Optical Metasurfaces and applications

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erc European Research Council

FLATLIGHT – Grant agreement 639109

Horizon 2020

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Collaboration

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- Qijie Wang (NTU, Singapore)
- Xie Yiyang (Beijing University of Technology, China)
- Stéphane Lanteri (INRIA, France)
- Nanfang Yu (Columbia University, USA)

DGA
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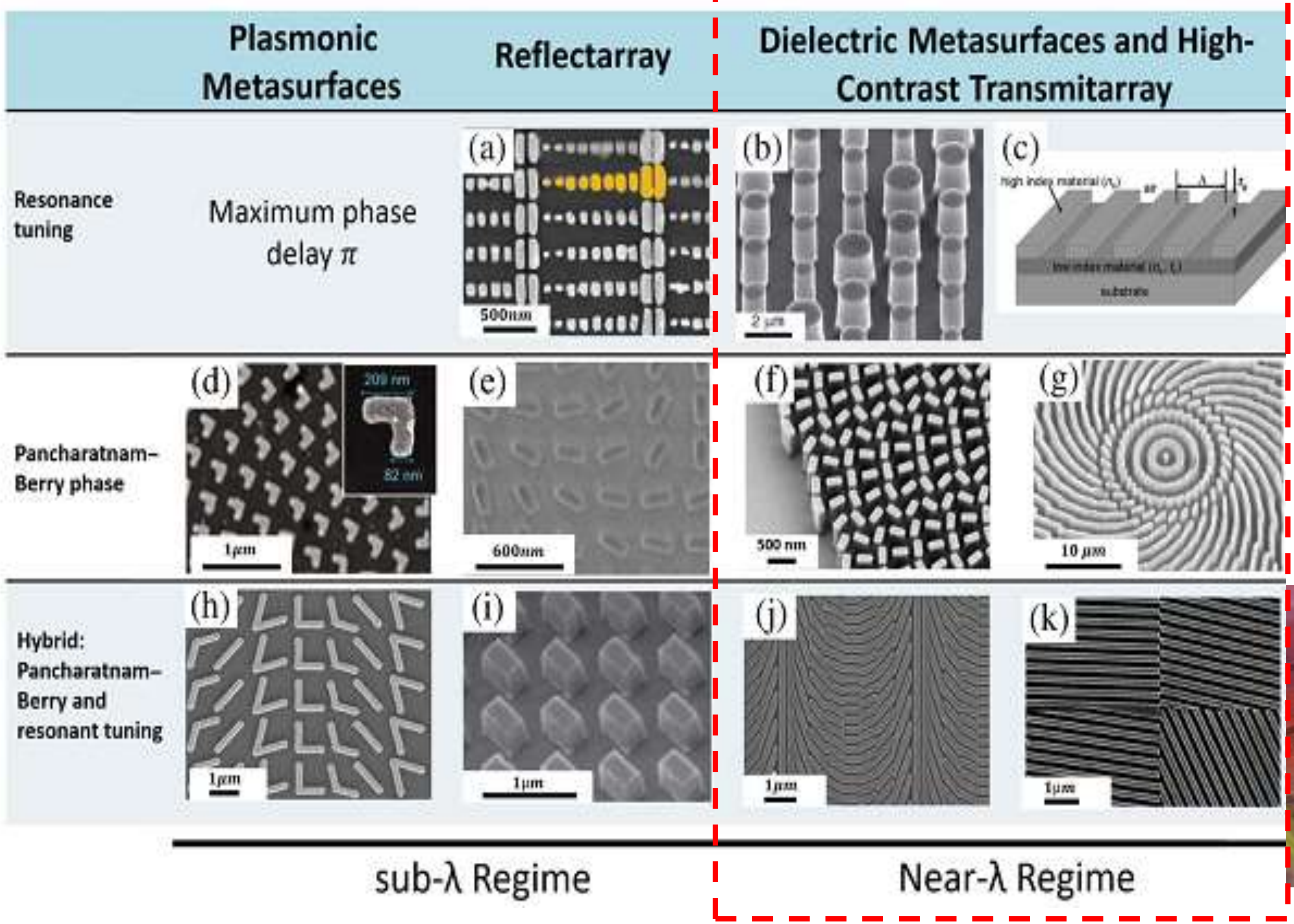
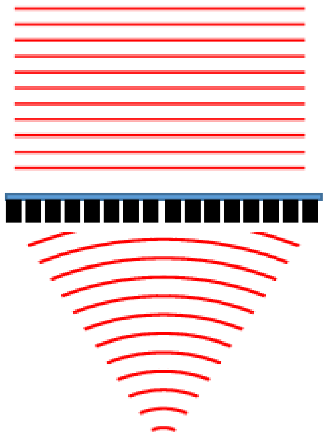
Motivation: planar optical components

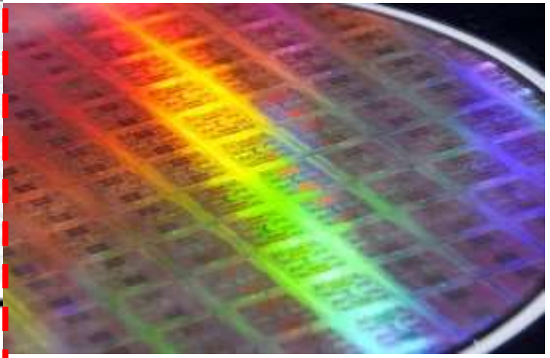
Engineering of the phase, amplitude, and polarization of light at an interface





Meta-lens (~nm)

P. Genevet, F. Capasso et. al, ***Optica***, *4*(1), 139-152.(2017)



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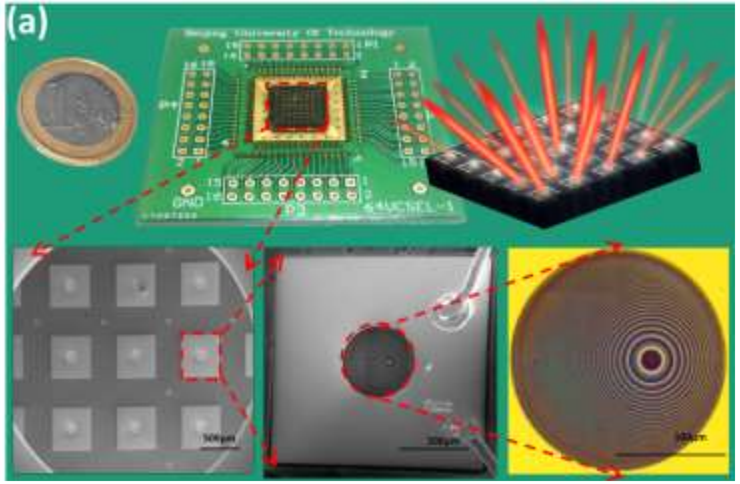
- Active meta-optics: controlling PL of plasmons-excitons in hybrid MoS2 metacavities



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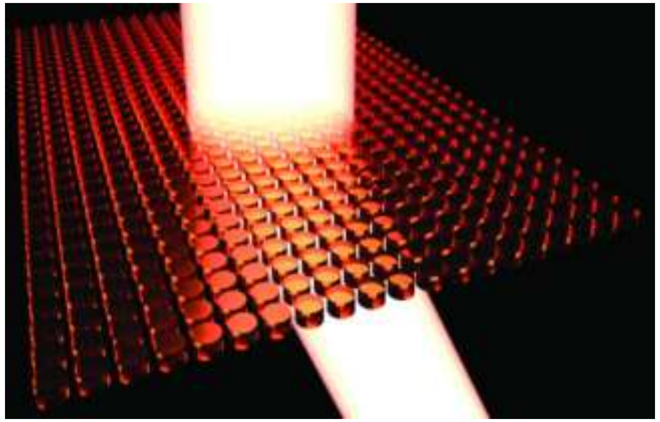
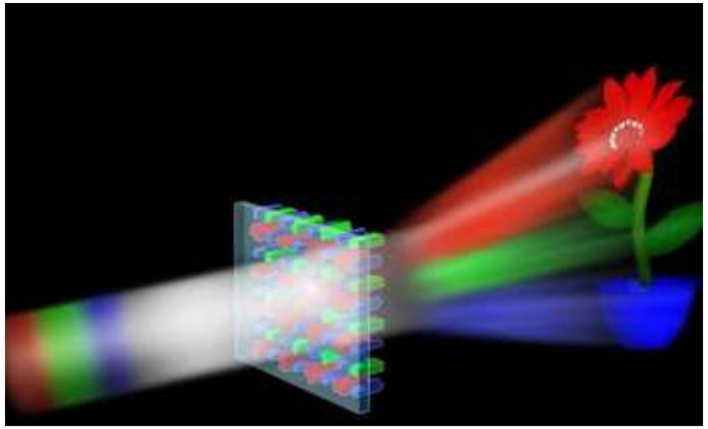
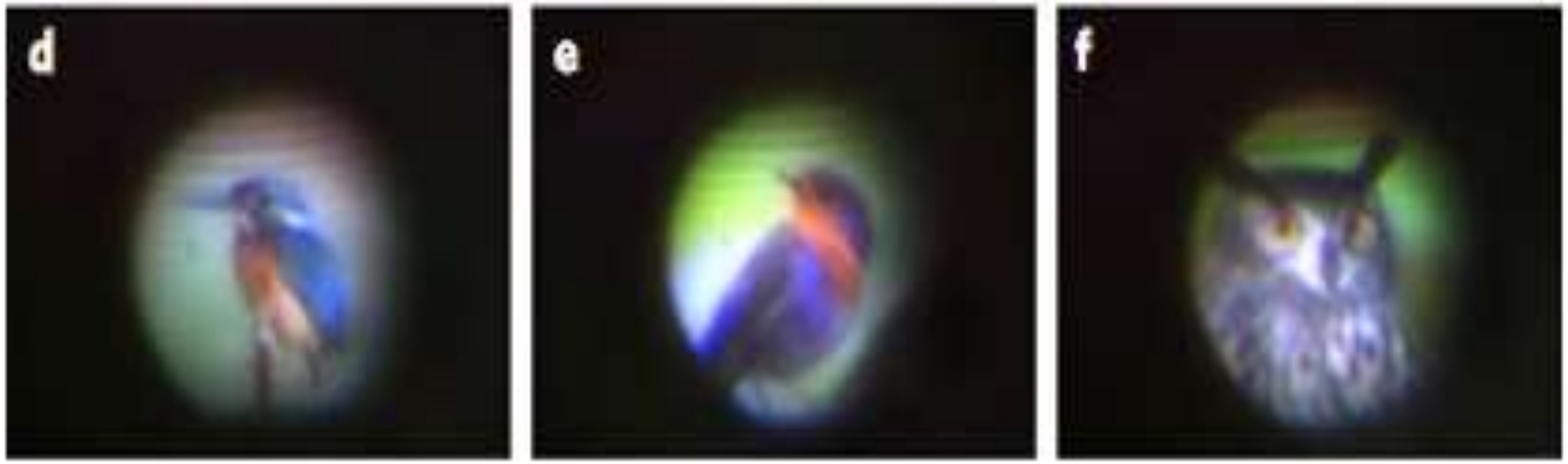
Dielectric Meta-optics for broad band wavefront shaping



