

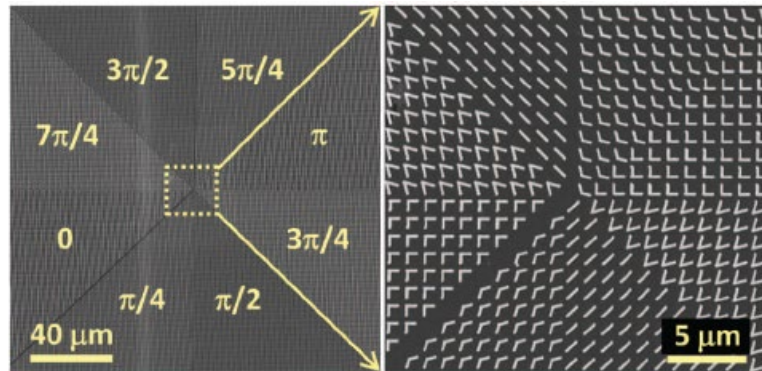
Selected Topics in Advanced Optics

Week 13 – part 1

Olivier J.F. Martin
Nanophotonics and Metrology Laboratory



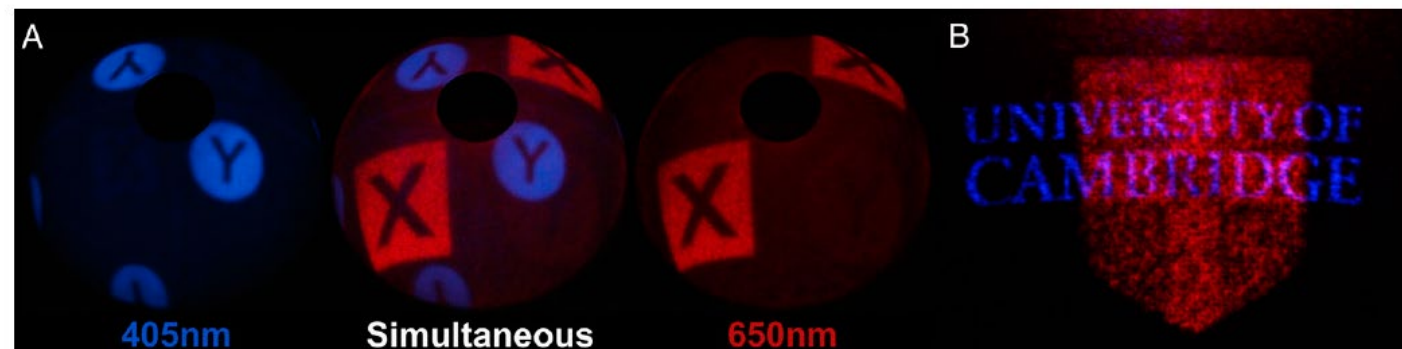
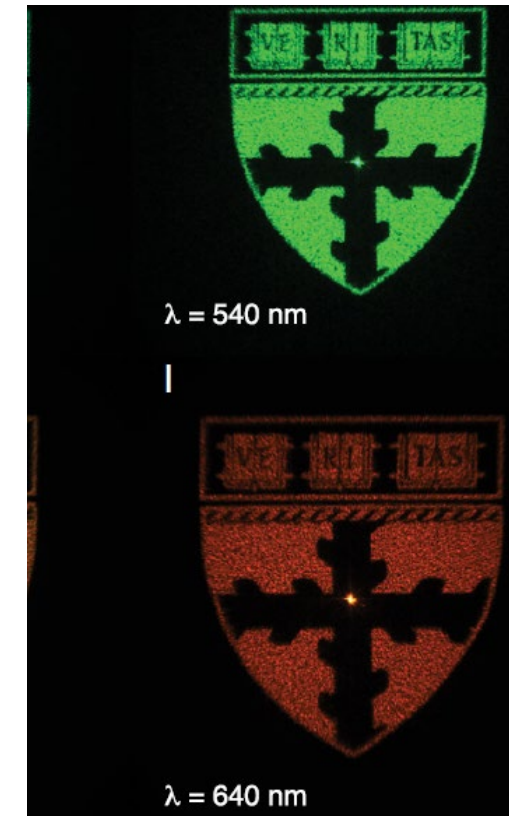
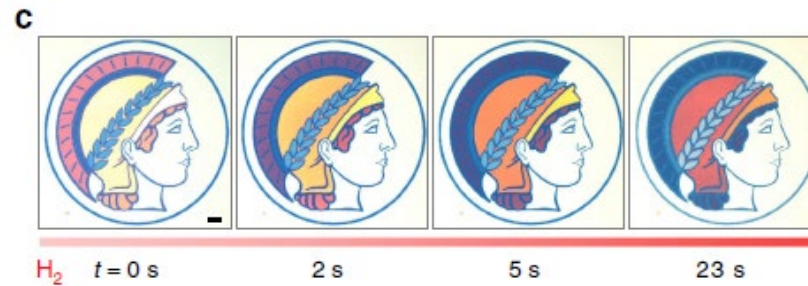
Metasurfaces – A potpourri of applications



Incident light :LCP

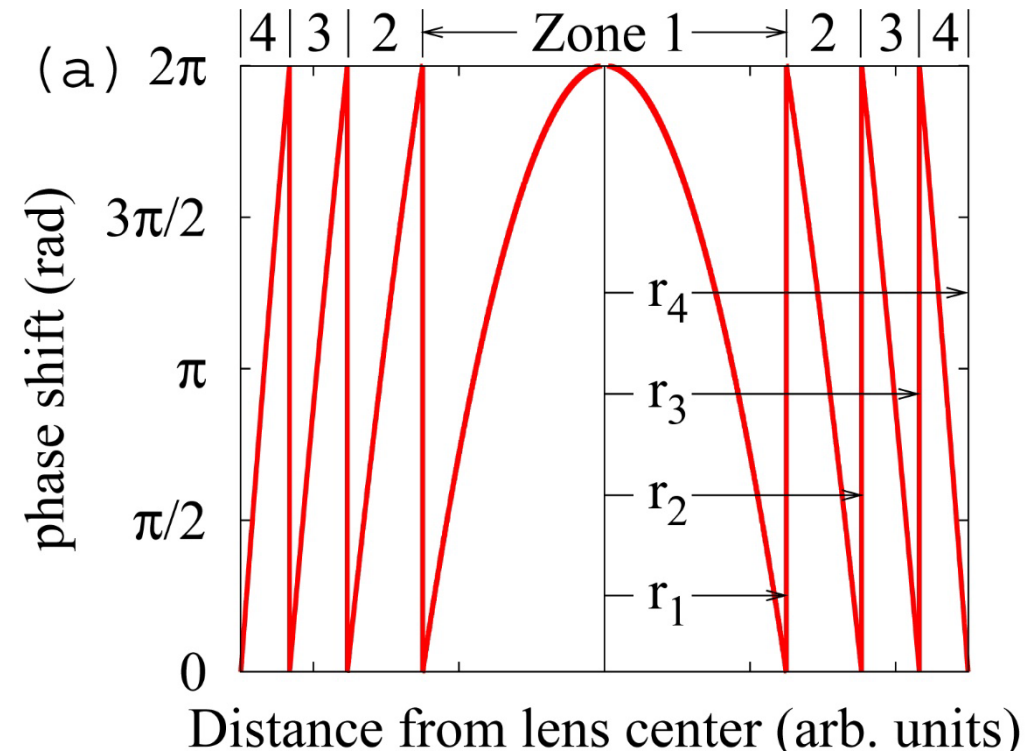


Incident light :RCP



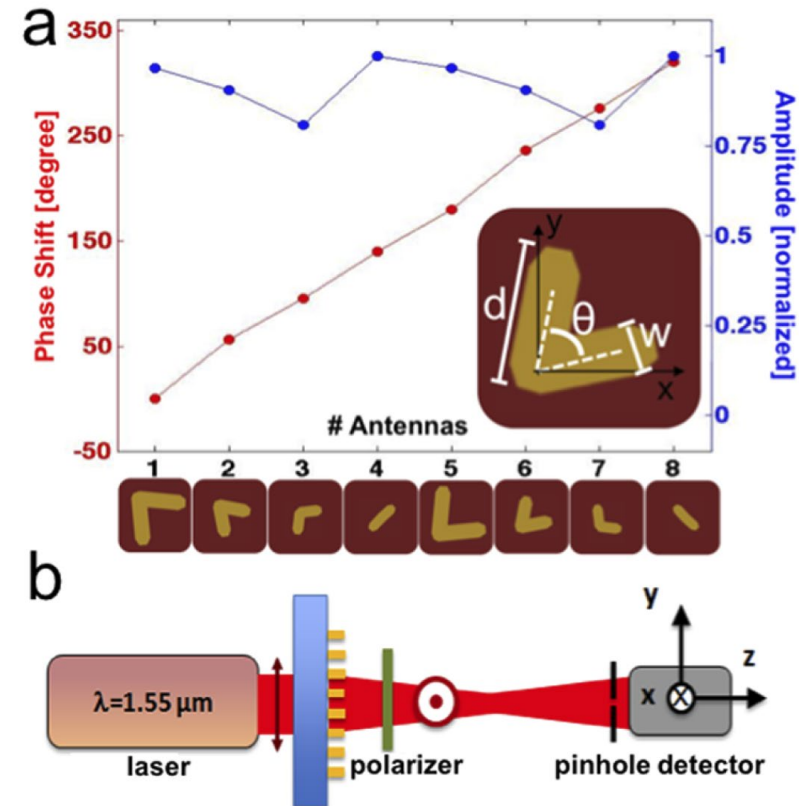
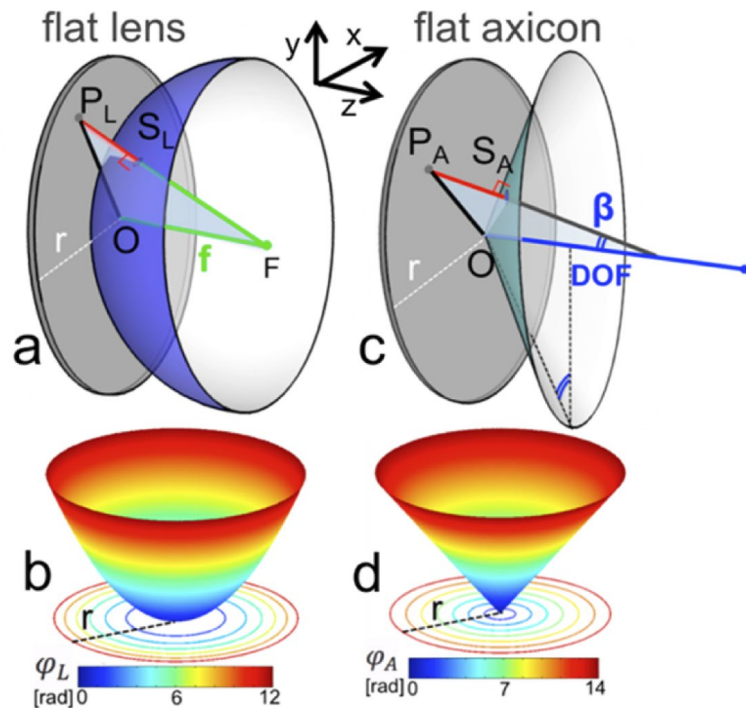
Metalenses

- In analogy with Fresnel lenses, a collection of plasmonic nanostructures can produce focusing effects, or more complex beam shaping



