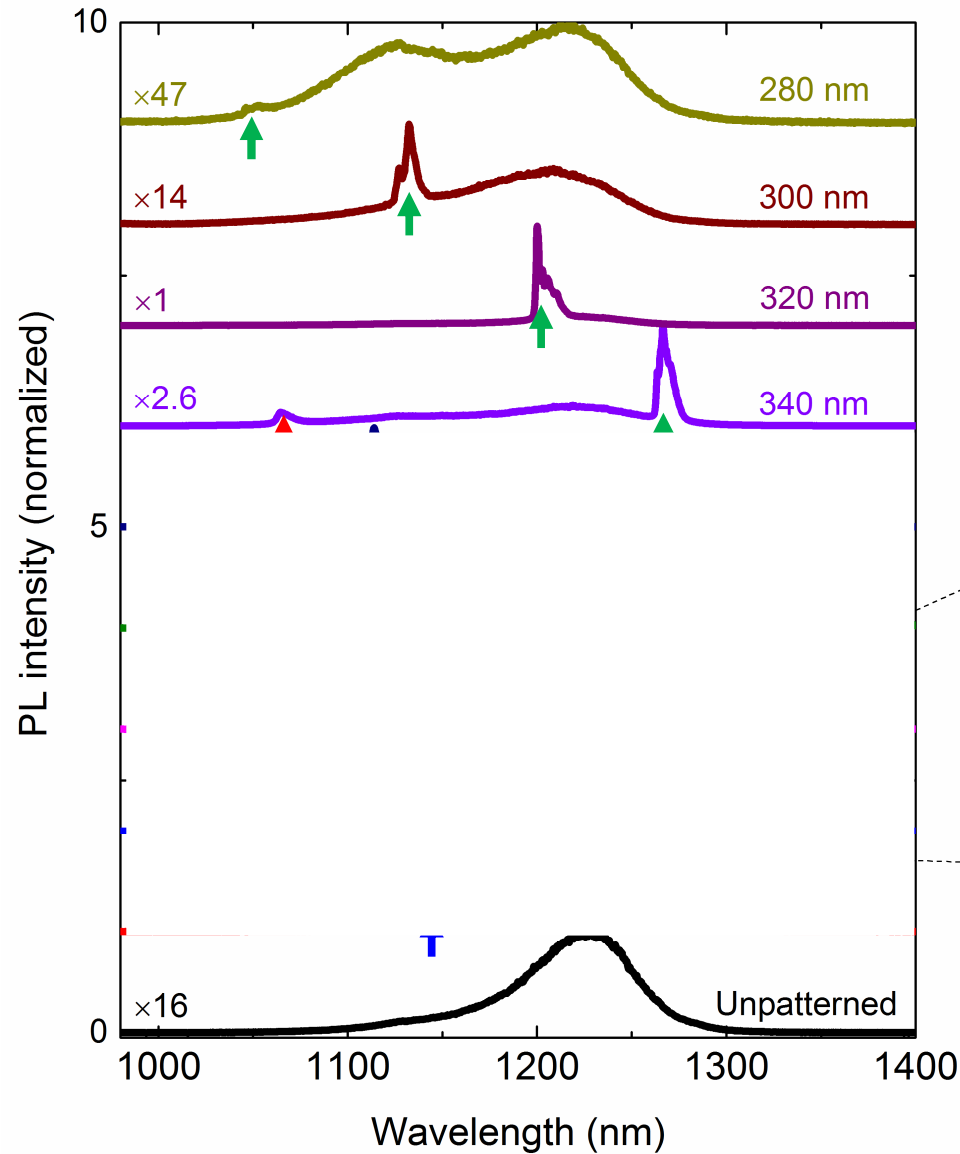
Embedding QDs emitters



Dark magnetic dipole mode

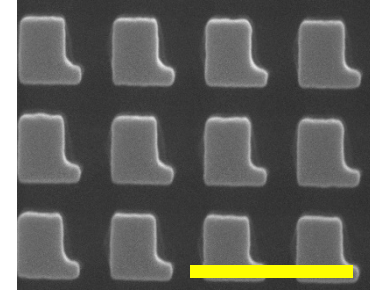


PL enhancement - dark modes (quadrupoles)