A. I. Kuznetsov, etal.
Science 354, 2472 (2016).



B. Wang etal. Nano
Letter 16, 5235(2016).



S. Wang, etal. Nature Nanotechnology, **113**, 227 (2018).

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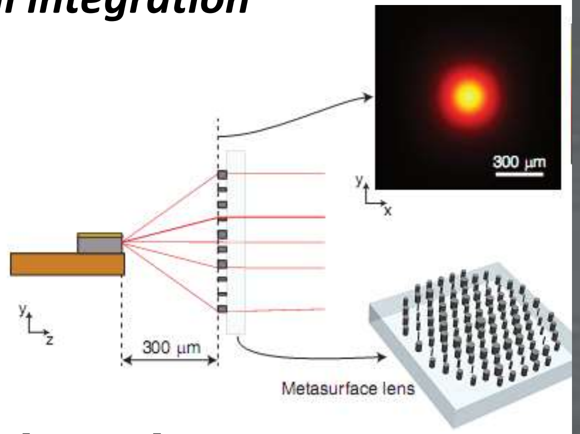
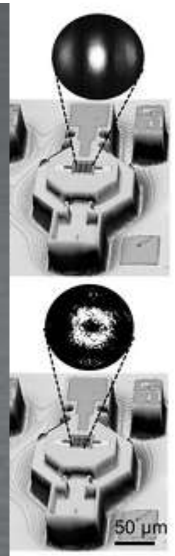
HCG integration for laser wavefront shaping

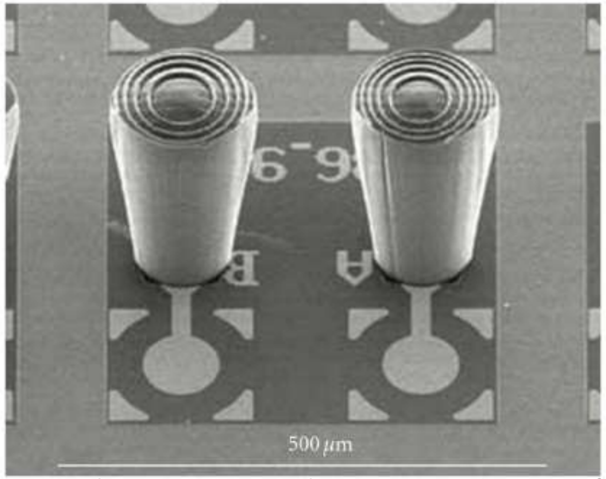
External integration



A. Arbabi, et al. *Optics Express* 23, 3

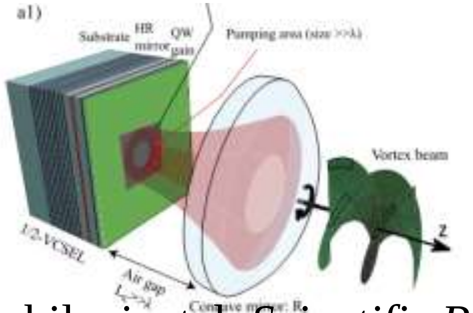


3(2018).

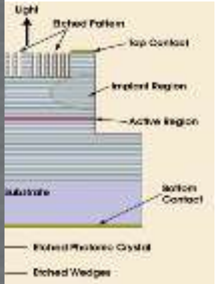


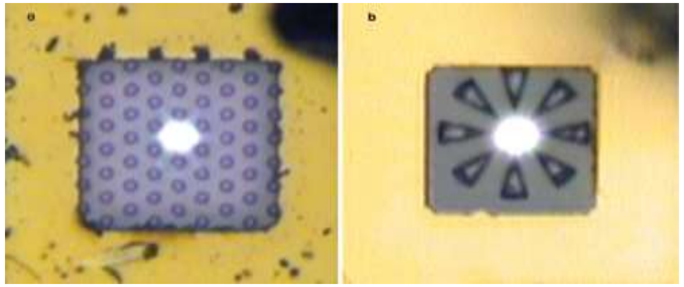
C. Gimkiewicz, et al., Proceedings of SPIE, 5443, 13–26, 2004

monolithic integration



M. S. Seghilani, etal. *Scientific Rep*



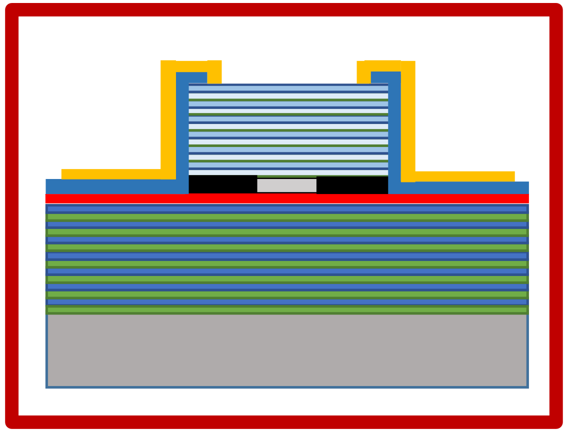


A. J. Danner, et al. APL **88**, 091114 2006

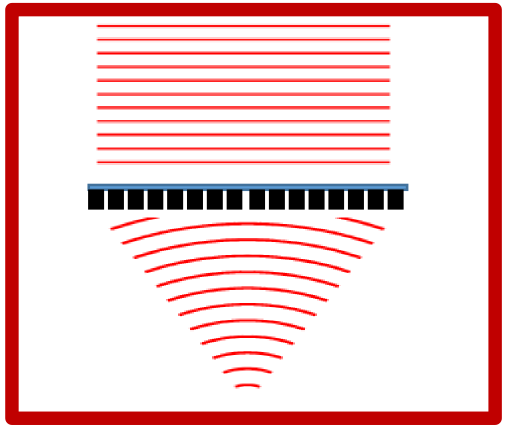
S. Astilean, P. Lalanne, P. Chavel, E. Cambril, and H. Launois, **Opt. Lett.** 23(7), 552–554 (1998).
C.J. Chang-Hasnain and W. Yang, **Advances in Optics and Photonics**, Vol. 4, Issue 3, pp. 379-440 (2012)
C. Chase, Y. Rao, W. Hofmann, and C. J. Chang-Hasnain, **Opt. Express** 18(15), 15461–15466 (2010).

Vertical Cavity Metasurface Emitting Laser (VCMEL)

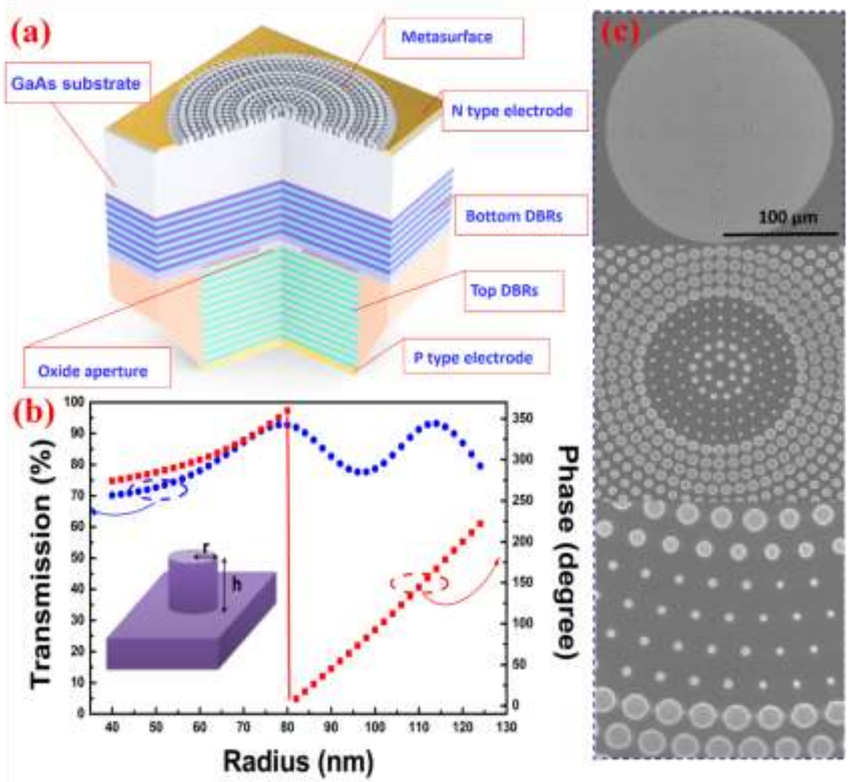
Advantages: low cost, Low power consumption, high beam quality, easy integration, high modulation speed...