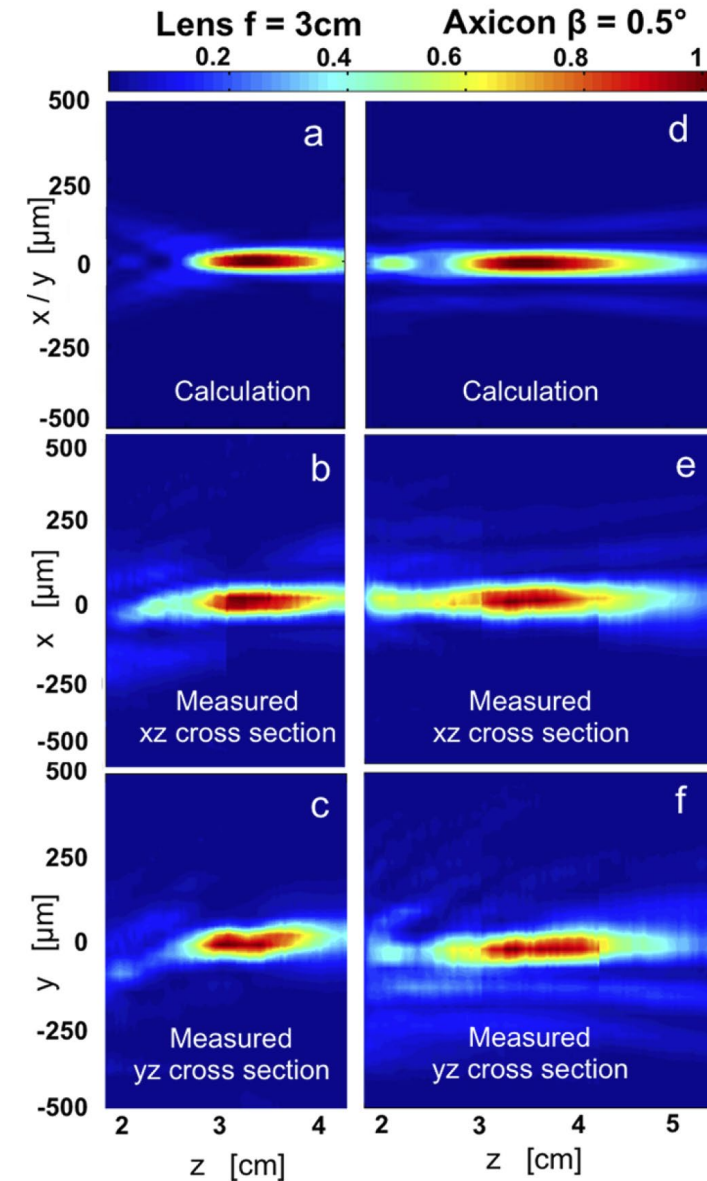
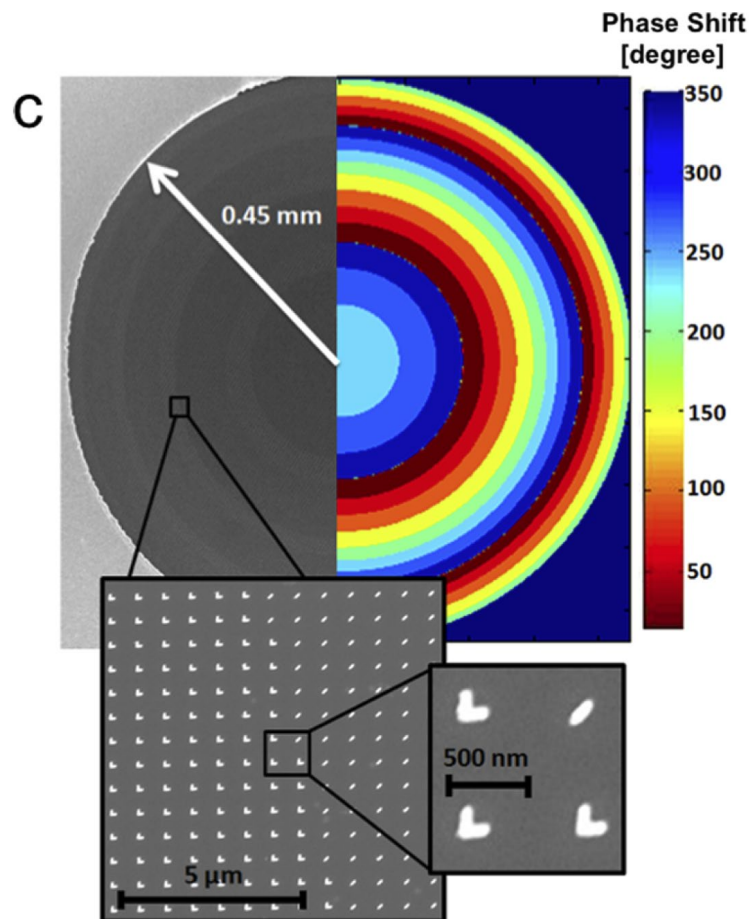
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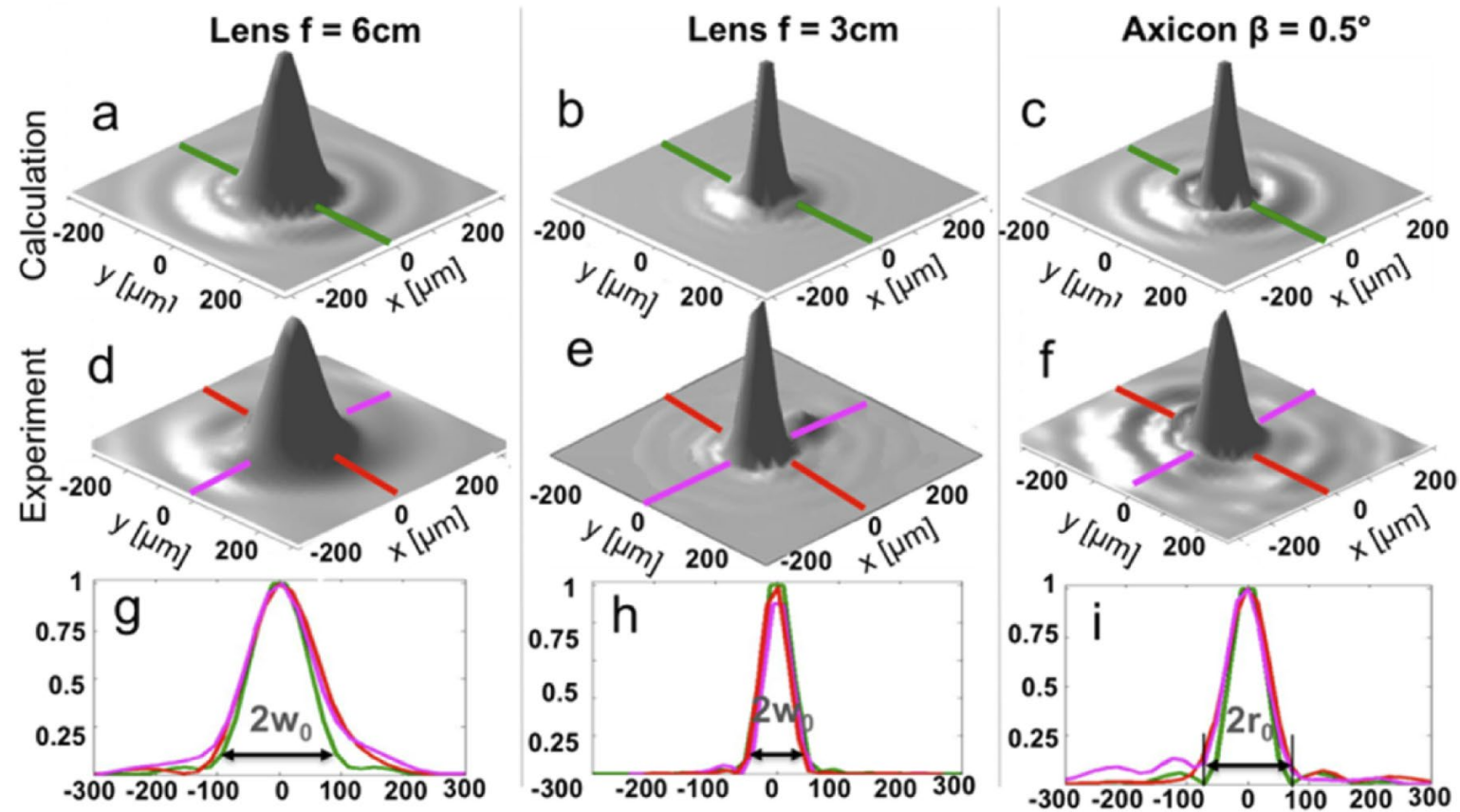
Metalenses

- V-shaped nanostructures provide the different phases required for the lens



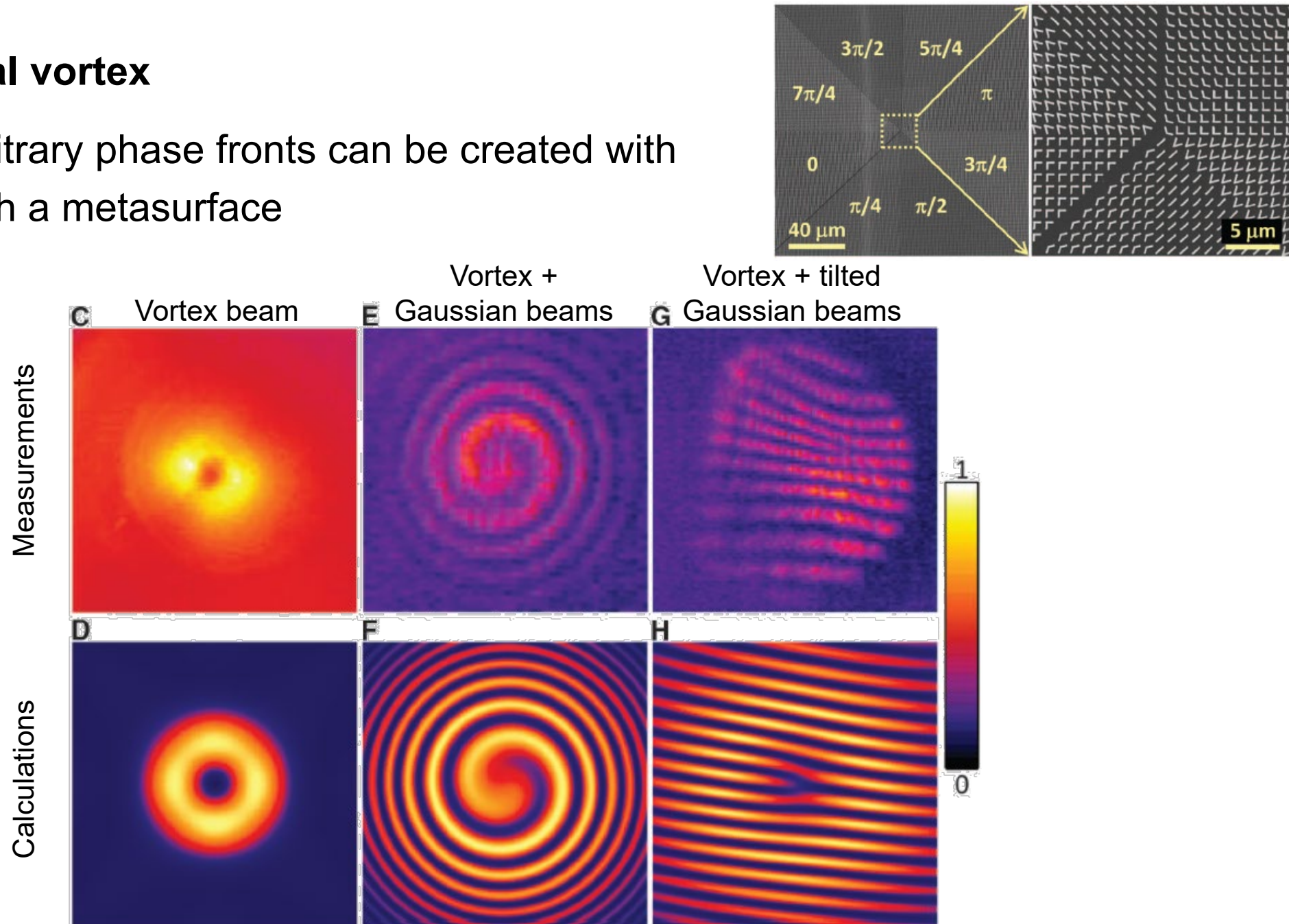
Metalenses

- Same focus spot as a real lens

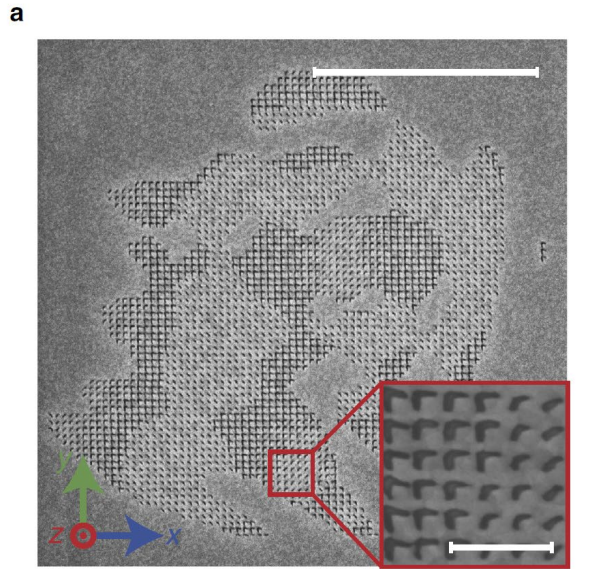


Optical vortex

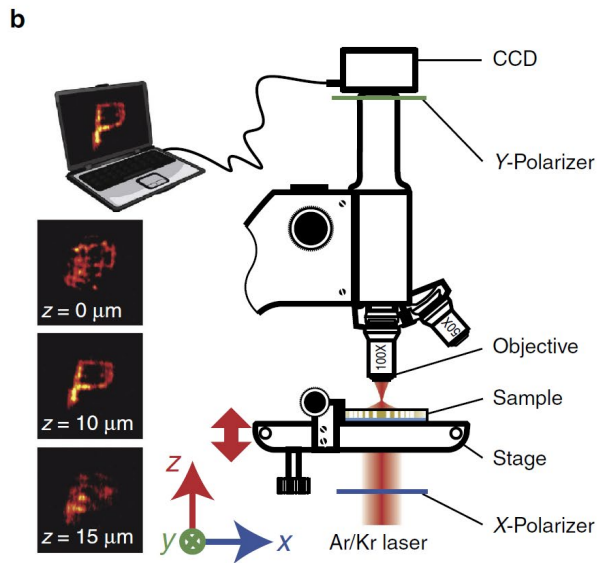
- Arbitrary phase fronts can be created with such a metasurface