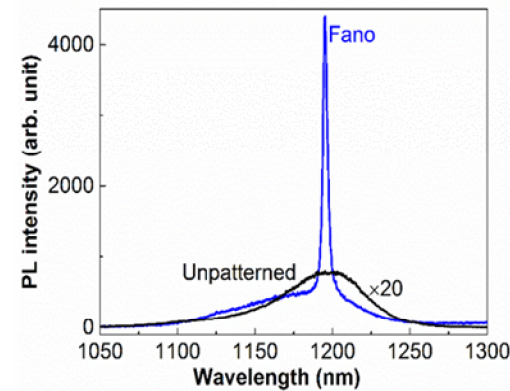


Thank you

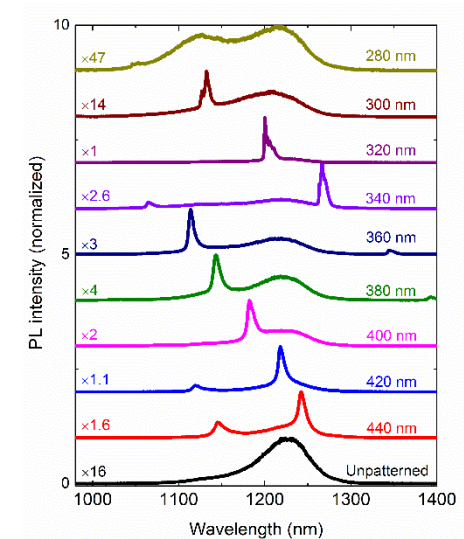
- First metasurface with emission media epitaxially grown inside