VCSEL



Metasurfaces

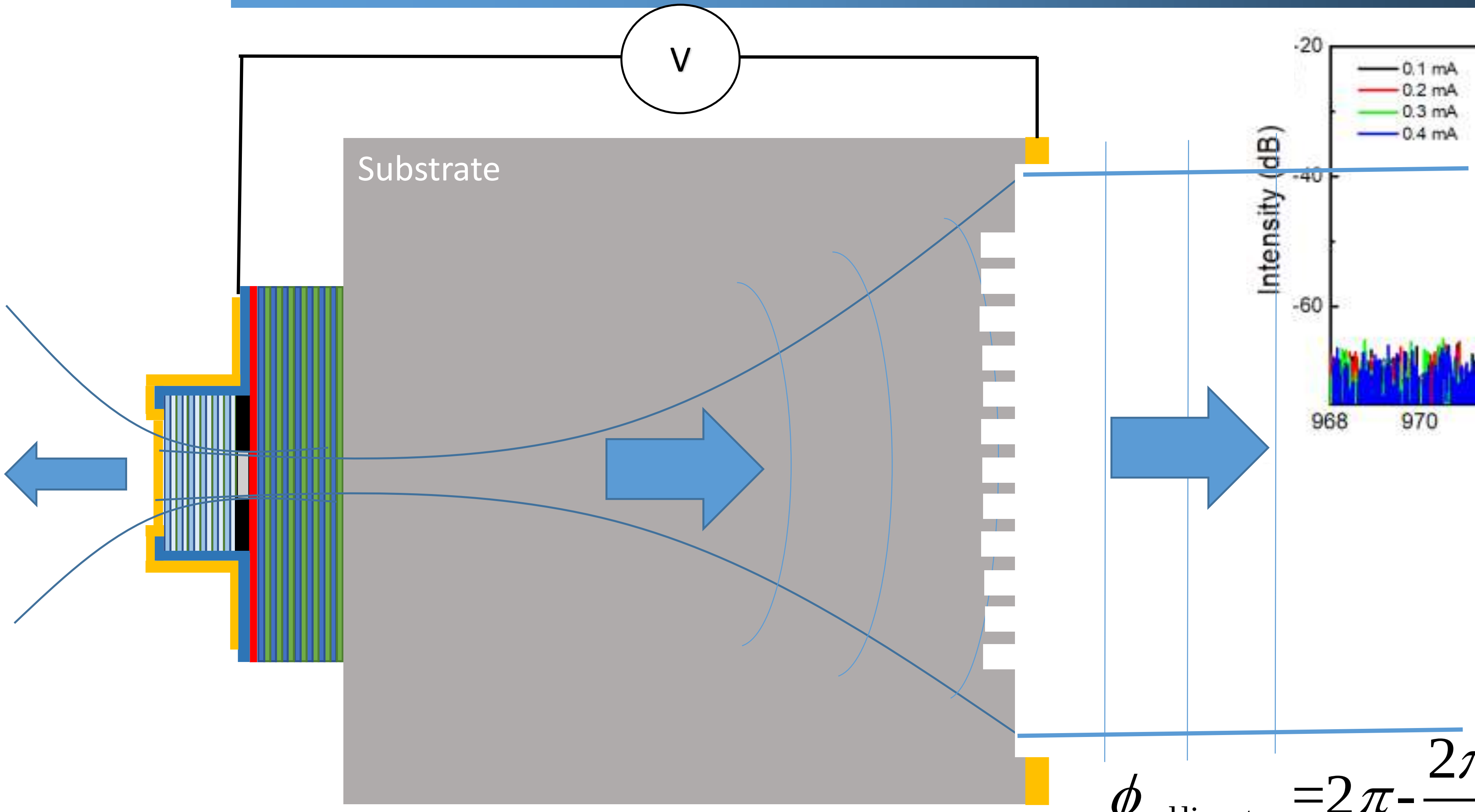


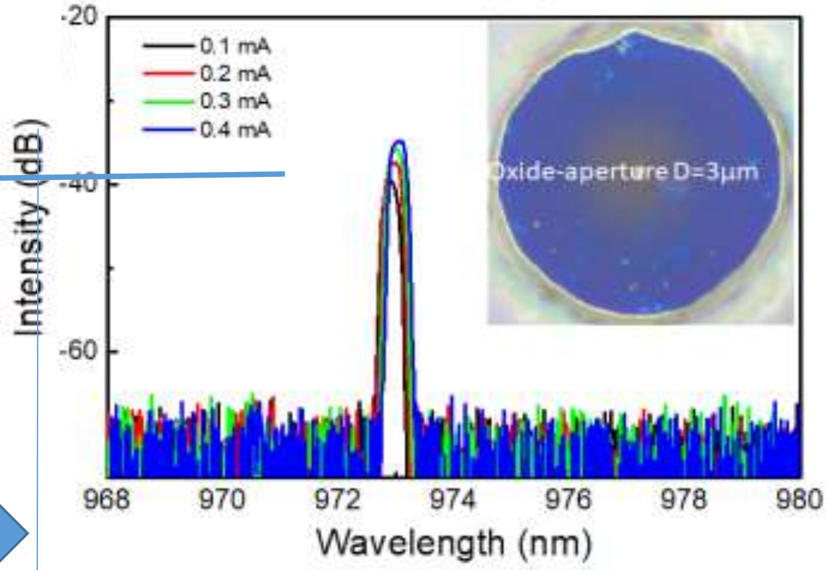
Self-collimated or nondiffracting Bessel laser

Electrically-pumped Vertical Cavity Metasurface-Emitting Lasers (VCMELs) for programmable directional lasing emissions

Y-Y. Xie, P-N. Ni, Q-H. Wang, Q. Kan, G. Briere, P-P. Chen, Z-Z. Zhao, A. Delga, H-D. Chen, C. Xu, and P. Genevet, (submitted 2019)

Vertical Cavity Metasurface Emitting Laser (VCMEL)





$$\phi_{collimator} = 2\pi - \frac{2\pi}{\lambda}\left(\sqrt{x^2 + y^2 + f^2} - f\right)$$

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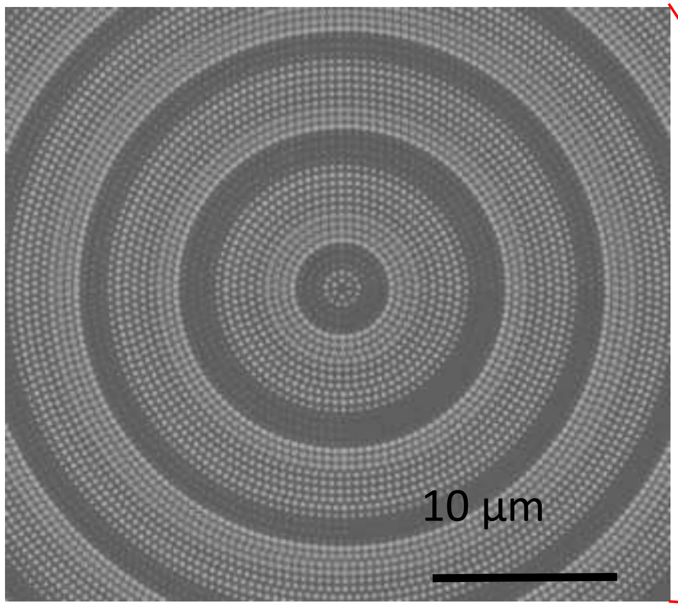
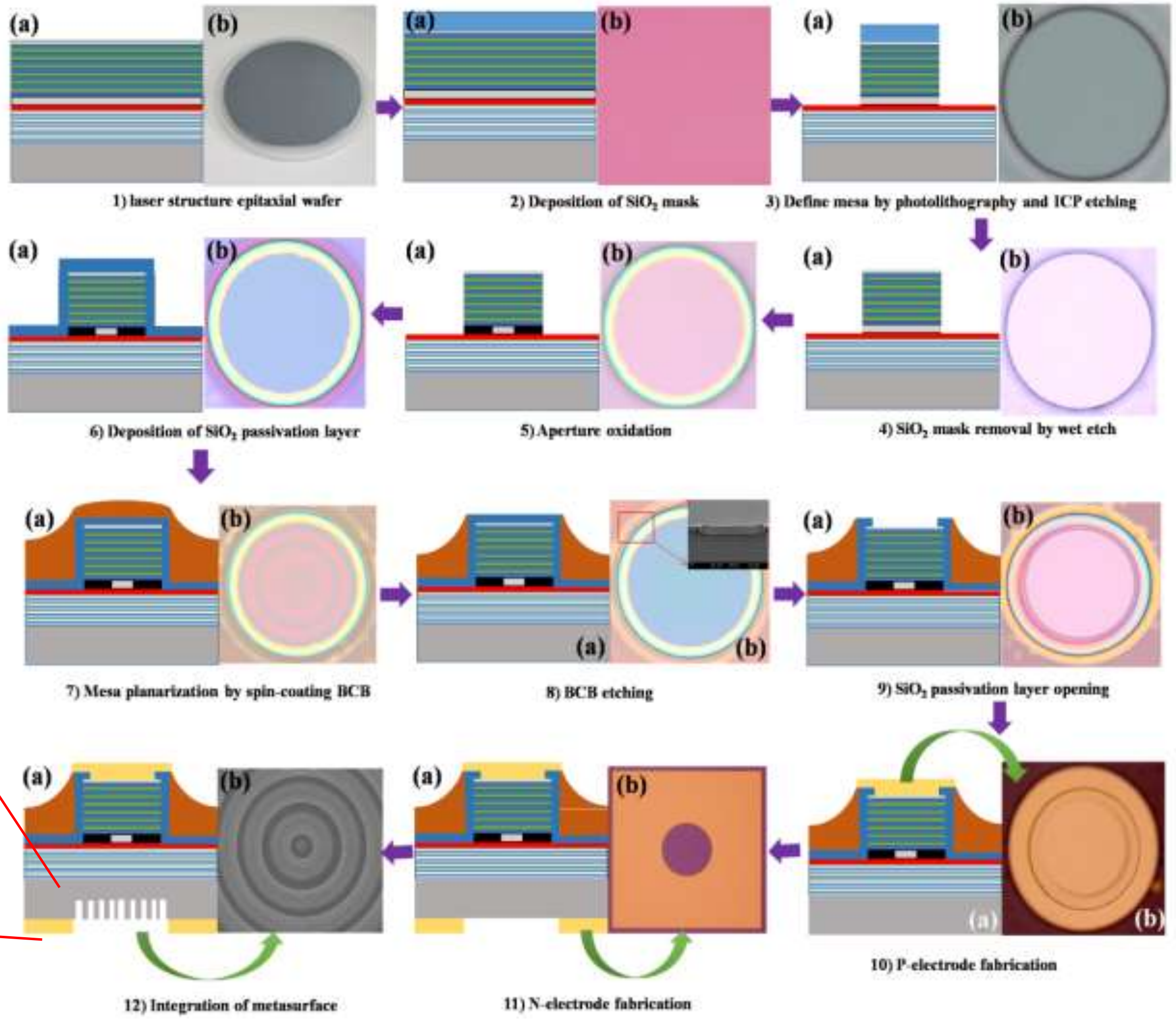
Vertical Cavity Metasurface Emitting Laser (VCMEL)

Fabrication summary of VCMEL





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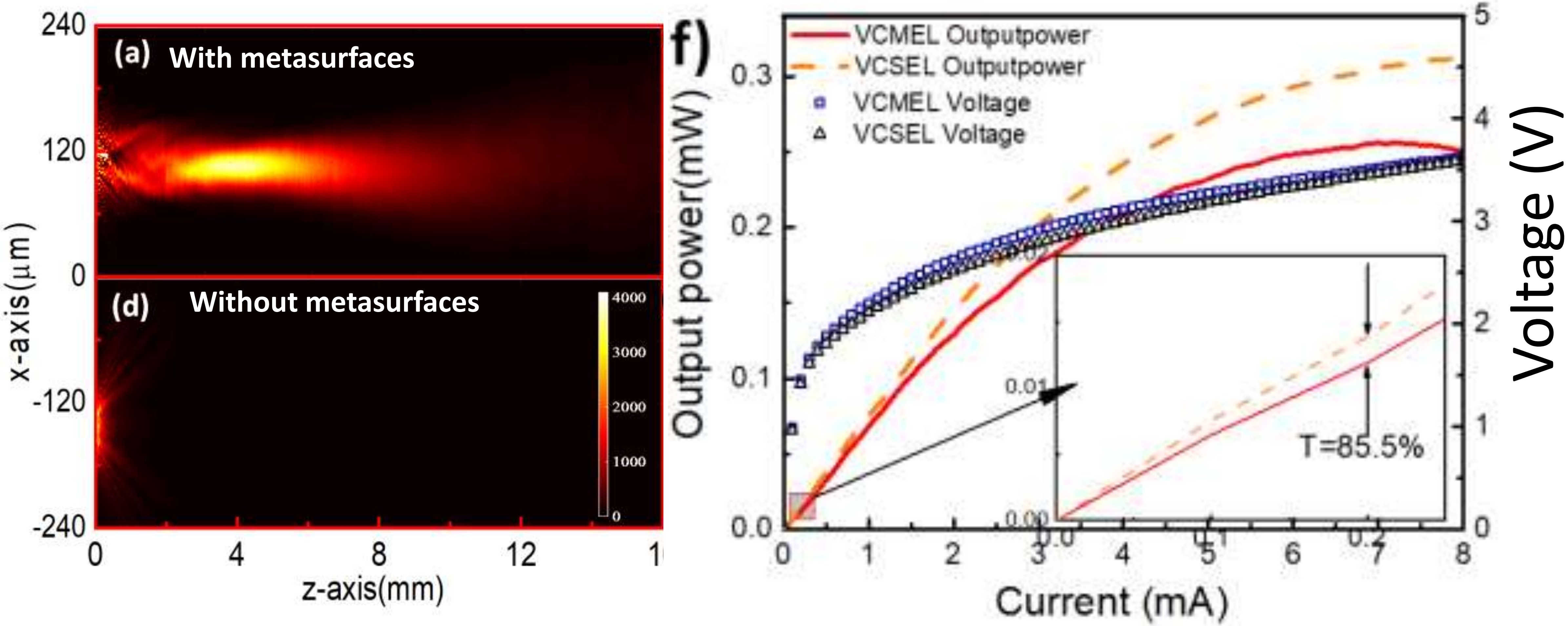