Meta-holograms



- Apertures in a metal film are used to produce the different phase elements



Meta-holograms

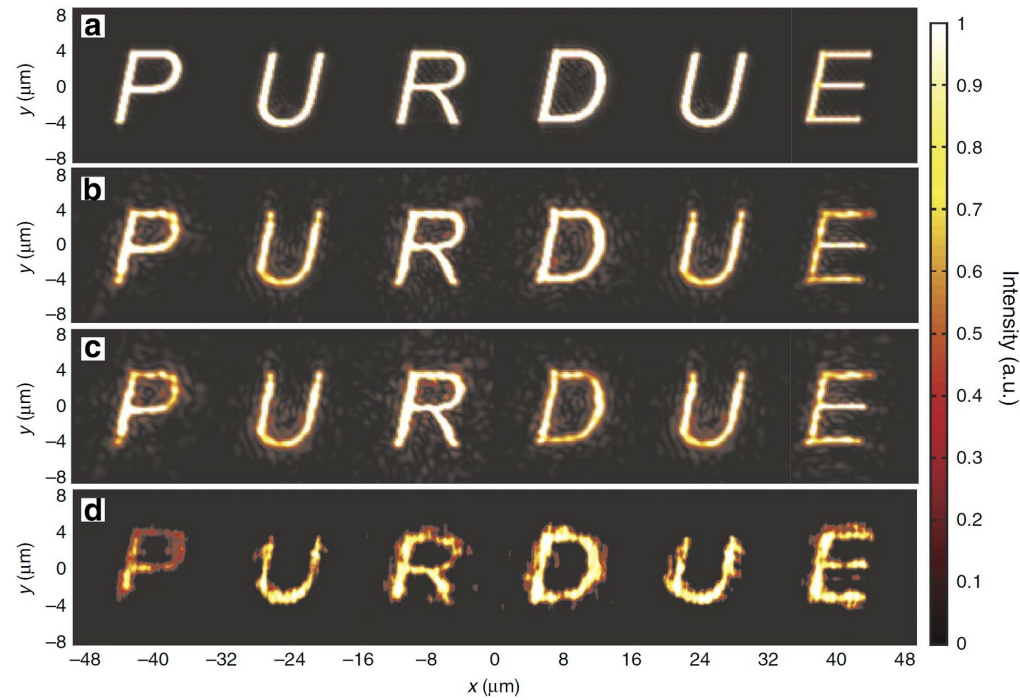
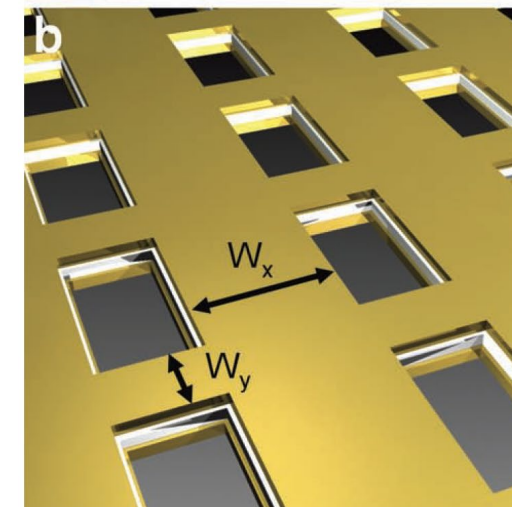
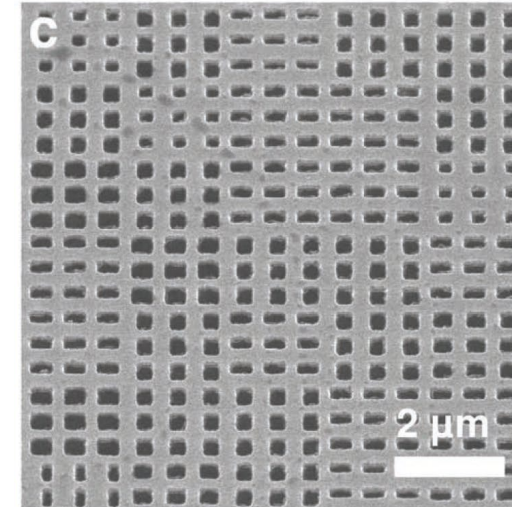
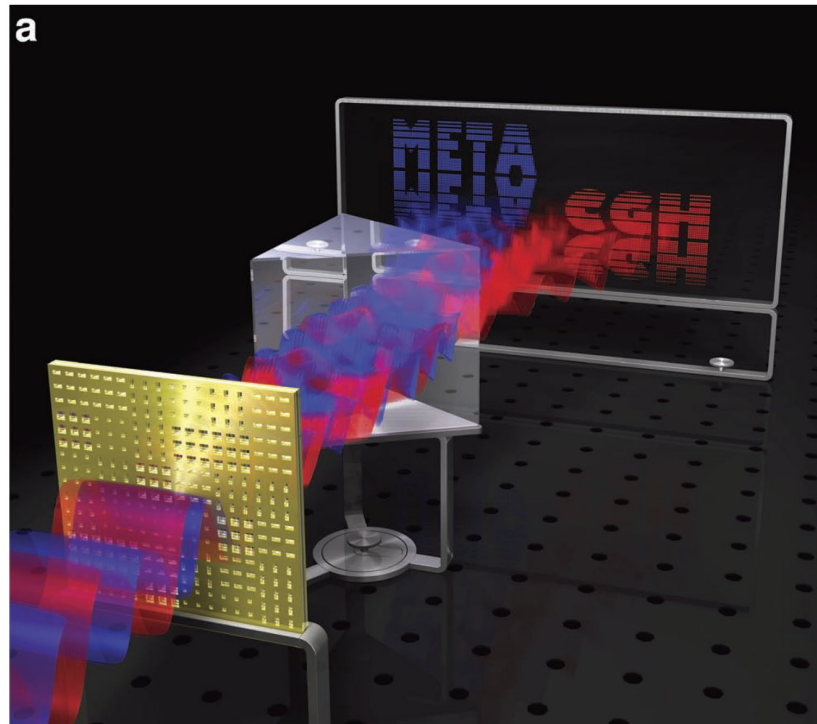


Figure 4 | Simulated holographic images compared with the experimental images. (a) The simulated holographic images created by an ideal metasurface hologram with smooth phase and amplitude modulations. (b) The simulated holographic images created by a metasurface hologram with an eight-level phase modulation and a four-level amplitude modulation. (c) The simulated holographic images created by a metasurface hologram with an eight-level phase modulation and a two-level amplitude modulation. (d) Holographic images obtained experimentally from the fabricated samples. All the images are taken from the same image plane $10\ \mu\text{m}$ above and parallel to the metasurface hologram.

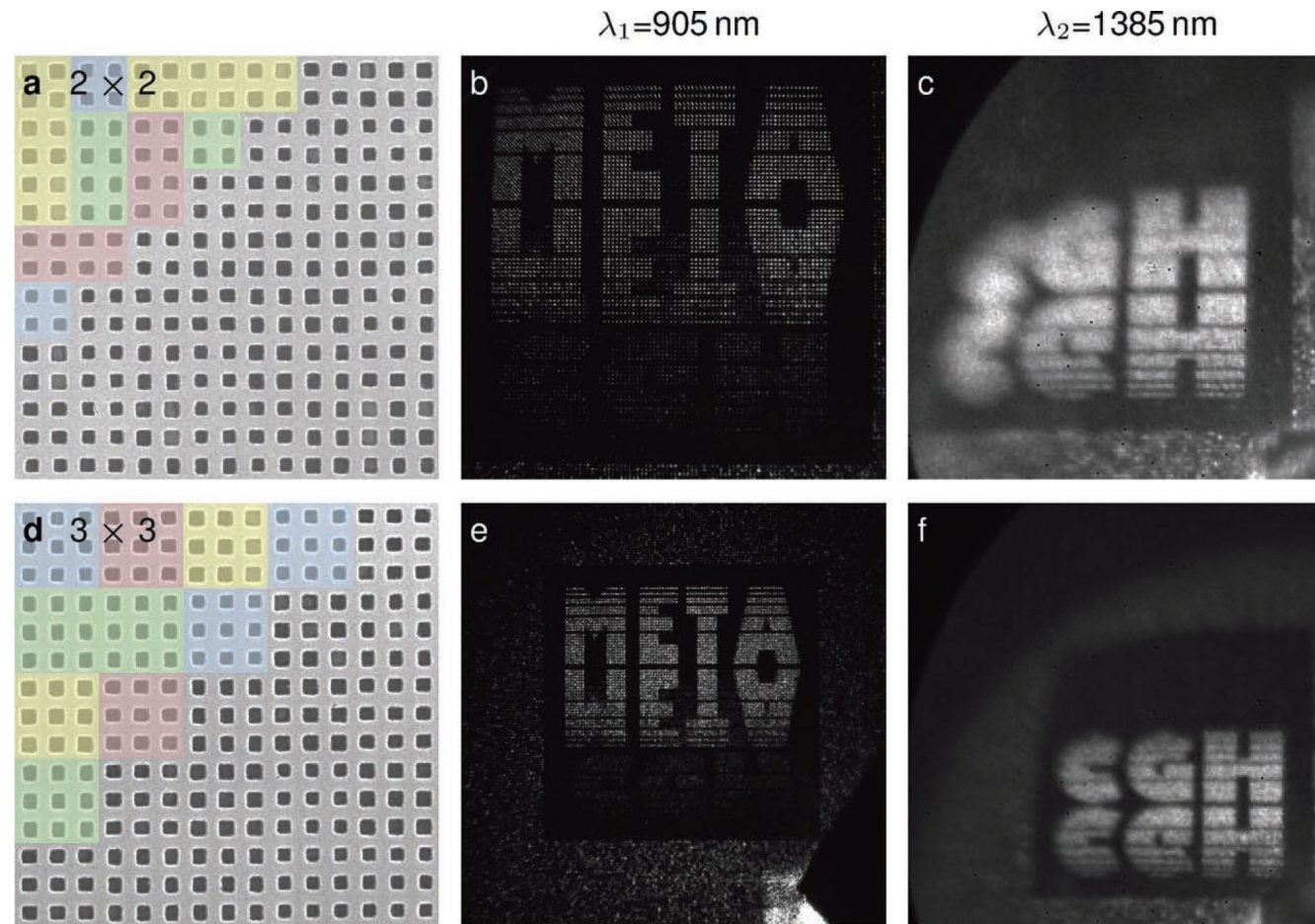
Meta-holograms and wavelength multiplexing effects

- Different apertures will produce different phases when illuminated with different wavelengths

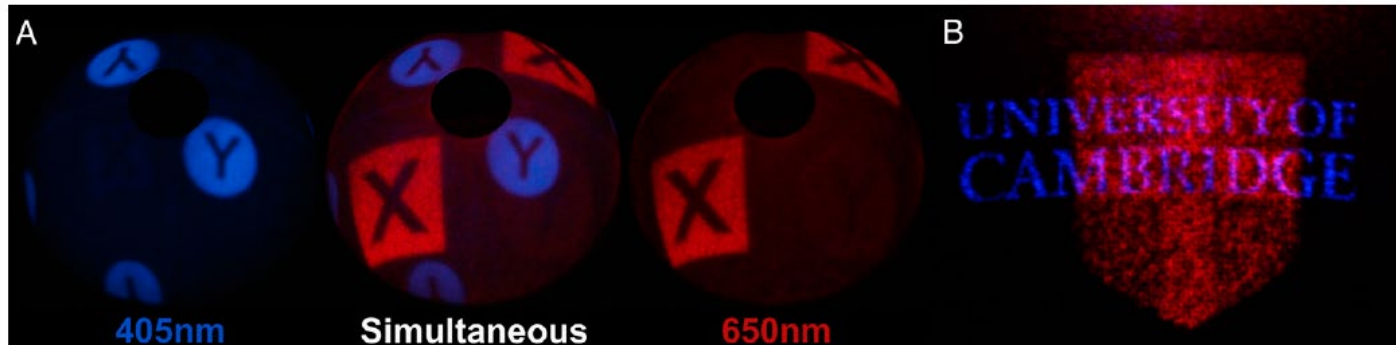
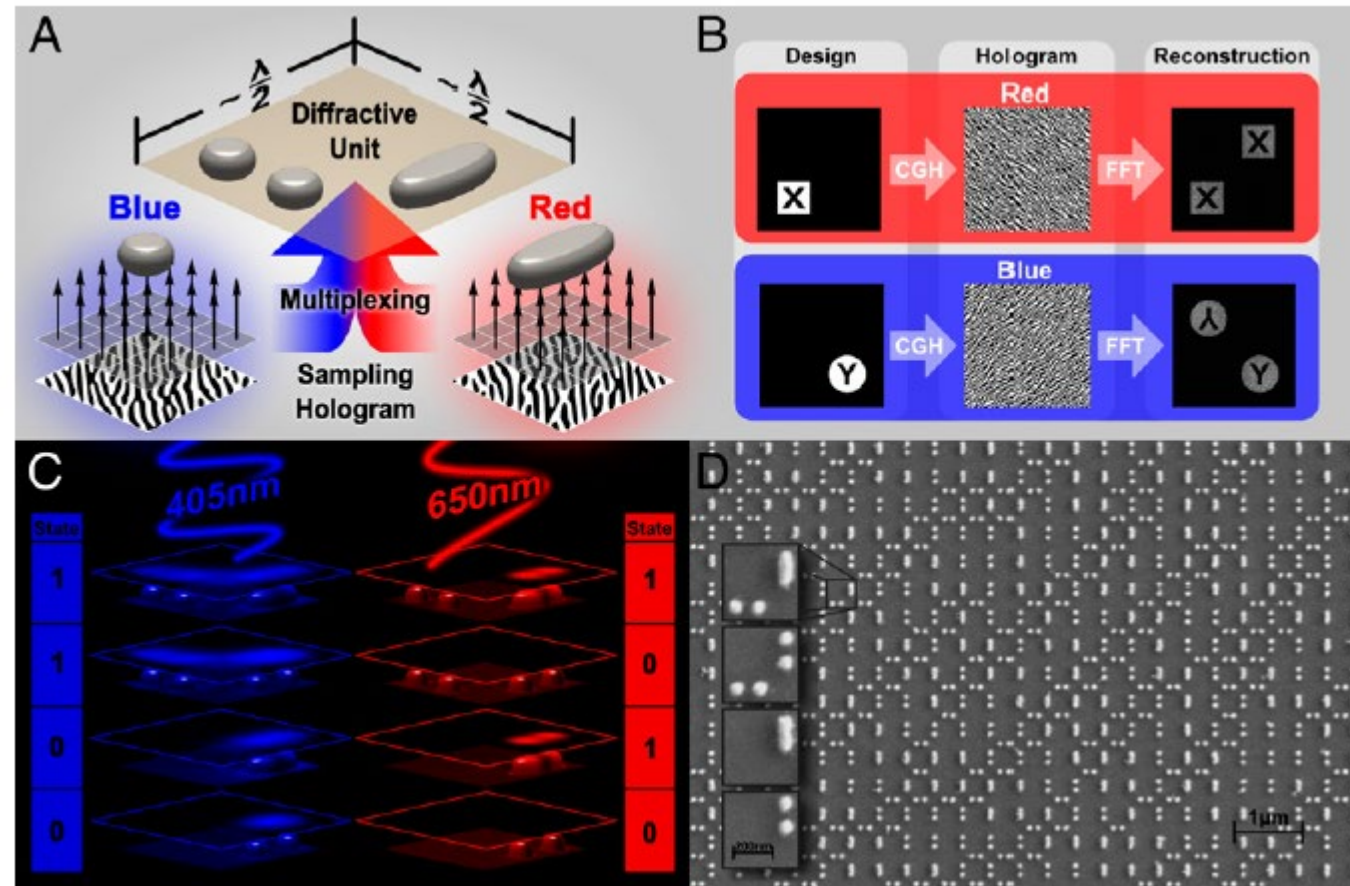