- Fano spectral enhancement



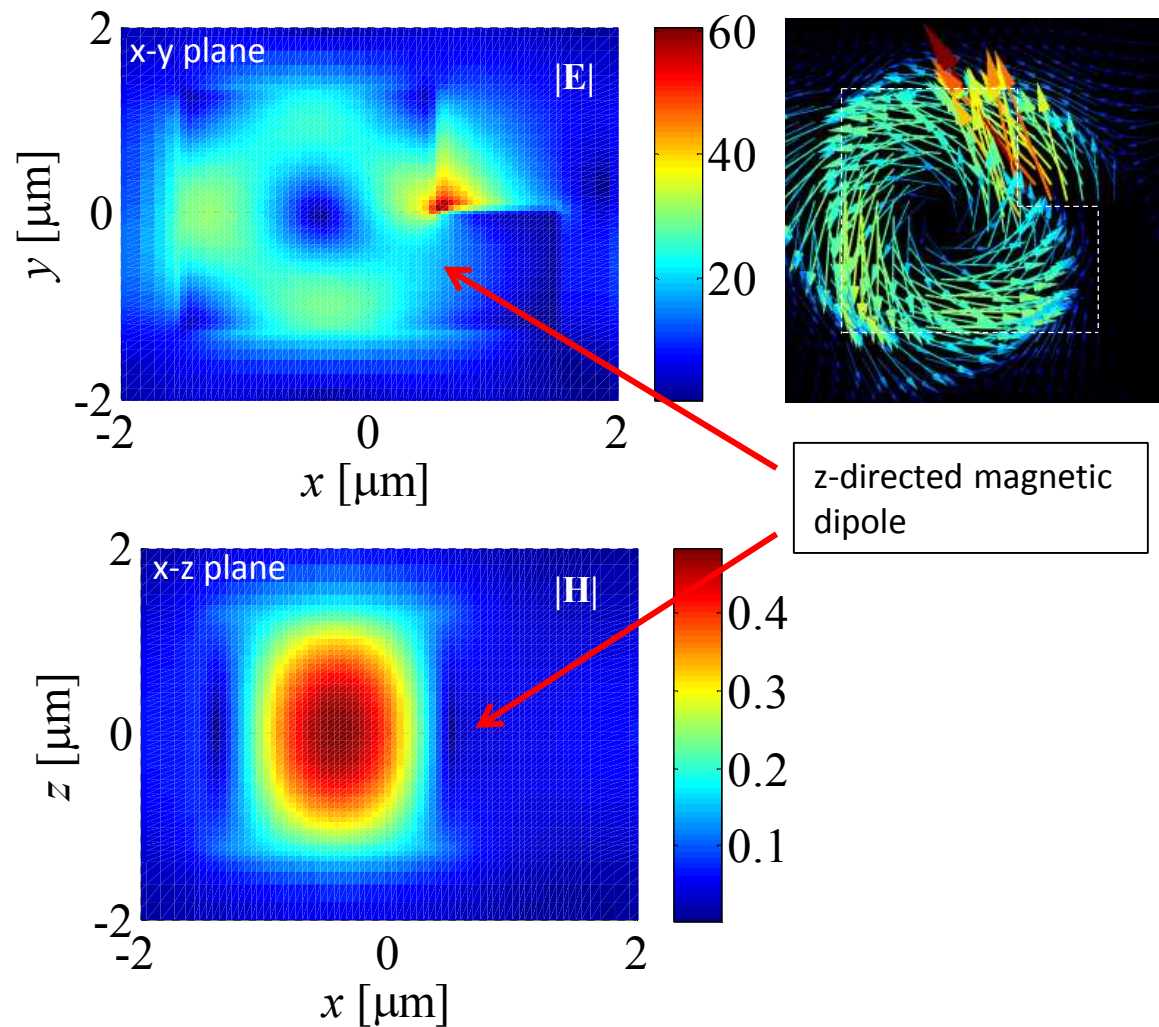
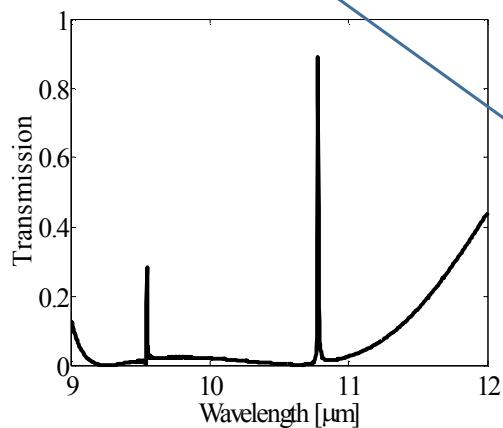
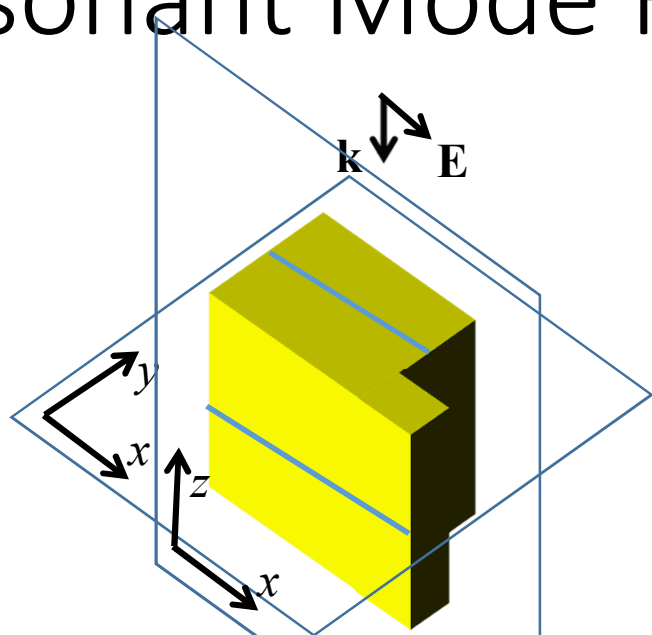
- Dark modes assisted PL enhancement



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Resonant Mode Field Profiles

FDTD simulations at the $\lambda = 10.8 \mu\text{m}$ resonance



High Q: Only a small array is needed