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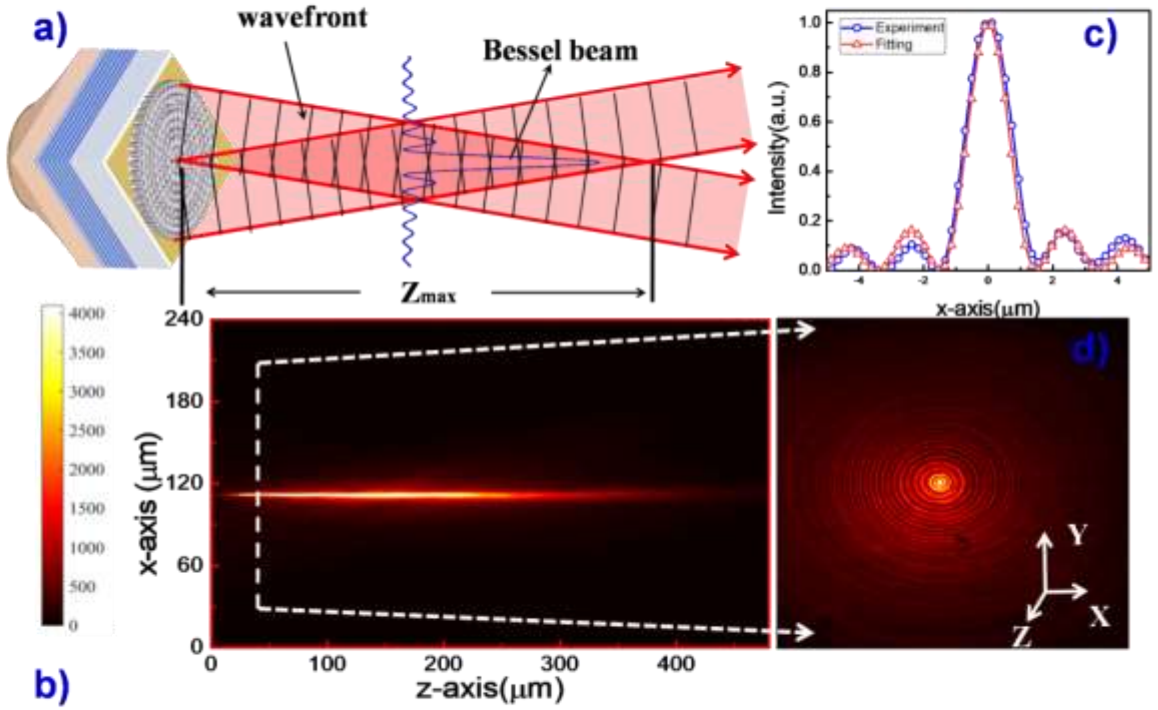
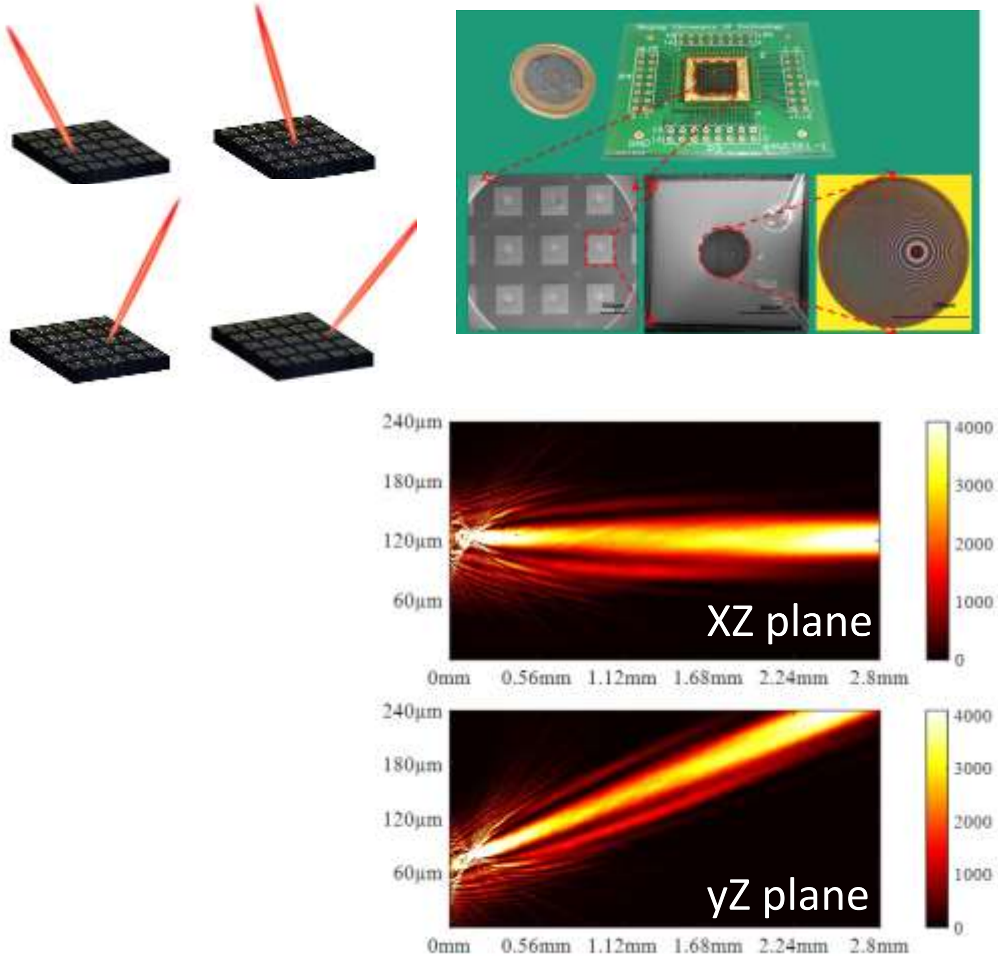
Applications Vertical Cavity Metasurface Emitting Lasers

Shaping Laser wavefront



Realization of 2D directional laser array



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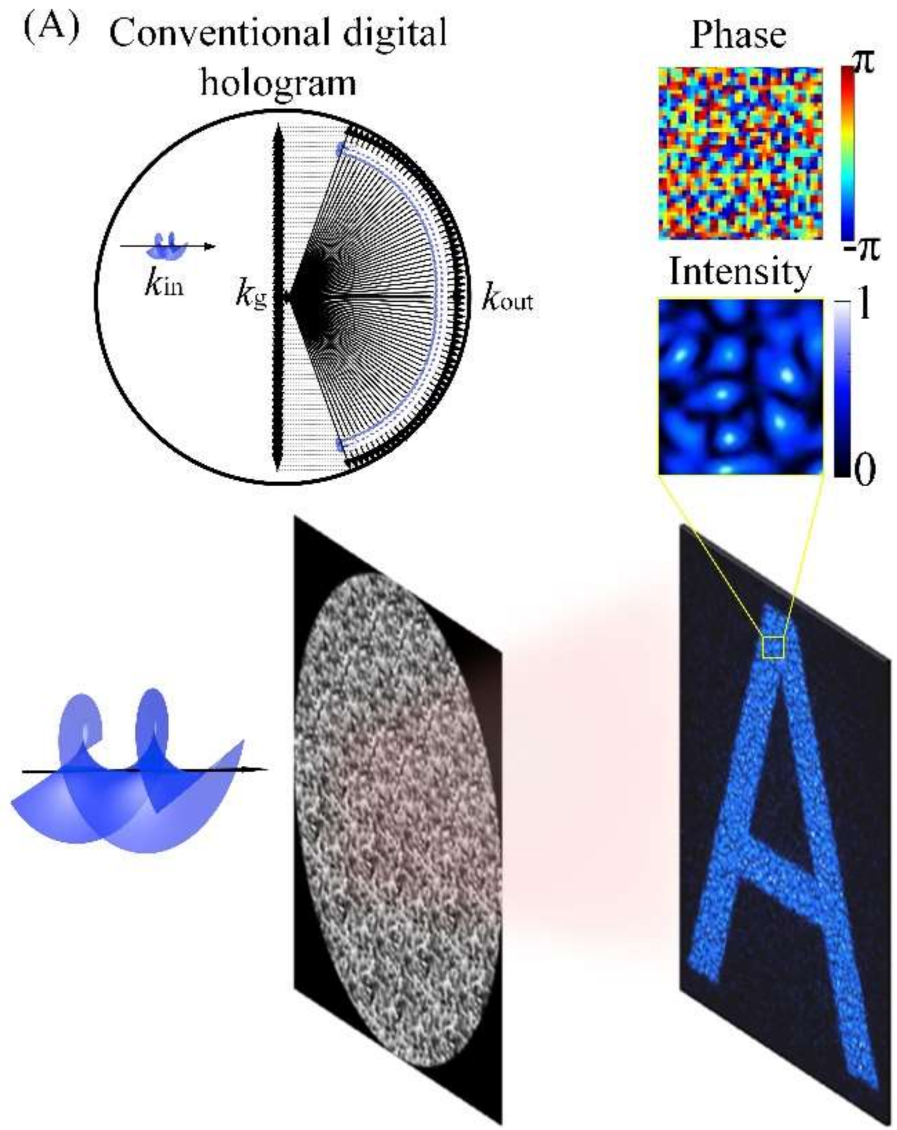
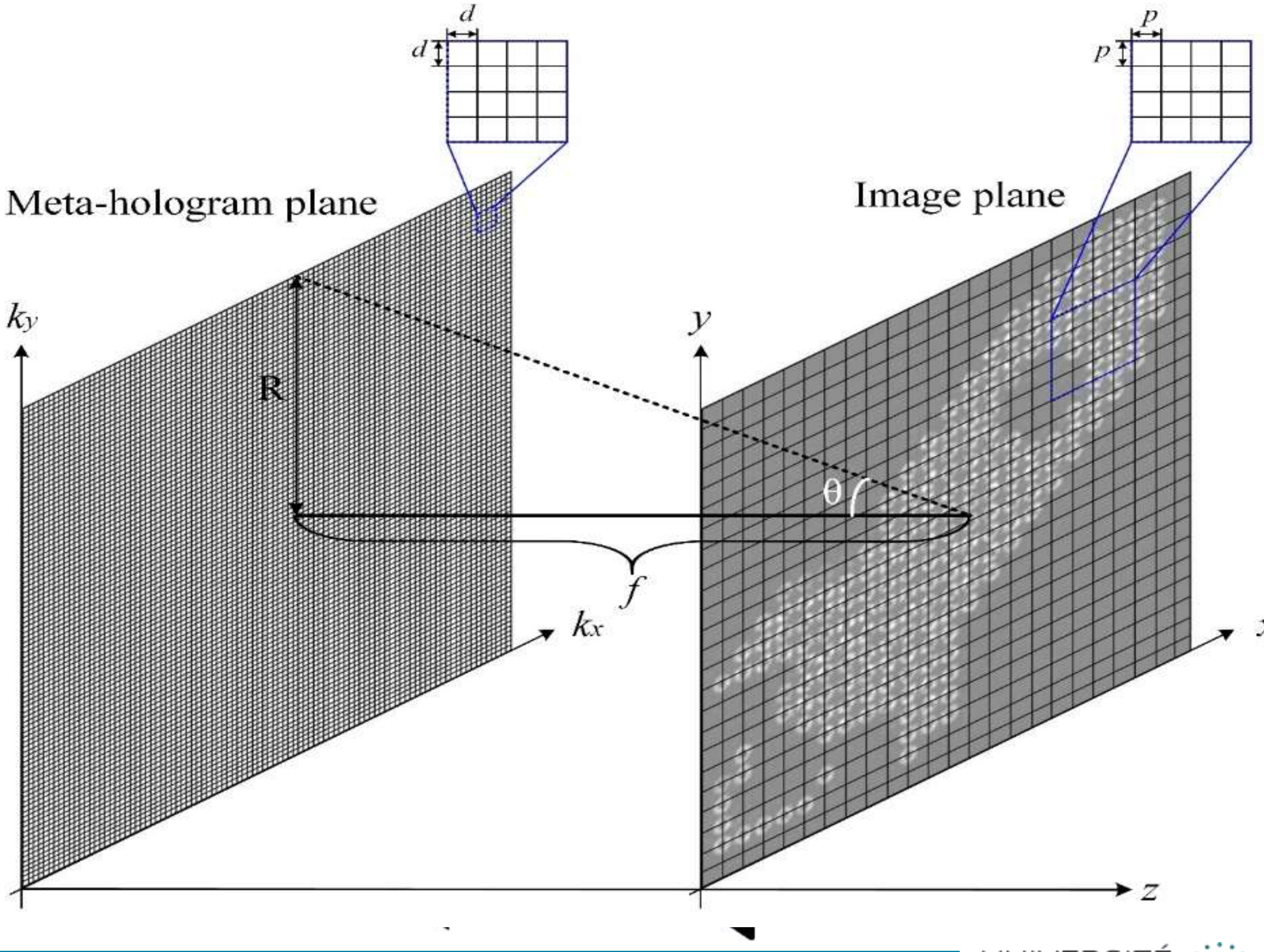
Outline of the presentation