Meta-holograms and wavelength multiplexing effects

- The number of unit cells used to define one hologram pixel influences the hologram quality



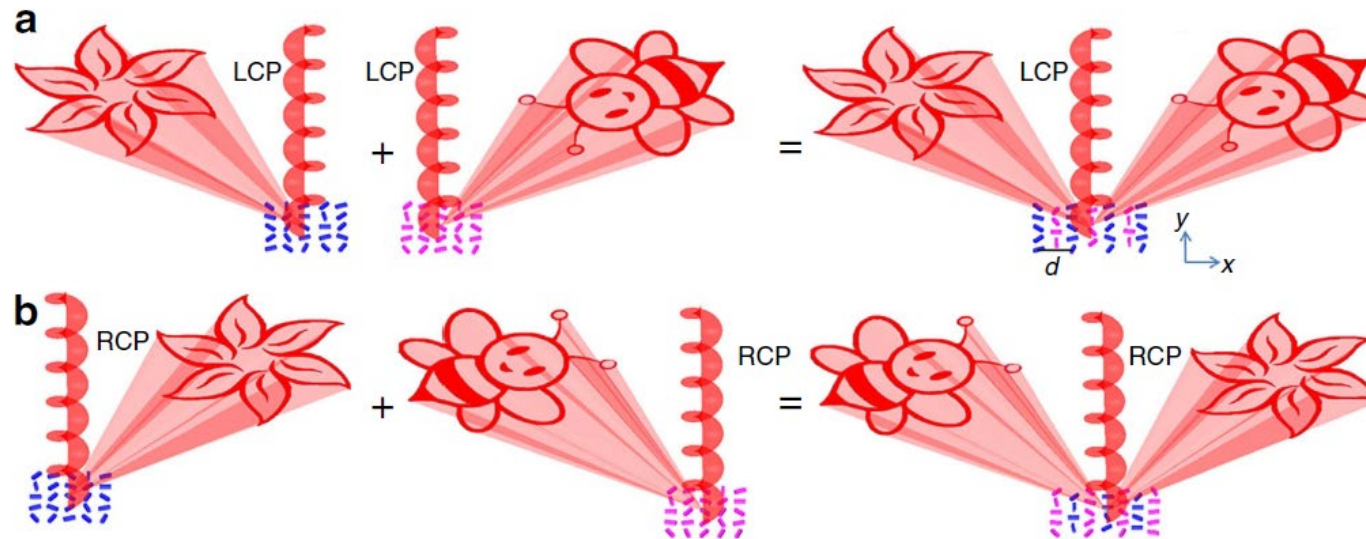
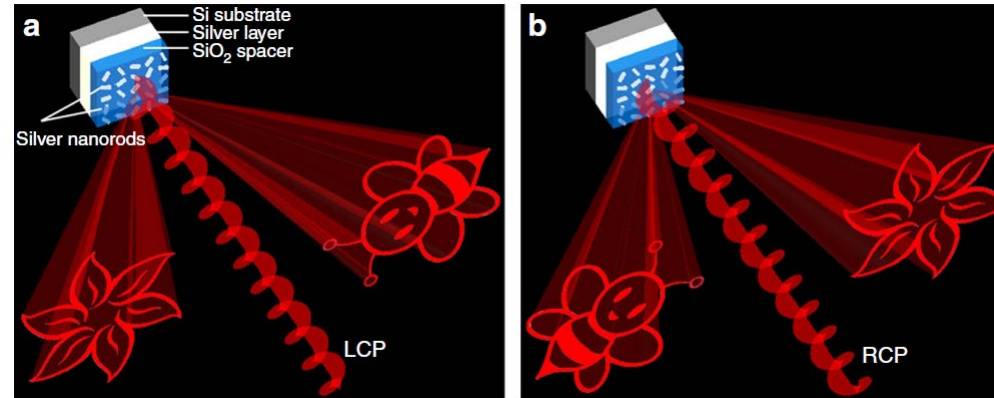
Meta-holograms and wavelength multiplexing effects



PNAS, vol. 111, p. 12679 (2014)

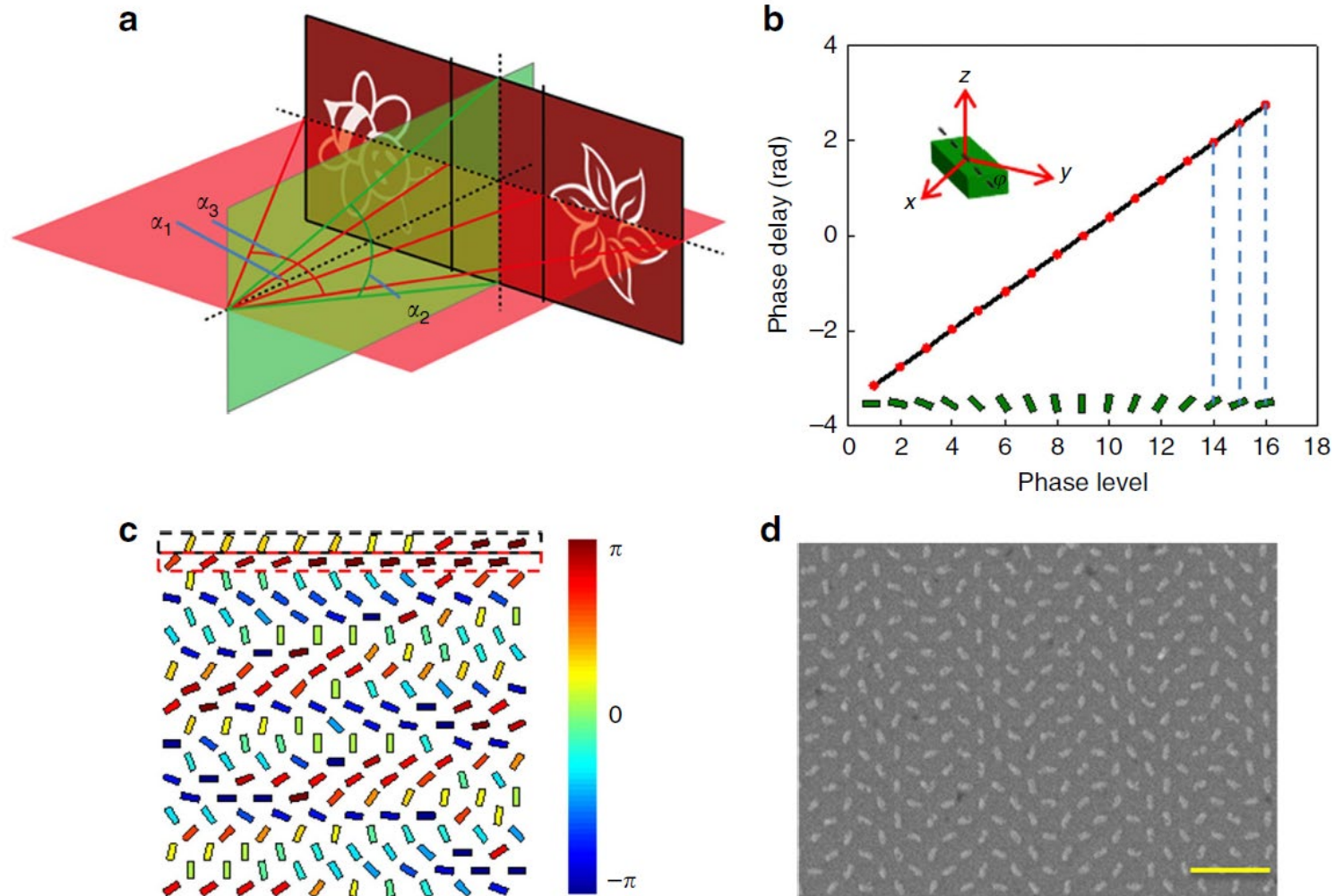
Meta-holograms and polarization multiplexing effects

- Two different meta-holograms with different responses for left and right circular polarizations can be superposed on the same sample



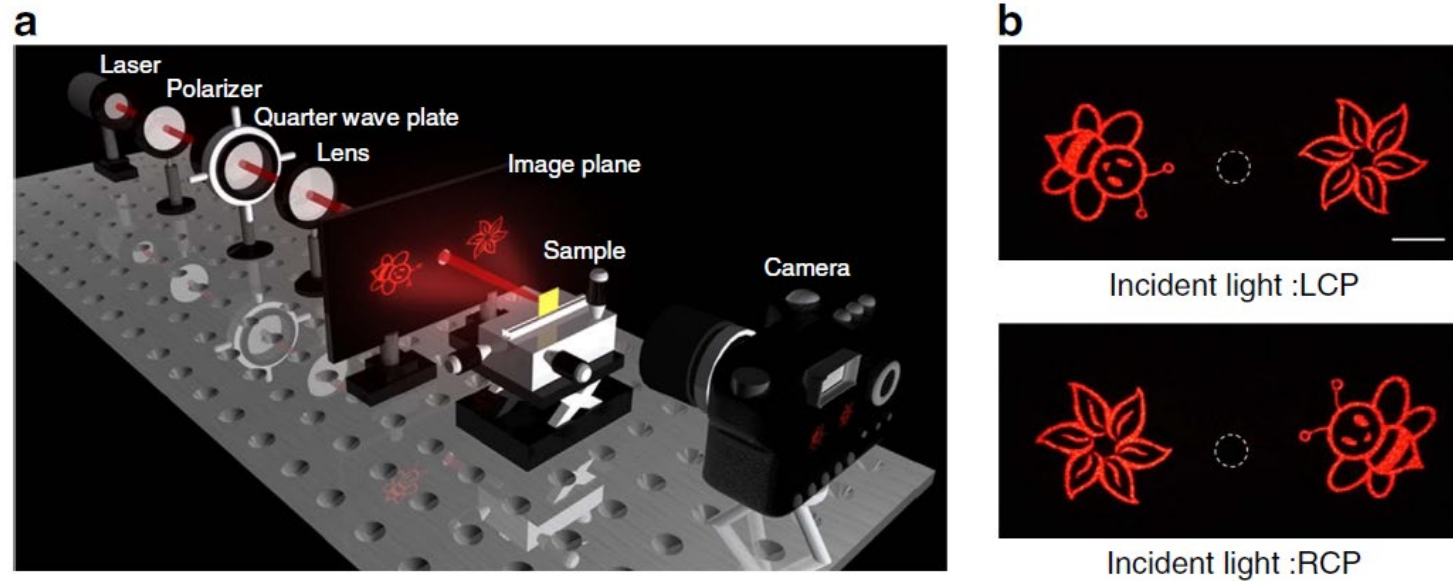
Meta-holograms and polarization multiplexing effects

- Each hologram is defined using plasmonic nanostructures

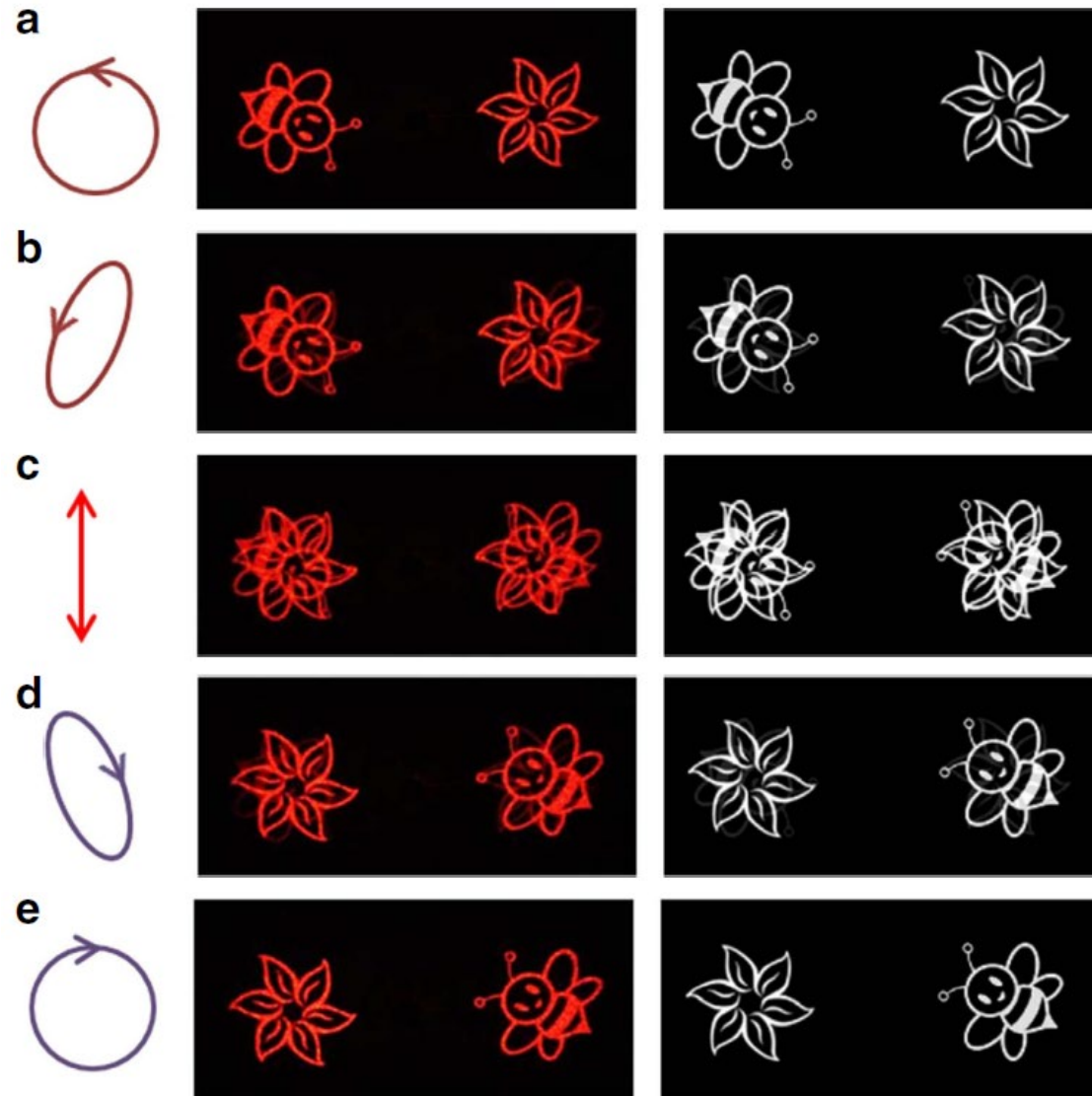


Meta-holograms and polarization multiplexing effects

- A different response is obtained, depending on the helicity (left or right) of the illumination

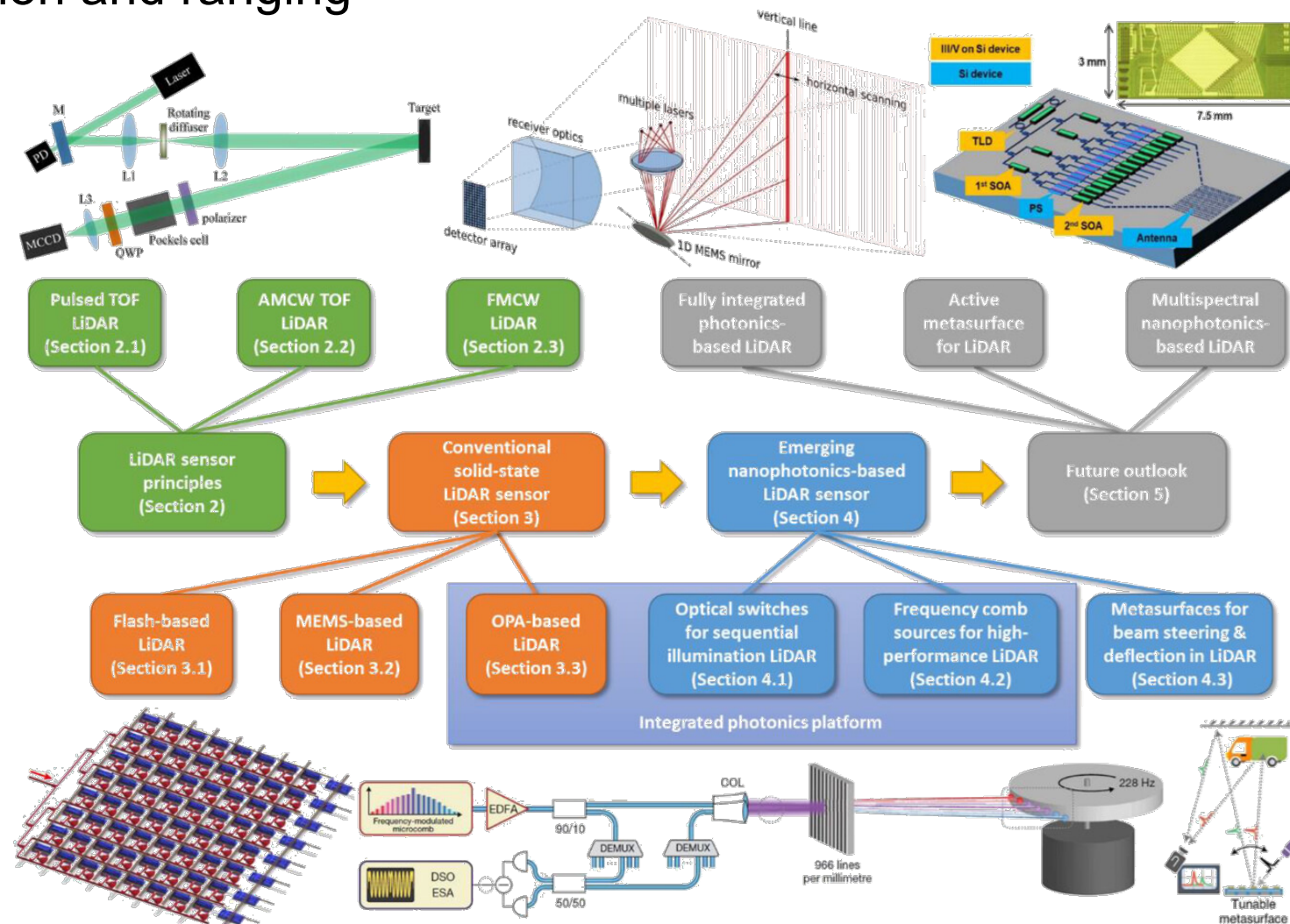


Meta-holograms and polarization multiplexing effects



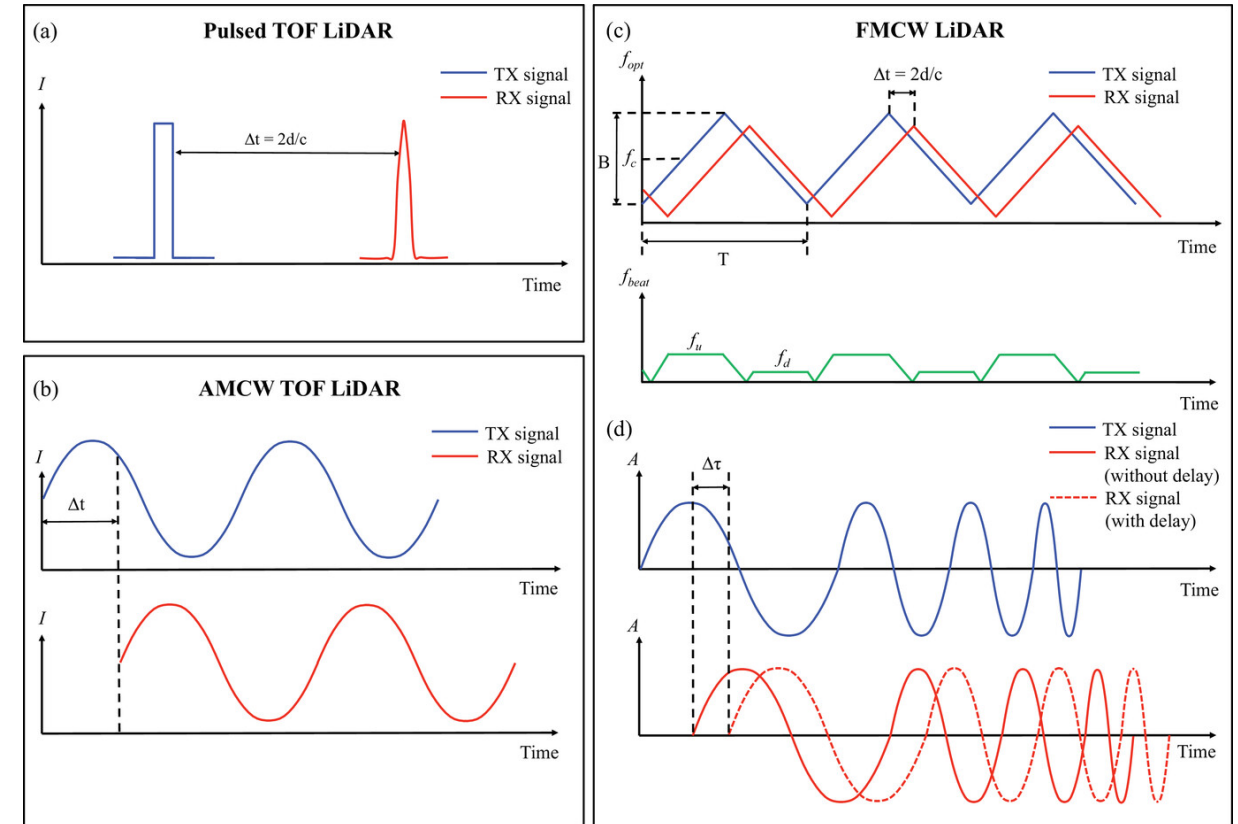
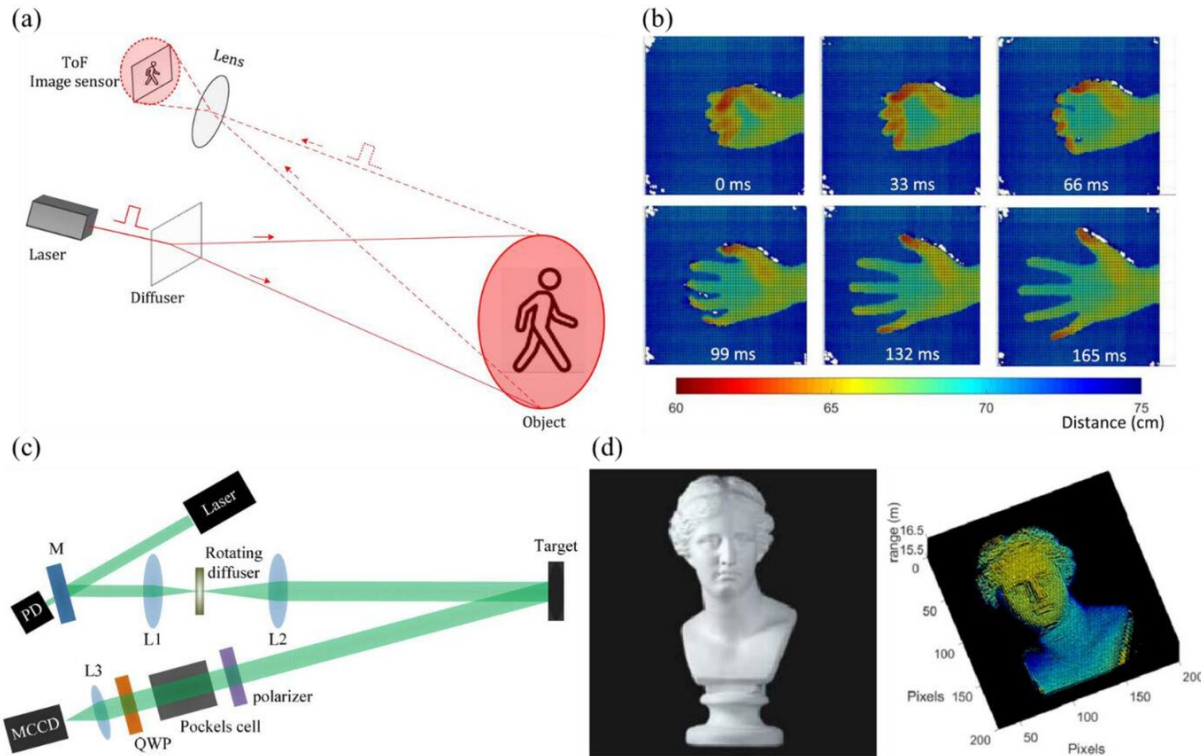
LiDAR