- Vertical metasurfaces emitting lasers for programmable directional lasing emissions
- Orbital Angular Momentum Holography
- Active meta-optics: controlling PL of plasmons-excitons in hybrid MoS2 metacavities

Orbital Angular Momentum Holography

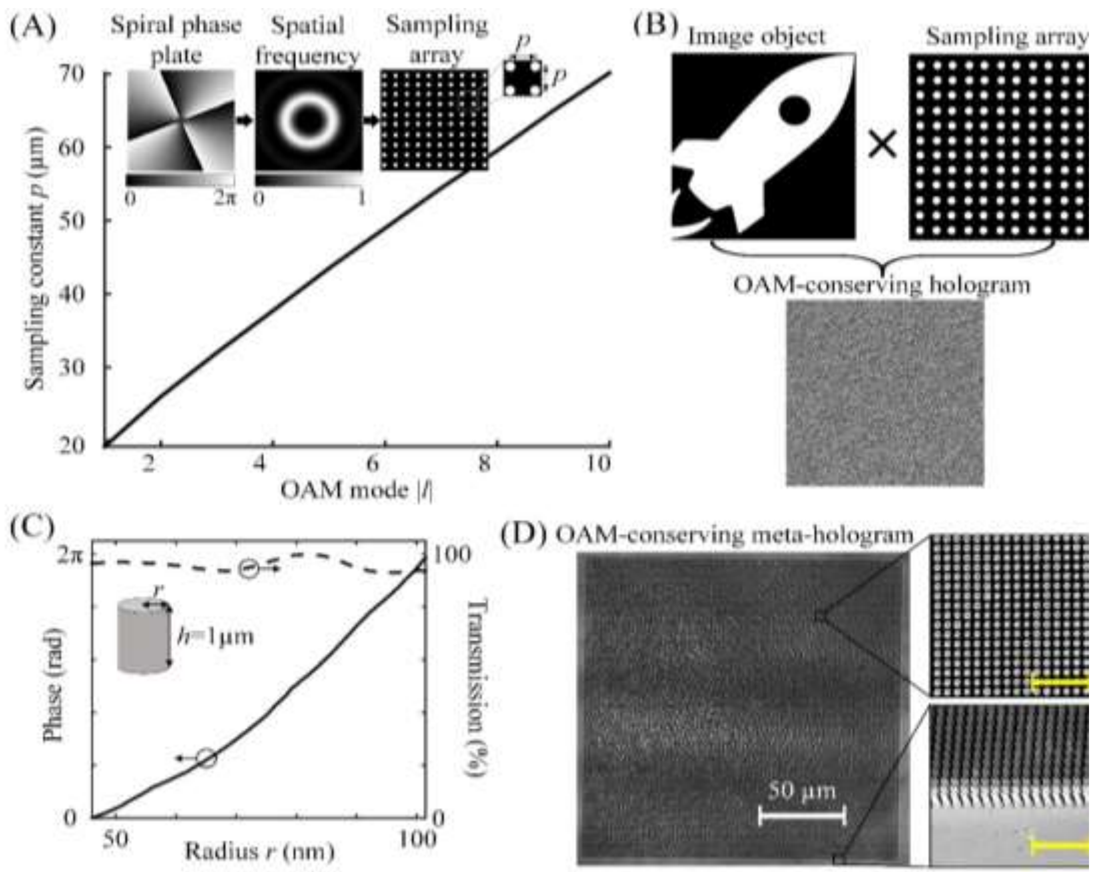


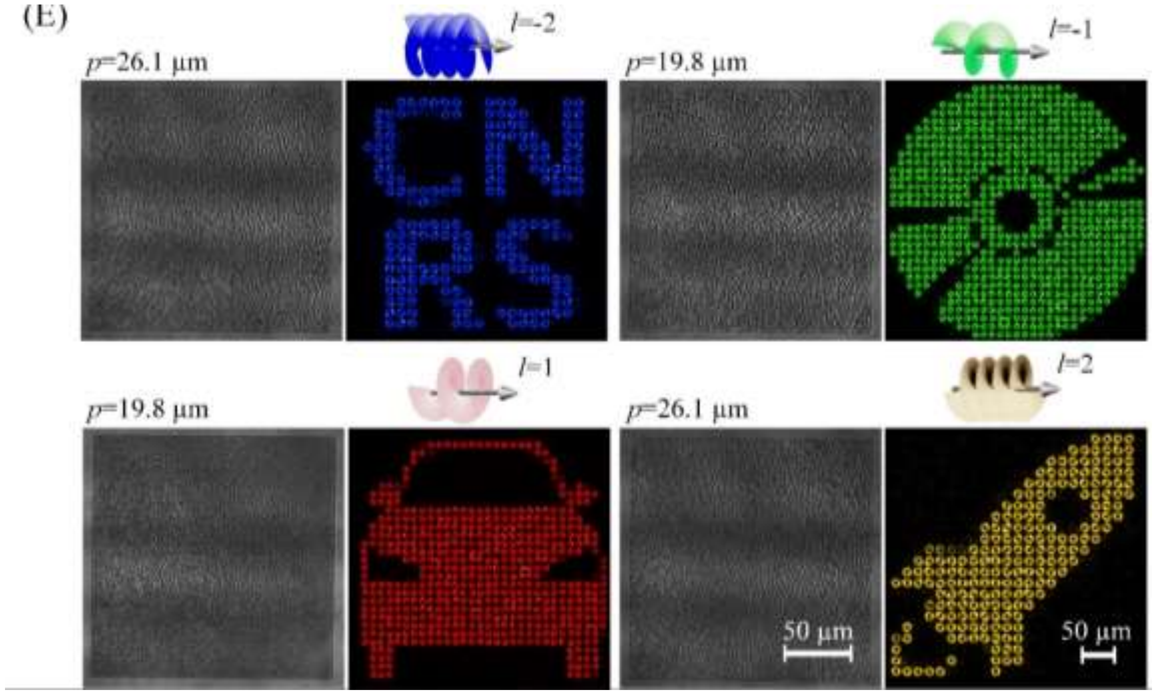


Orbital Angular Momentum Holography

Experimental realization with GaN metasurfaces

OAM-conserving meta-hologram



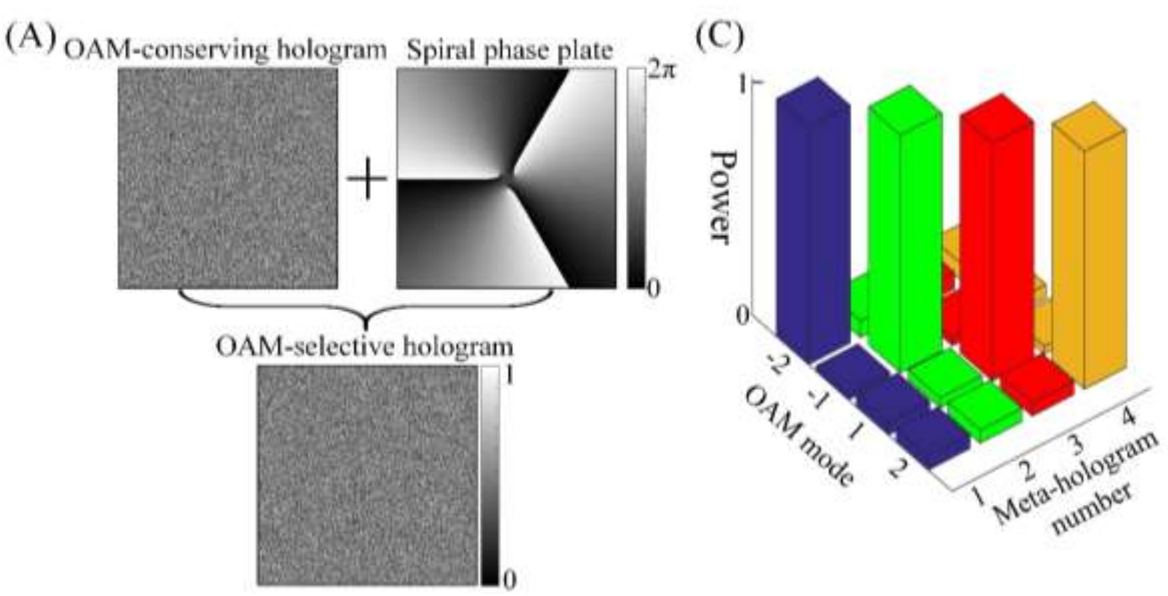