- Light detection and ranging



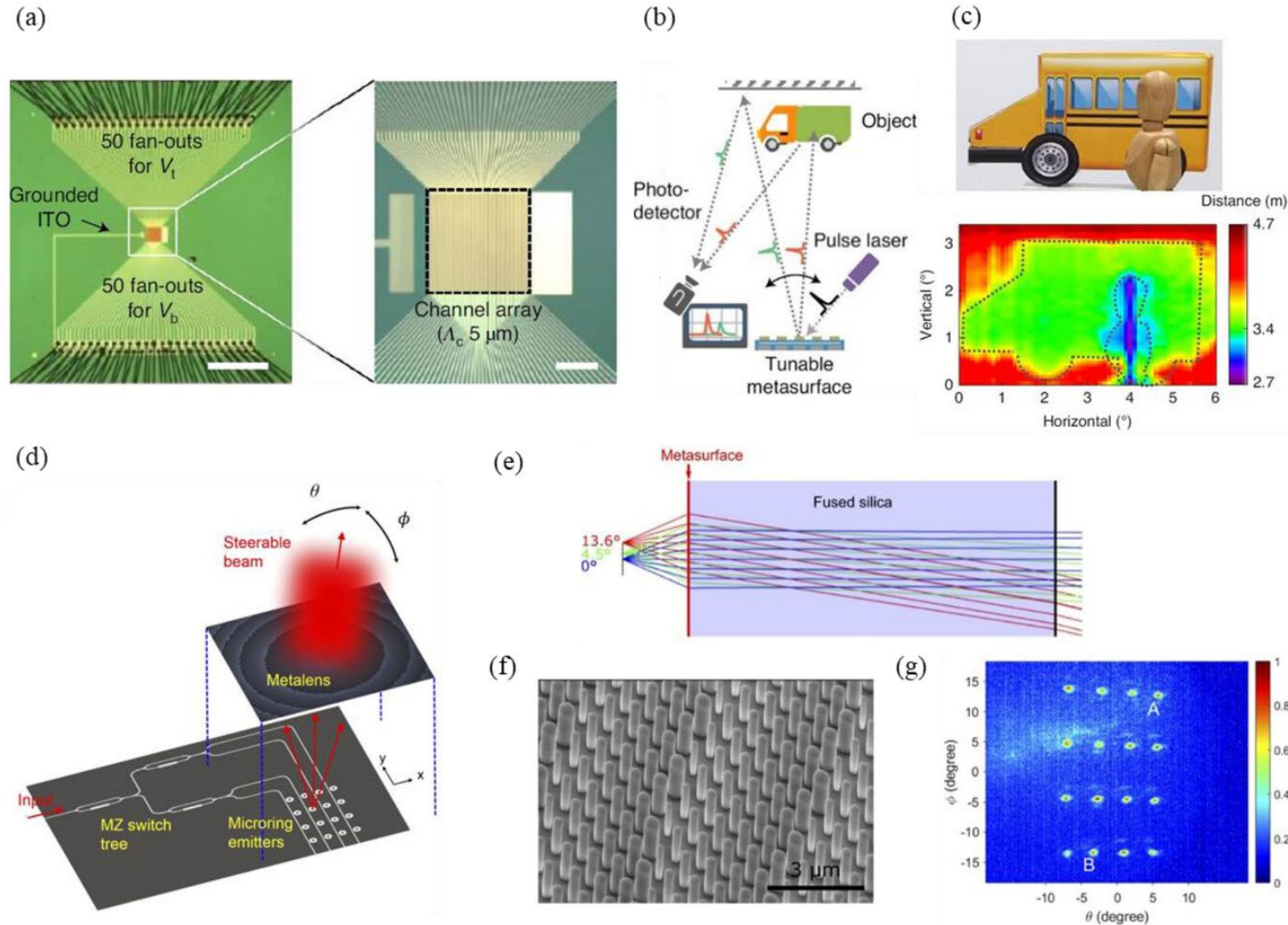
LiDAR

- Different implementations and principles of operation



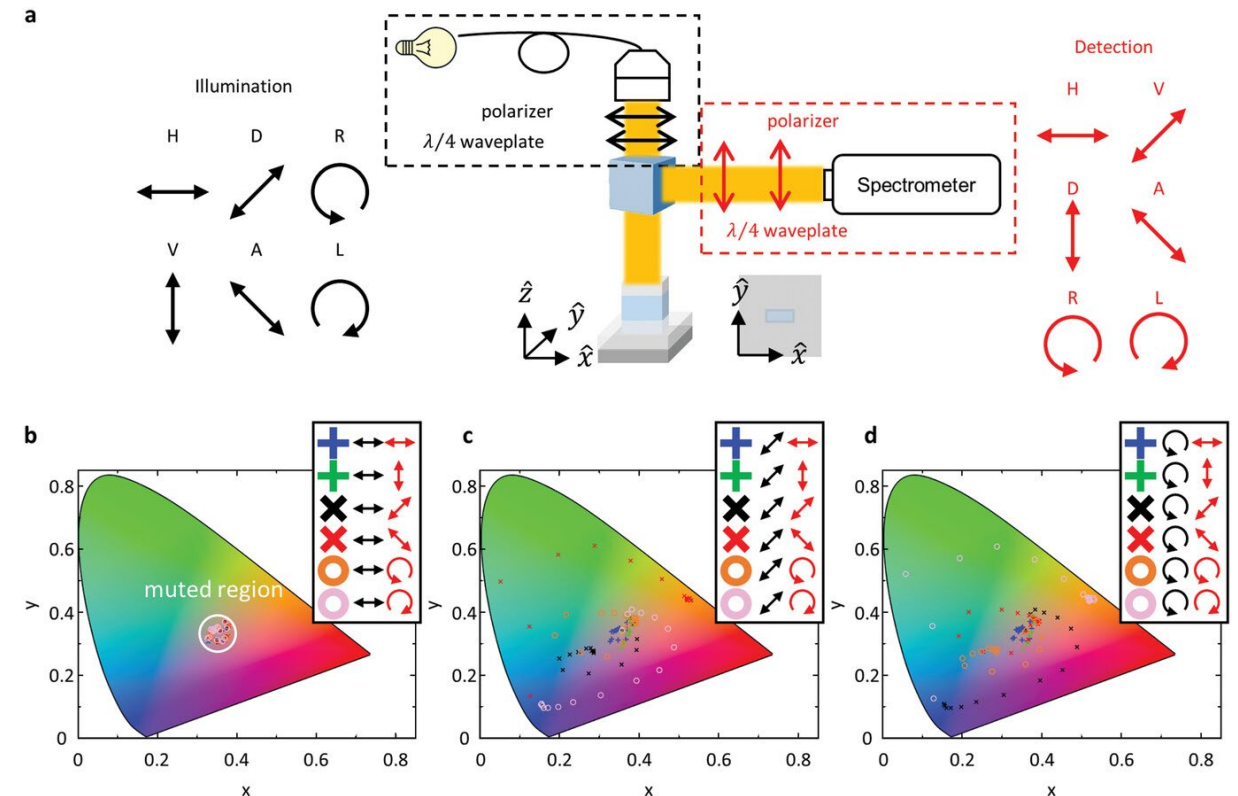
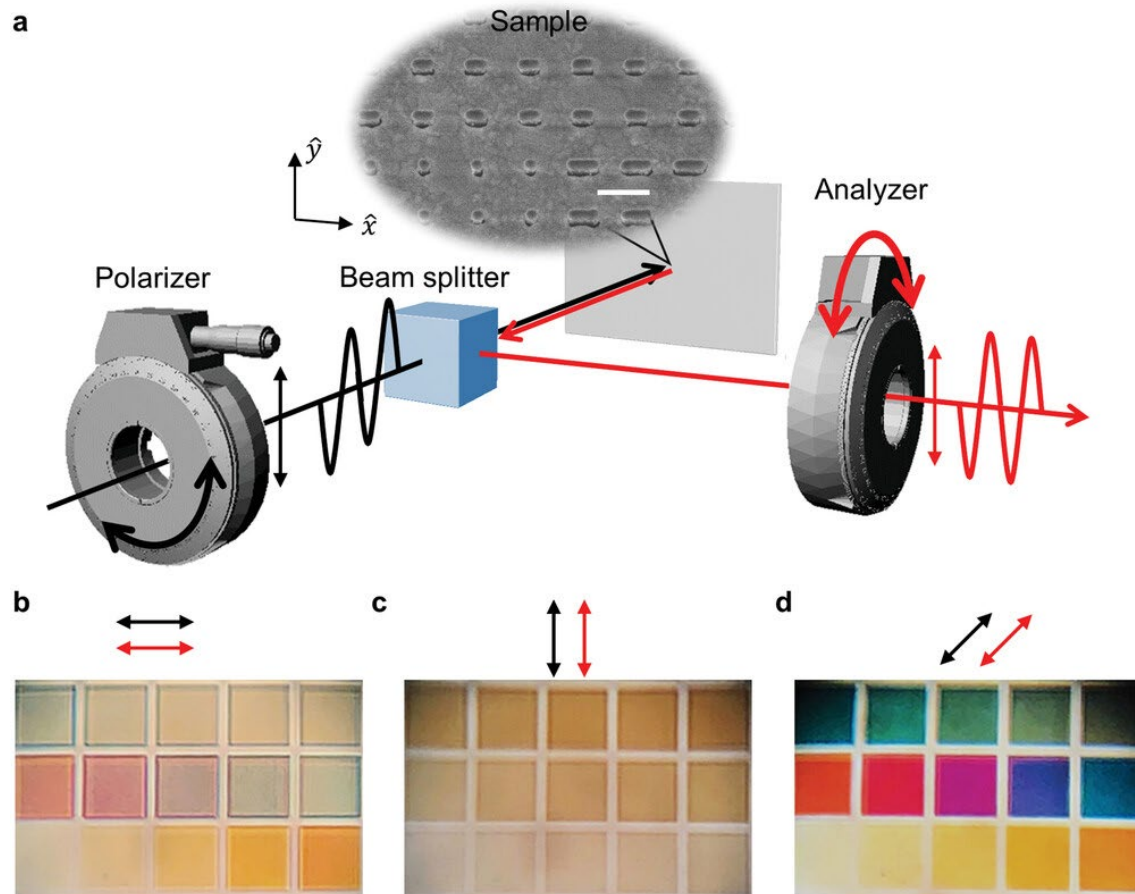
LiDAR

- Metasurfaces are usually used for scanning the scene

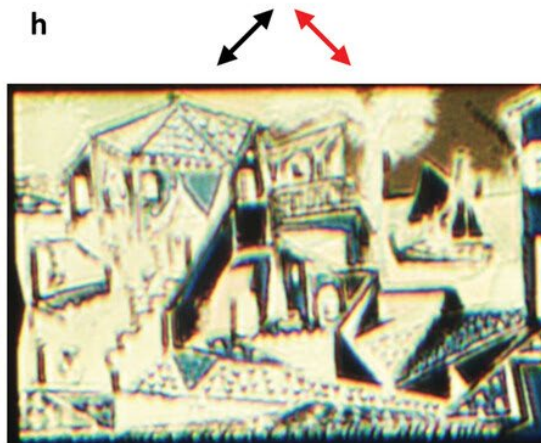
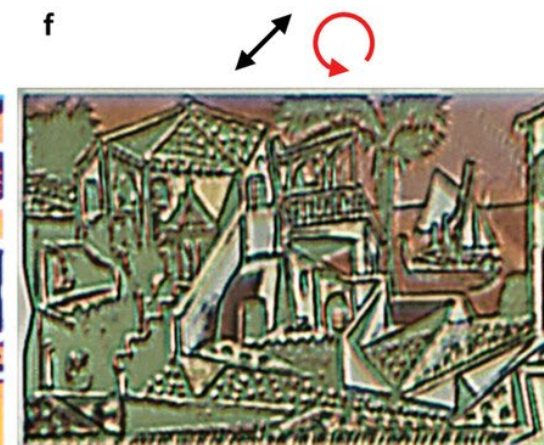
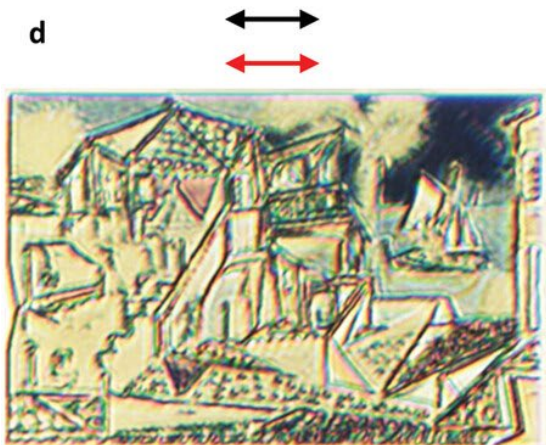
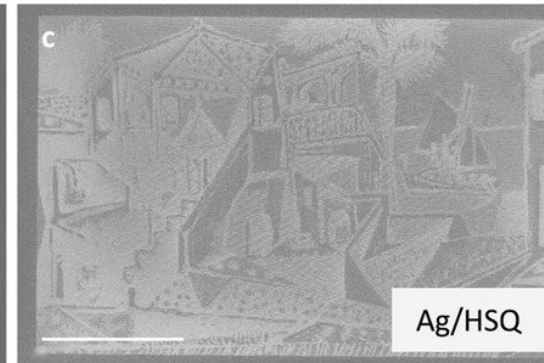


Art...?

- Metasurfaces can also produce some interesting colorful effects



Art...?



Selected Topics in Advanced Optics

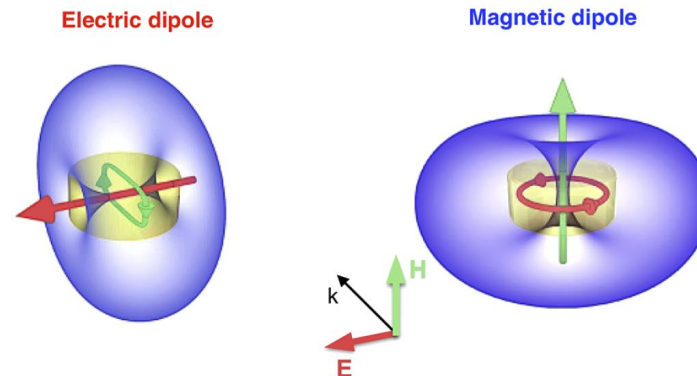
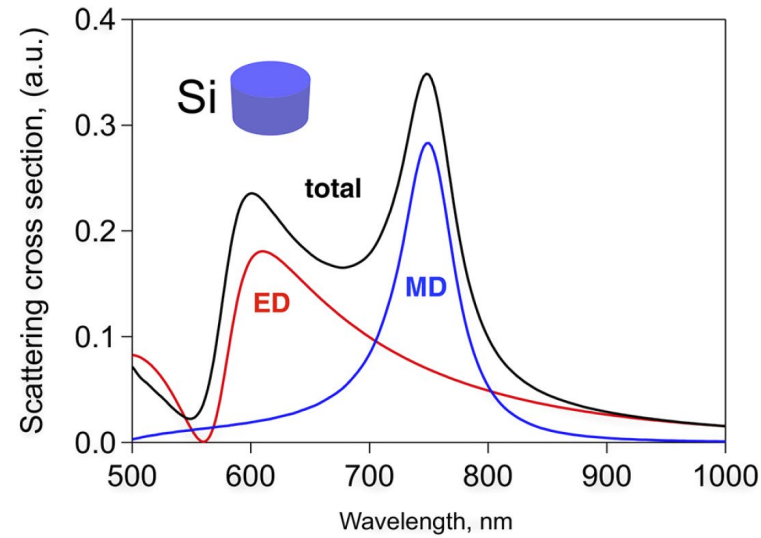
Week 13 – part 2

Olivier J.F. Martin
Nanophotonics and Metrology Laboratory



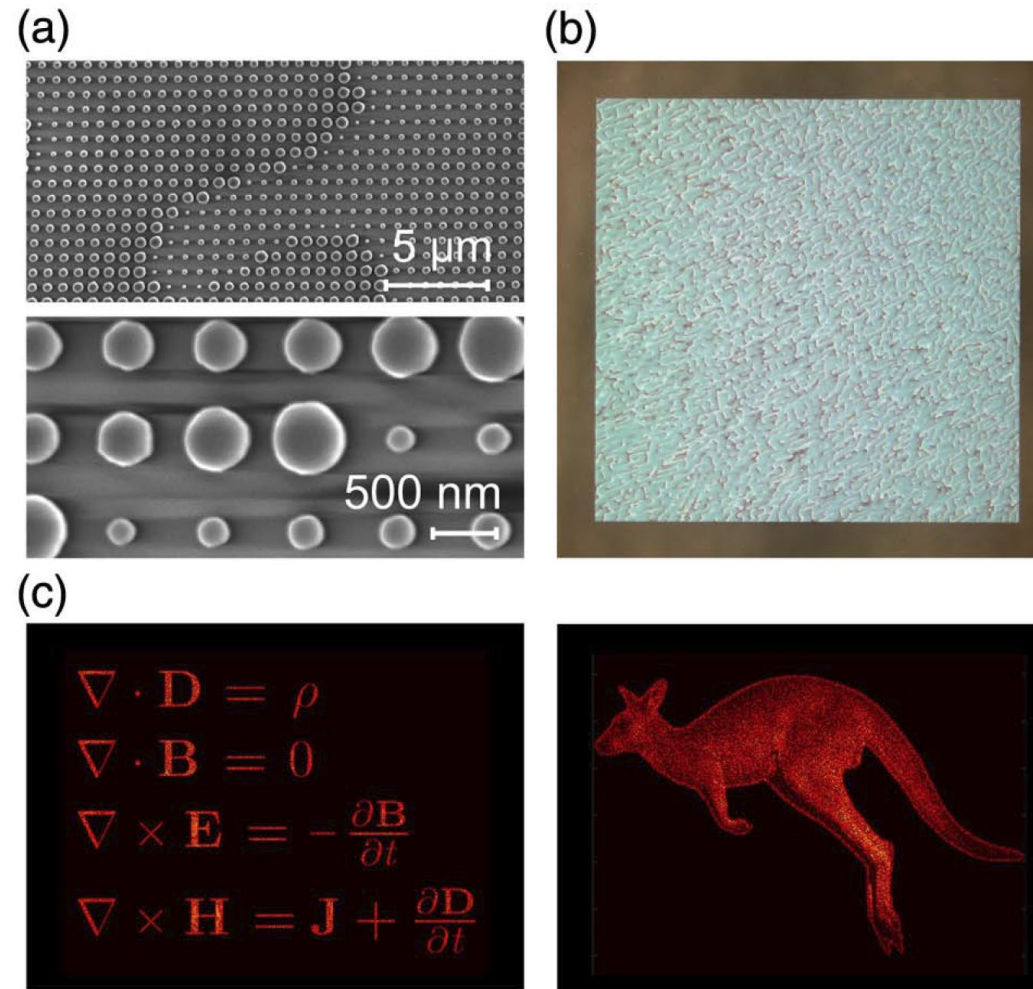
Metasurfaces governed by Mie resonances

- Dielectric resonators have lower losses than plasmonic ones and are also associated with phase shifts



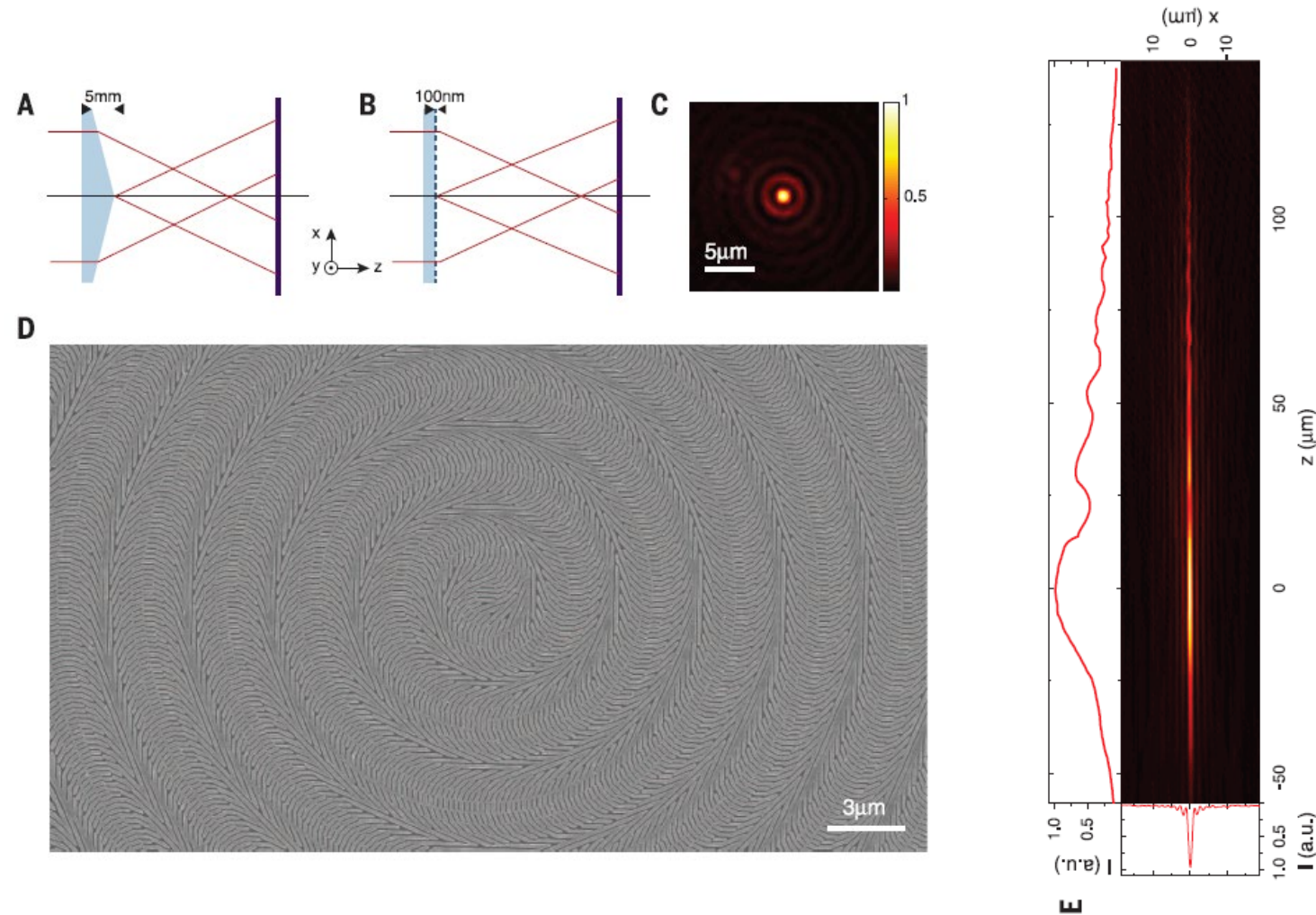
Dielectric metasurfaces

- The phase is engineered with transparent nanostructures with varying dimensions