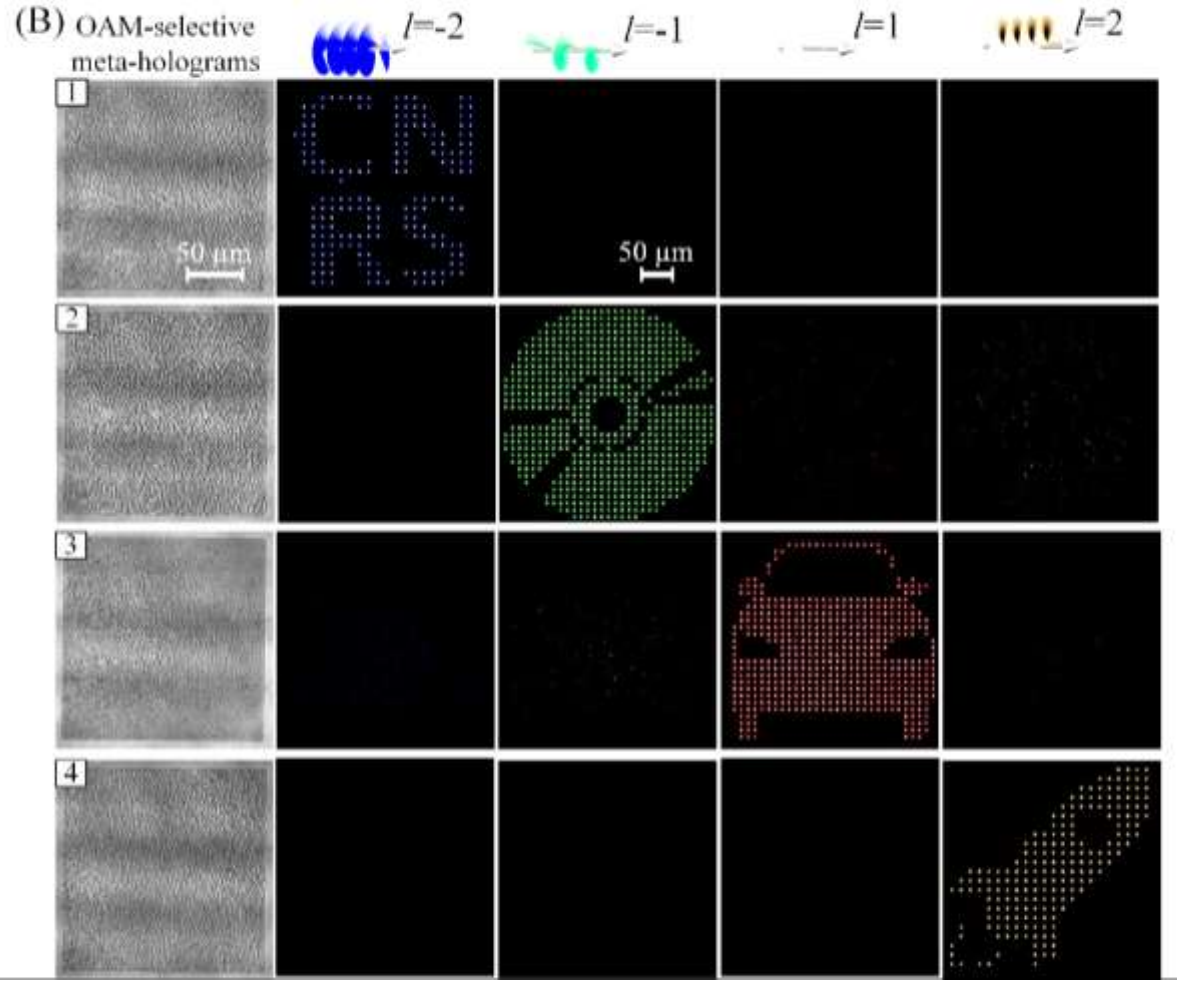
H.Ren, G. Briere, X. Fang, P. Ni, R. Sawant, S. Héron, S. Chenot, S. Vézian, B. Damilano, V. Brändli, S. A. Maier, and P. Genevet (Nature Communications, in press 2019)

Orbital Angular Momentum Holography

Experimental realization with GaN metasurfaces

OAM-selective meta-hologram





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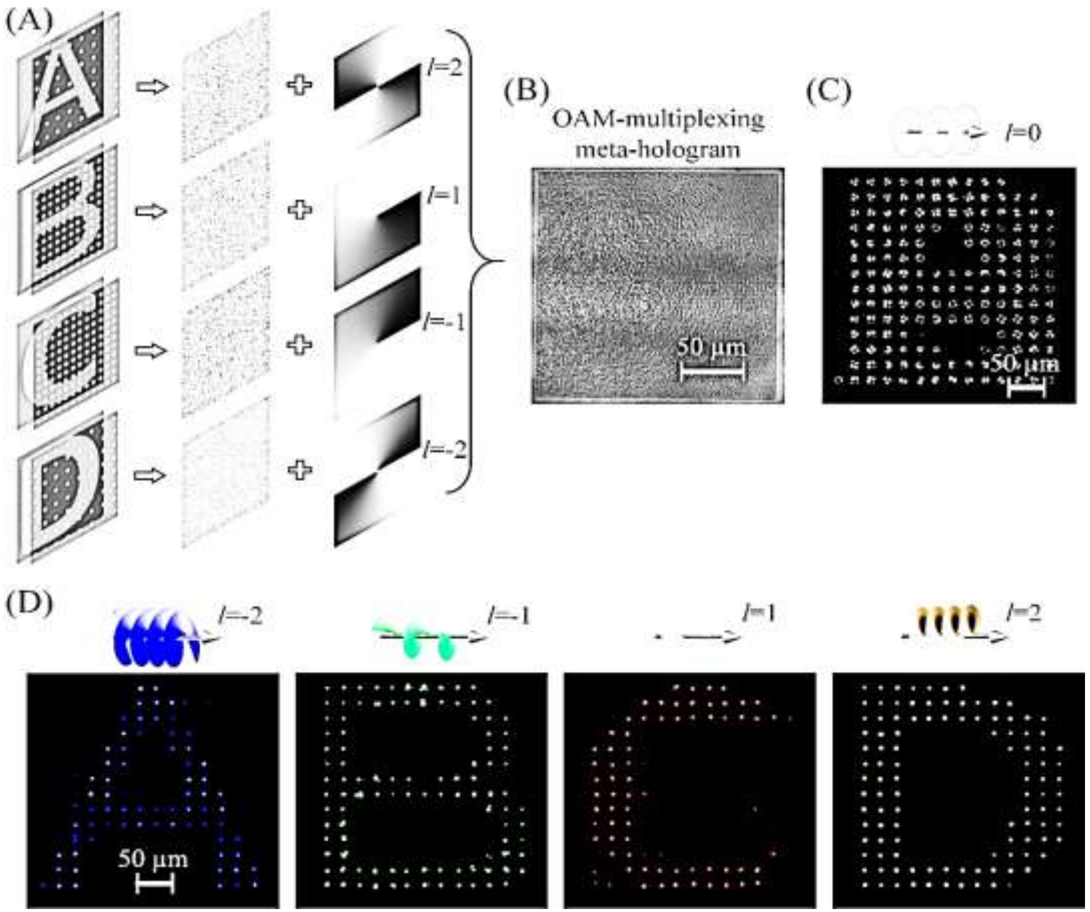
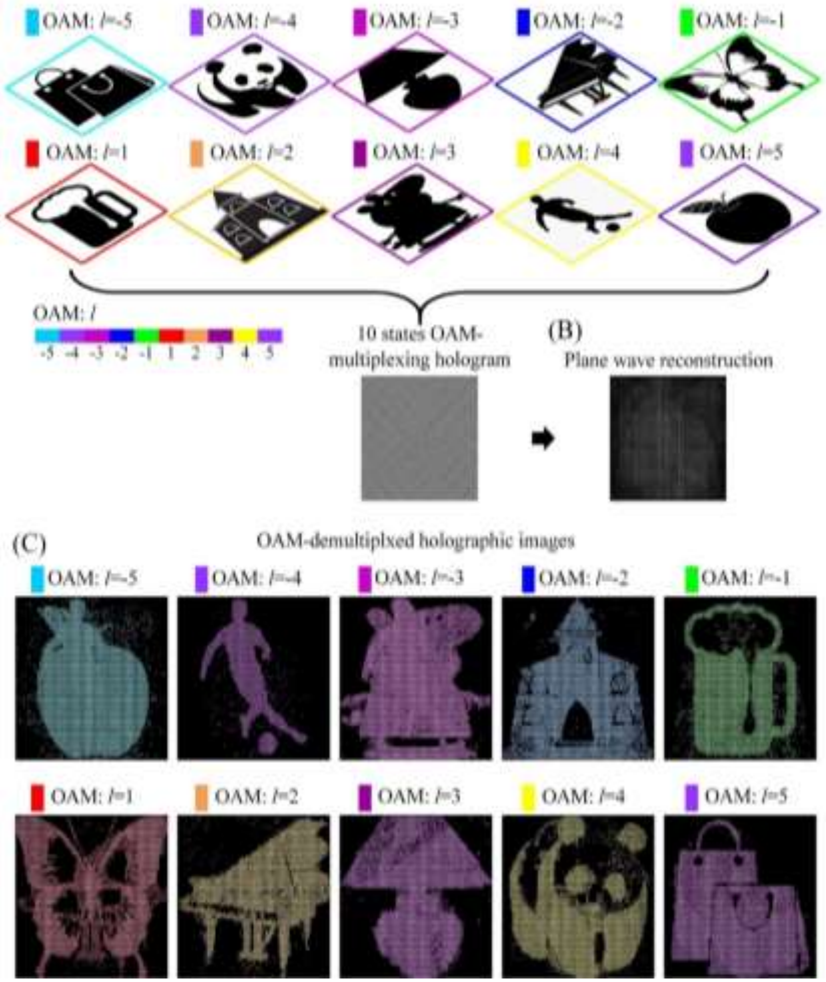
Orbital Angular Momentum Holography

Experimental realization with GaN metasurfaces



OAM-multiplexing meta-hologram



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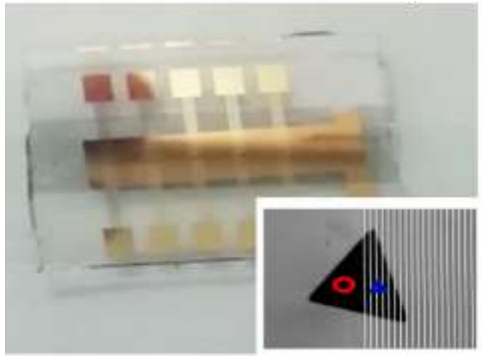
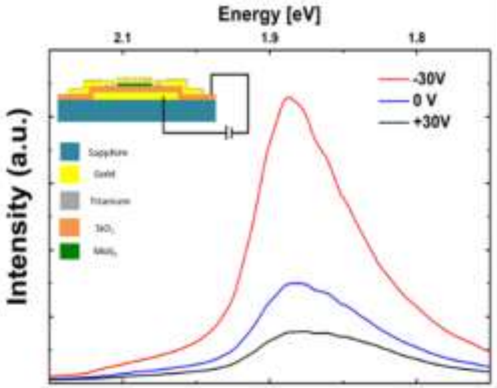
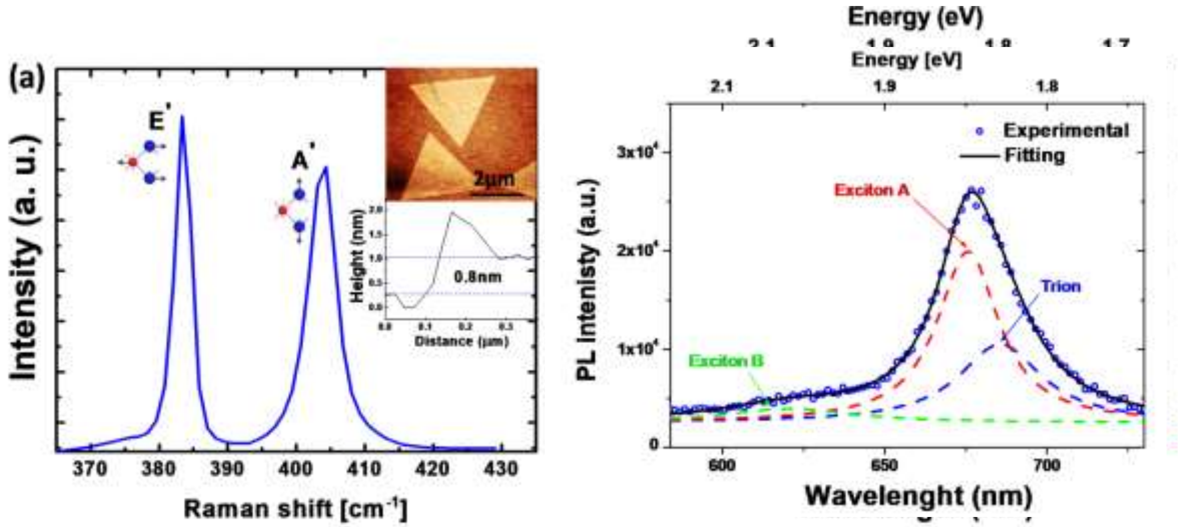
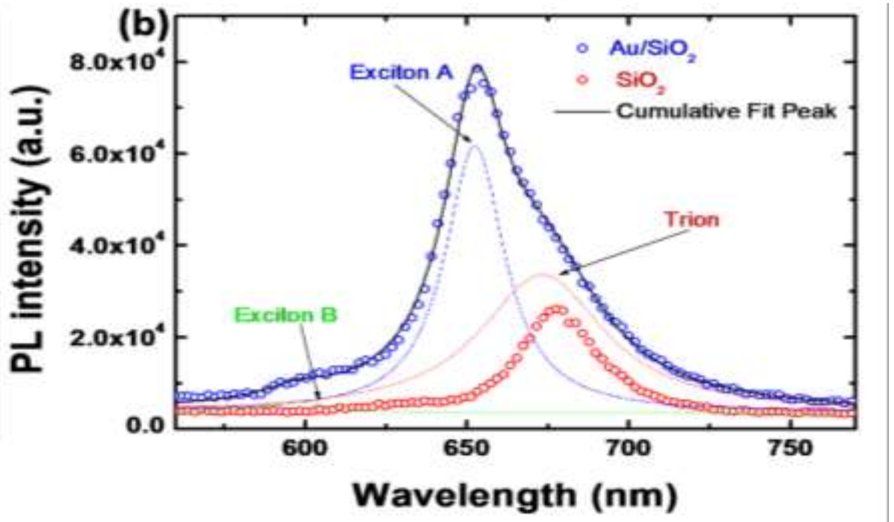




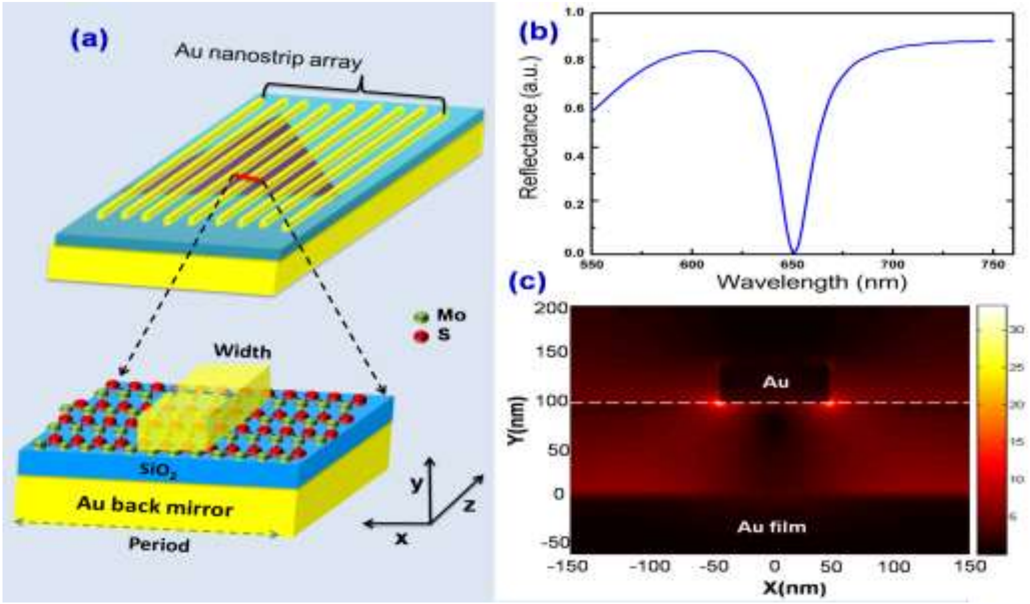
Gate-tunable emission of exciton-plasmon polaritons

MoS2 (atomic thin layer, trigonal prismatic coordination)



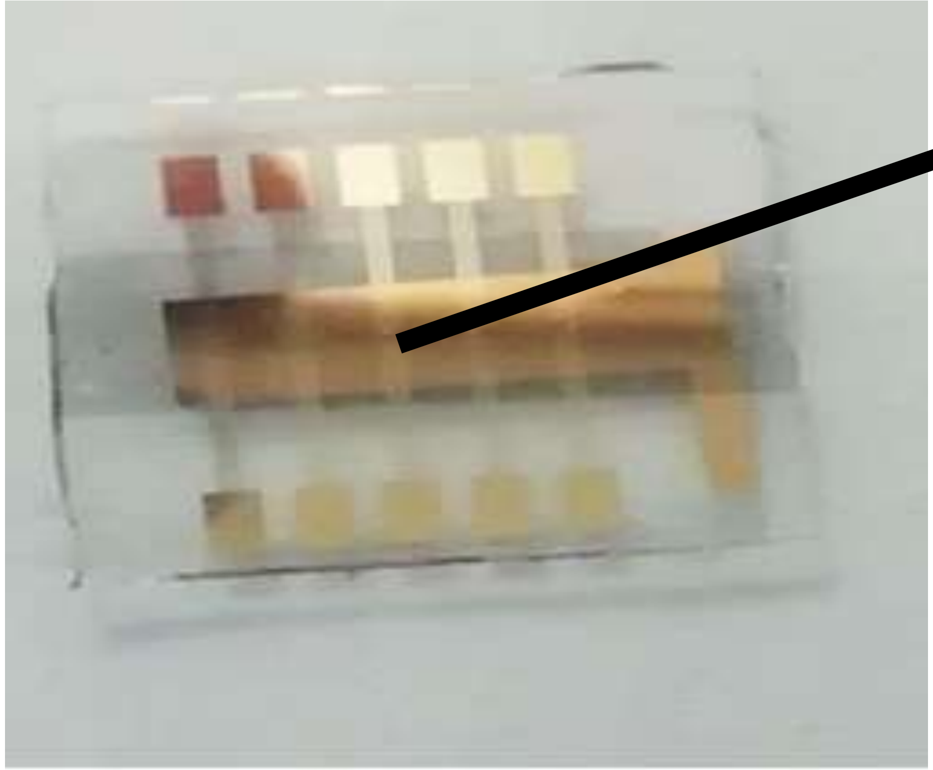


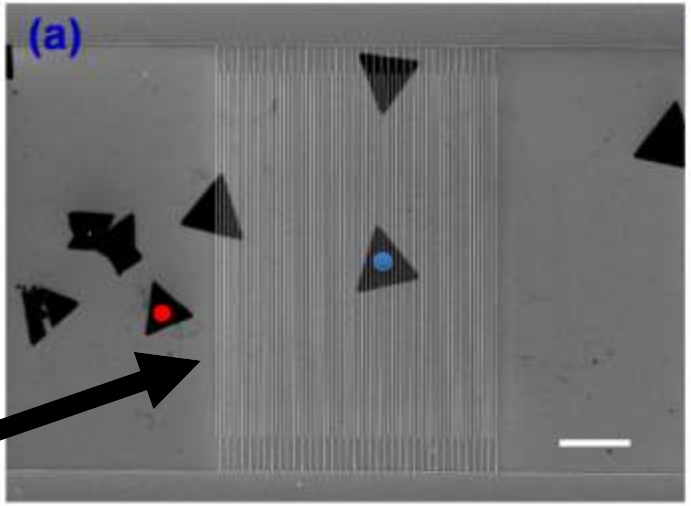
Hybridization of MoS2-gap-mode metasurfaces

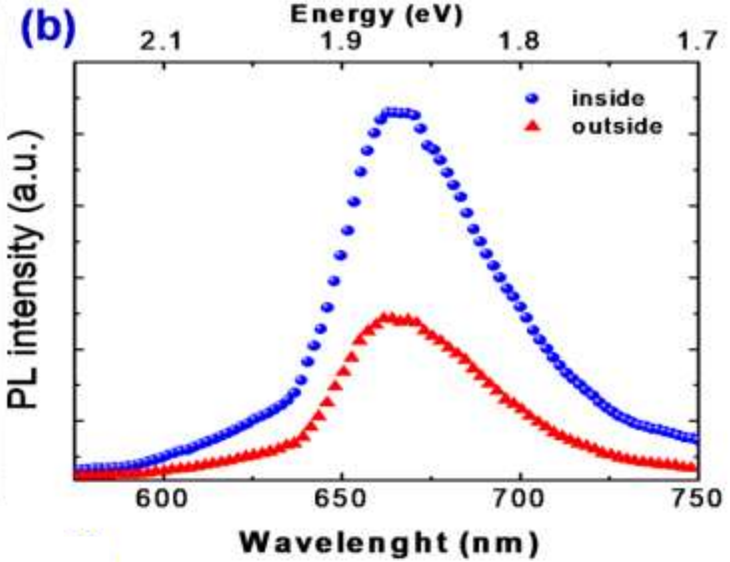


Gate-tunable emission of exciton-plasmon polaritons

Cavity enhancement and Polarization control



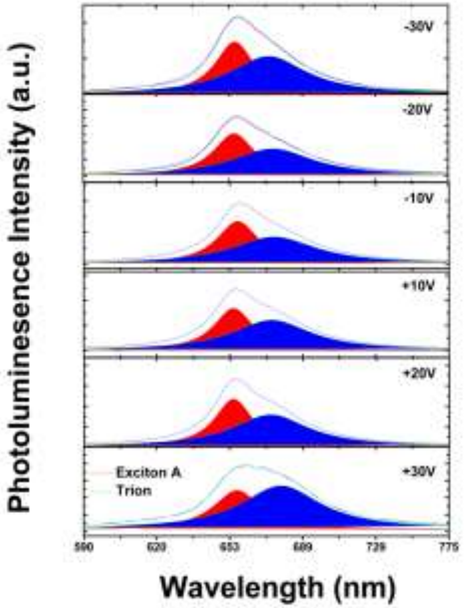


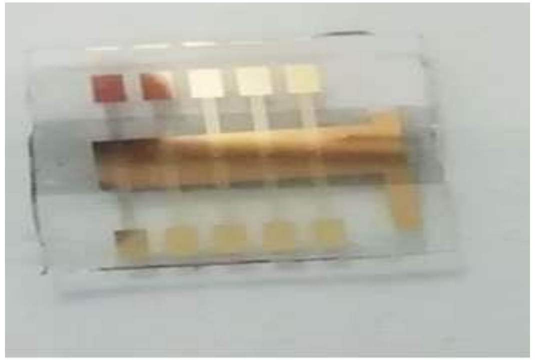


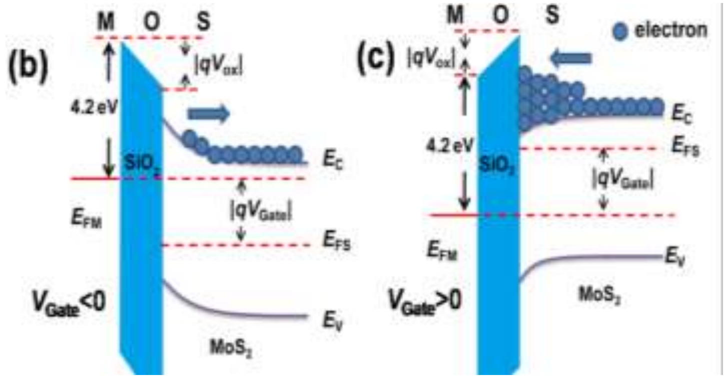
P. Ni, A. De Luna Bugallo, E. Strupietchonski, and P. Genevet
“Gate-tunable emission of exciton-plasmon polaritons in hybrid MoS2-gap-mode metasurfaces"(accepted ACS Photonics 2019)

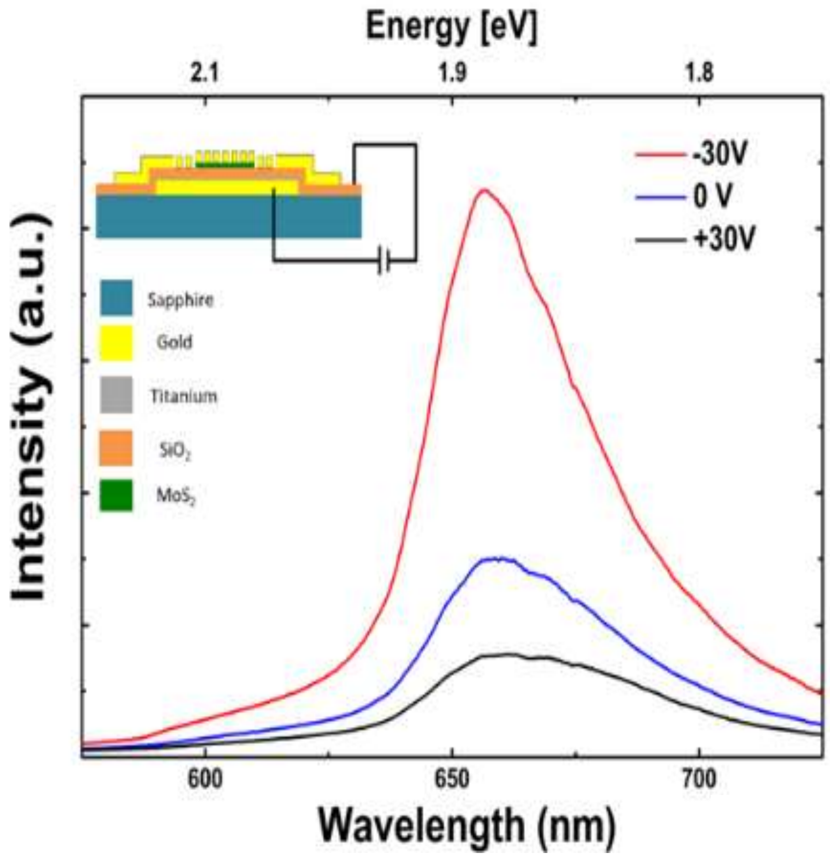
Gate-tunable emission of exciton-plasmon polaritons

Electrical doping induced modulation









Tuning: Physical mechanism

Applying a gate voltage across the metallic cavity results in electrical doping of the MoS2, which favor optically resonant and highly emissive A-excitons instead of non-radiative charged trion states

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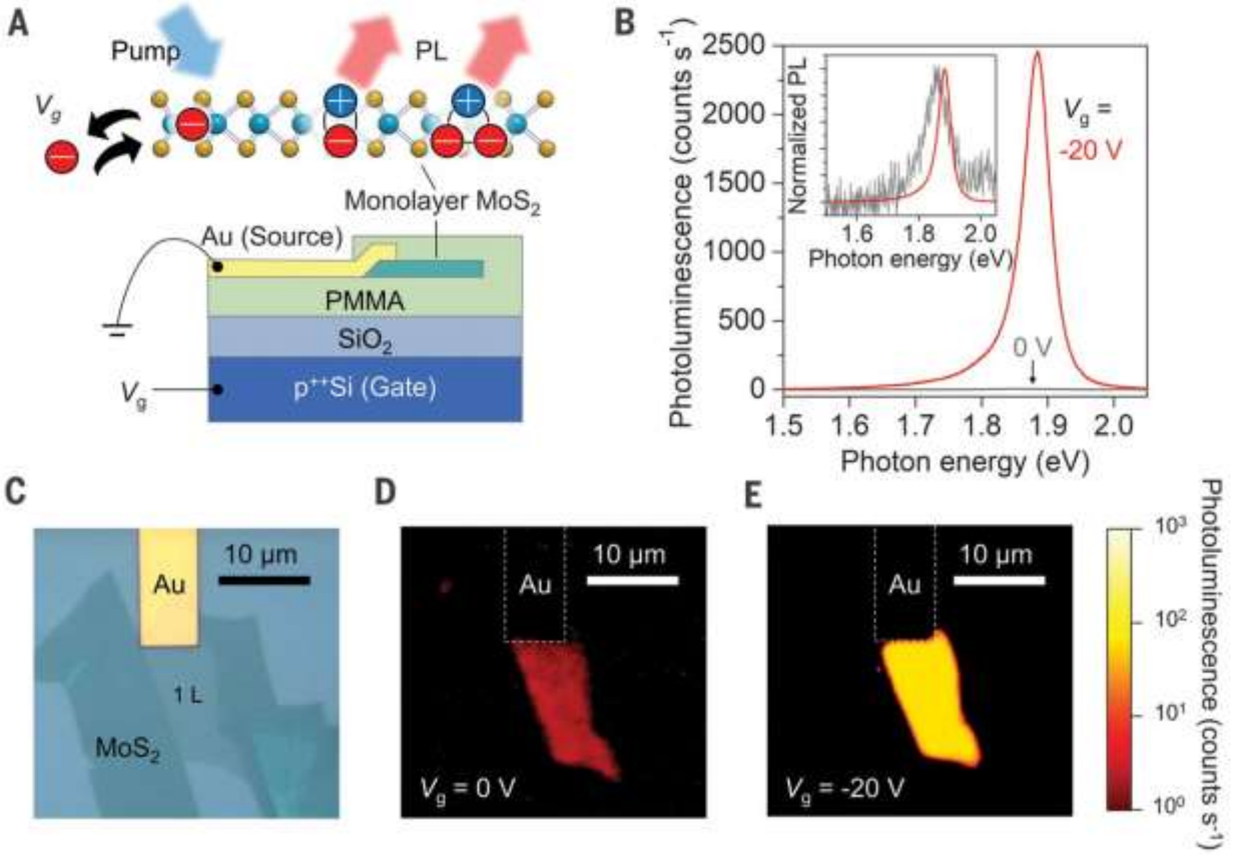
Gate-tunable emission of exciton-plasmon polaritons

DEVICE TECHNOLOGY

Electrical suppression of all nonradiative recombination pathways in monolayer semiconductors

Der-Hsien Lien[1,2*], Shiekh Zia Uddin[1,2*], Matthew Yeh[1,2], Matin Amani[1,2], Hyungjin Kim[1,2], Joel W. Ager III[2,3], Eli Yablonovitch[1], Ali Javey[1,2]†

Defects in conventional semiconductors substantially lower the photoluminescence (PL) quantum yield (QY), a key metric of optoelectronic performance that directly dictates the maximum device efficiency. Two-dimensional transition-metal dichalcogenides (TMDCs), such as monolayer MoS_2, often exhibit low PL QY for as-processed samples, which has typically been attributed to a large native defect density. We show that the PL QY of as-processed MoS_2 and WS_2 monolayers reaches near-unity when they are made intrinsic through electrostatic doping, without any chemical passivation. Surprisingly, neutral exciton recombination is entirely radiative even in the presence of a high native defect density. This finding enables TMDC monolayers for optoelectronic device applications as the stringent requirement of low defect density is eased.



Science 03 May 2019:
Vol. 364, Issue 6439, pp. 468-471
DOI: 10.1126/science.aaw8053

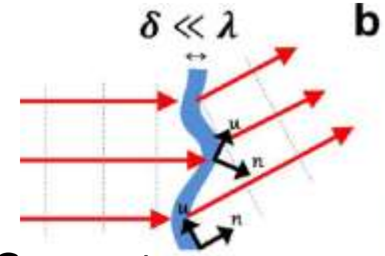
P. Ni, A. De Luna Bugallo, E. Strupietchonski, and P. Genevet
"Gate-tunable emission of exciton-plasmon polaritons in hybrid MoS2-gap-mode metasurfaces"(accepted ACS Photonics 2019)

Conclusion and perspectives

Optical metasurfaces, composed of ultrathin subwavelength meta-atoms, have enabled flat-optics such as ultrathin lenses, color filters, polarimeters, holograms and absorbers. Among the plethora of applications currently attracting great interest, next generation of imaging systems and display techniques could further benefit from metasurface technology.

- ❖ Metaoptics for imaging (performances???)
- ❖ Metasurface Holograms for Projective Display Techniques
- ❖ Metasurface Colorations for Reflective Display Techniques
- ❖ Metasurfaces polarimeters
- ❖ Metasurface beam splitters for quantum optics applications
- ❖ Nonlinear metasurfaces
- ❖ Metasurfaces for real time wavefront manipulation
- ❖ Metasurfaces for LiDAR applications
- ❖ Conformal Metasurfaces, …

Outfitting next generation displays with optical metasurfaces
I Kimet al. ACS Photonics 5 (10), 3876-3895 (2018)



Genevet group

A. Faraon group