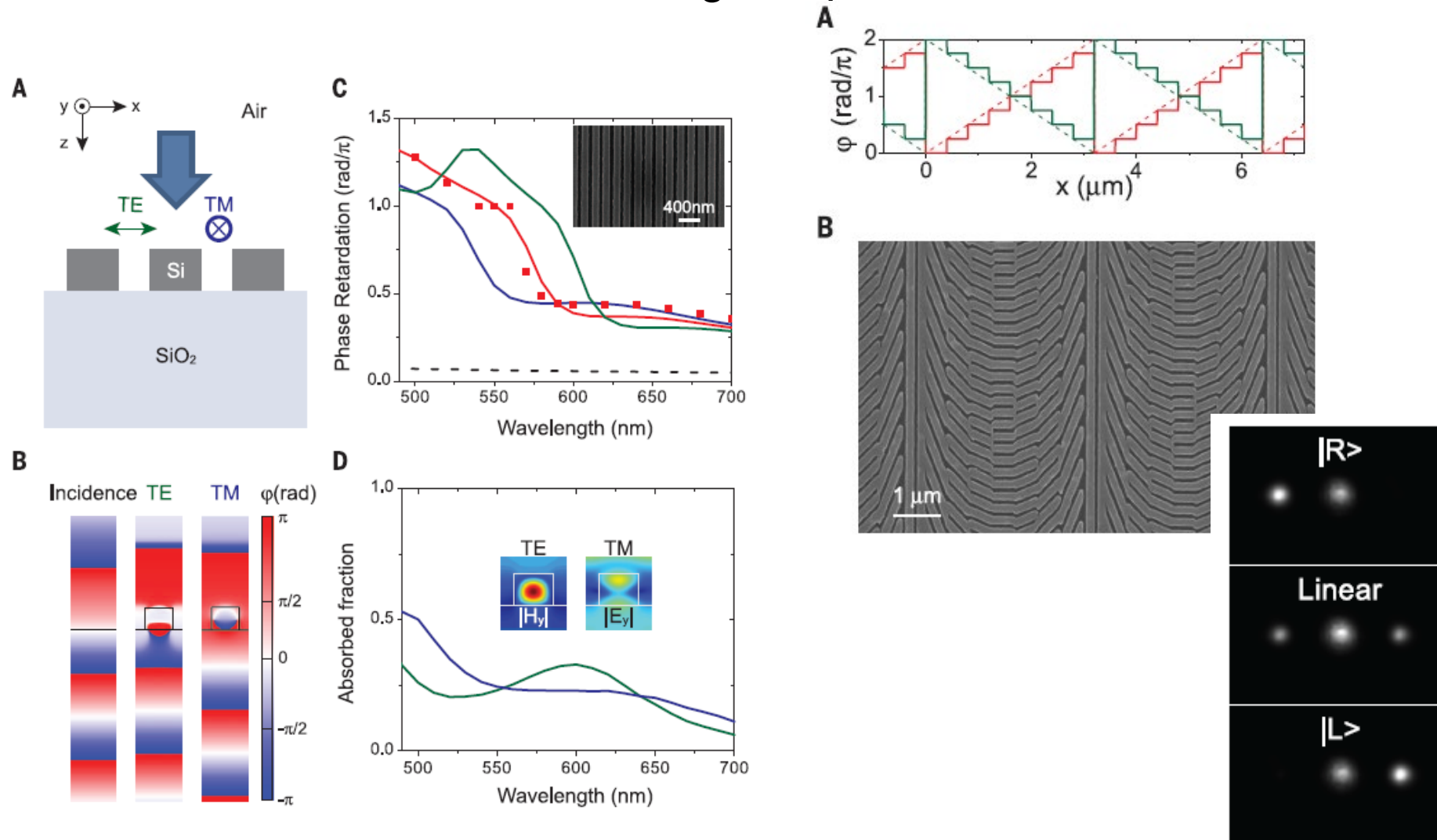
Dielectric metasurfaces

- A phase shift can also be obtained using steep structures in Si



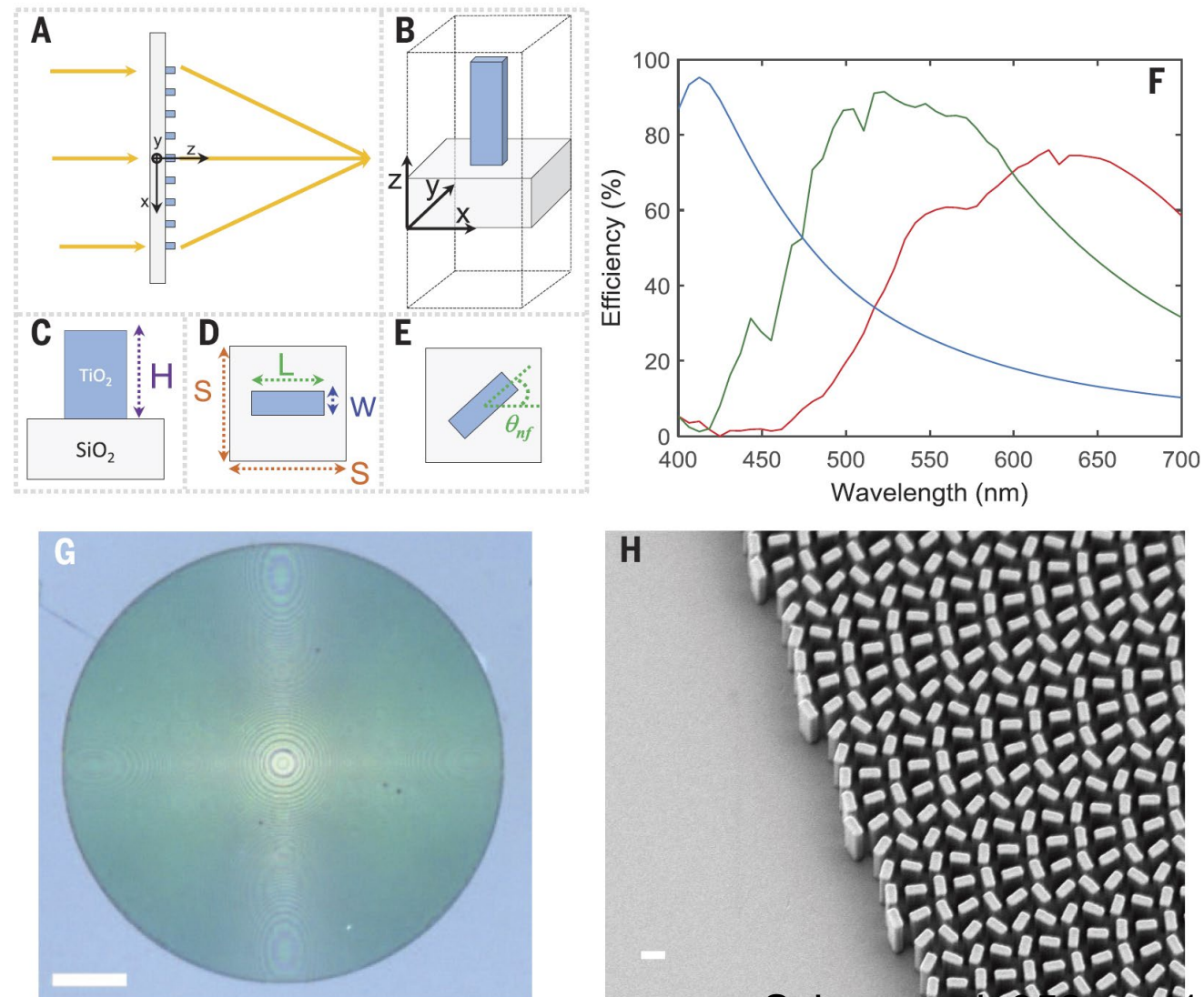
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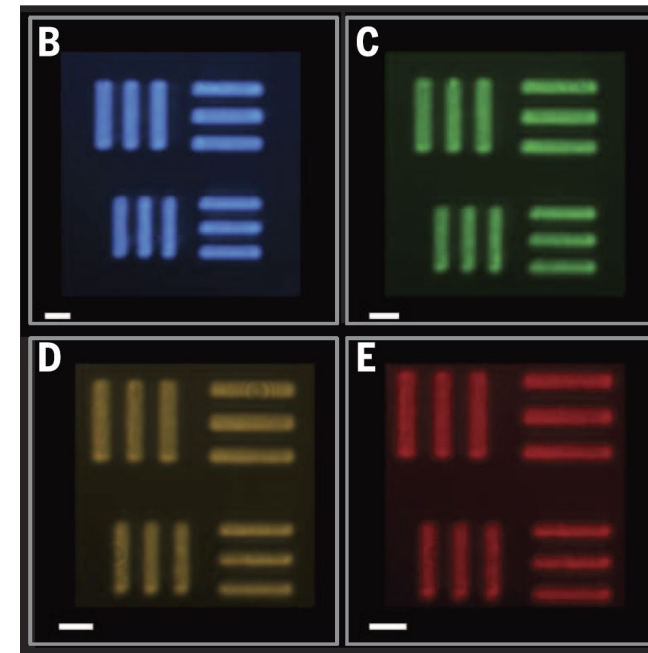
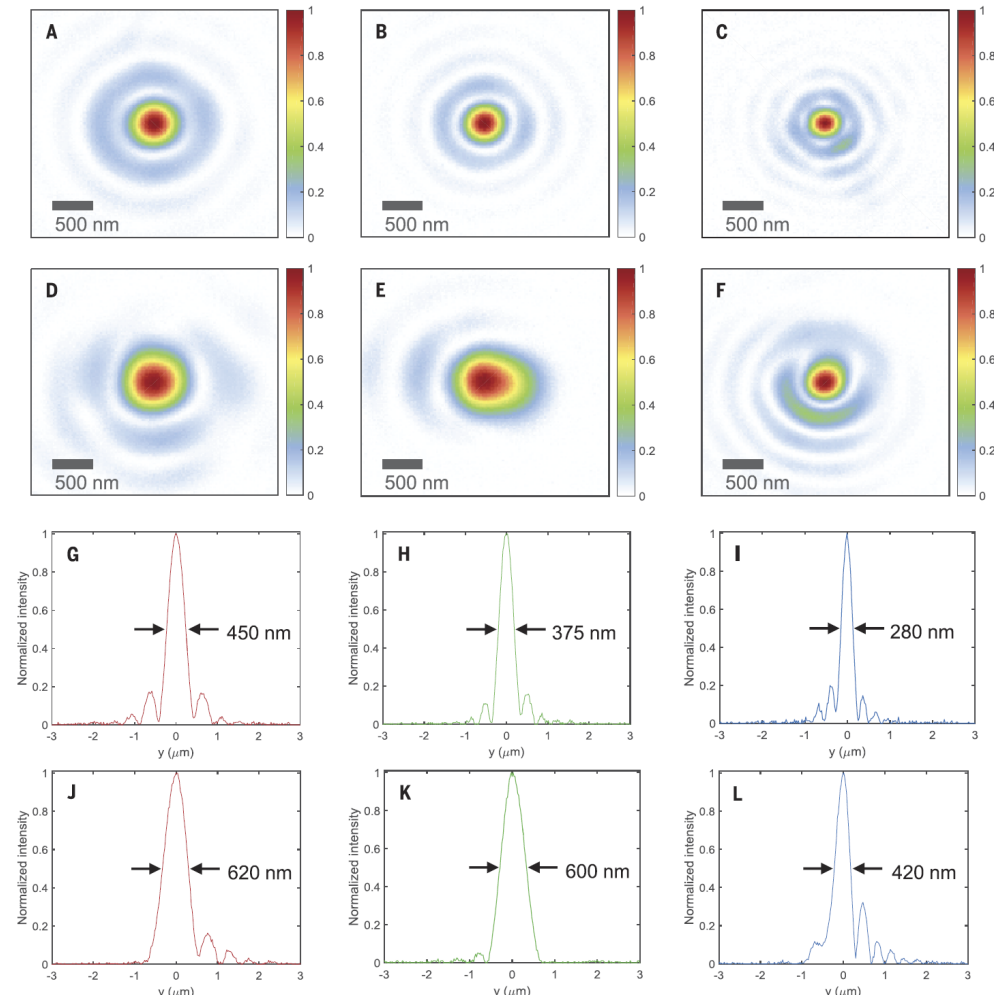
Dielectric metasurfaces

- Design based on TiO_2 nanofins, which orientation determines the phase response



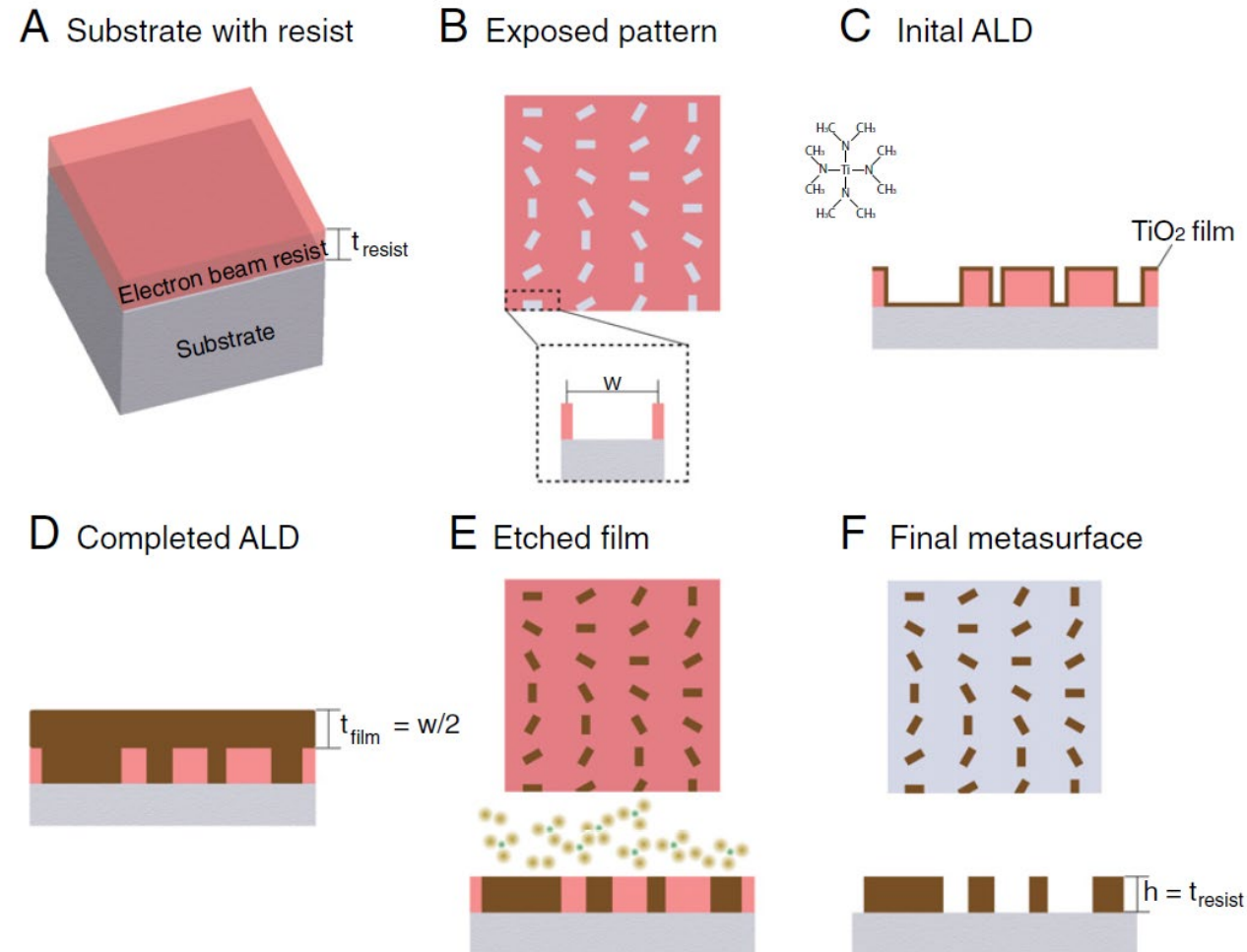
Dielectric metasurfaces

- Such a surface can be highly achromatic



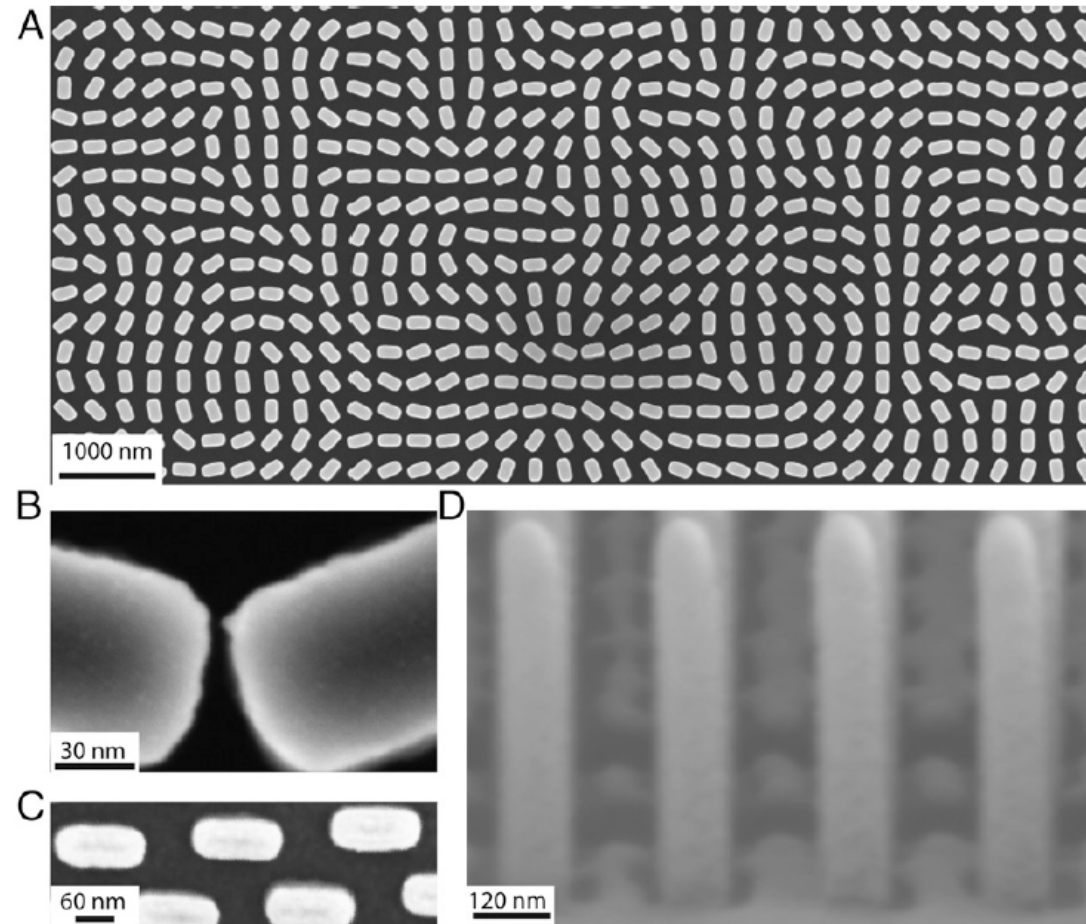
Fabrication of nanofin

- A very smooth surface is required, here fabrication in TiO_2



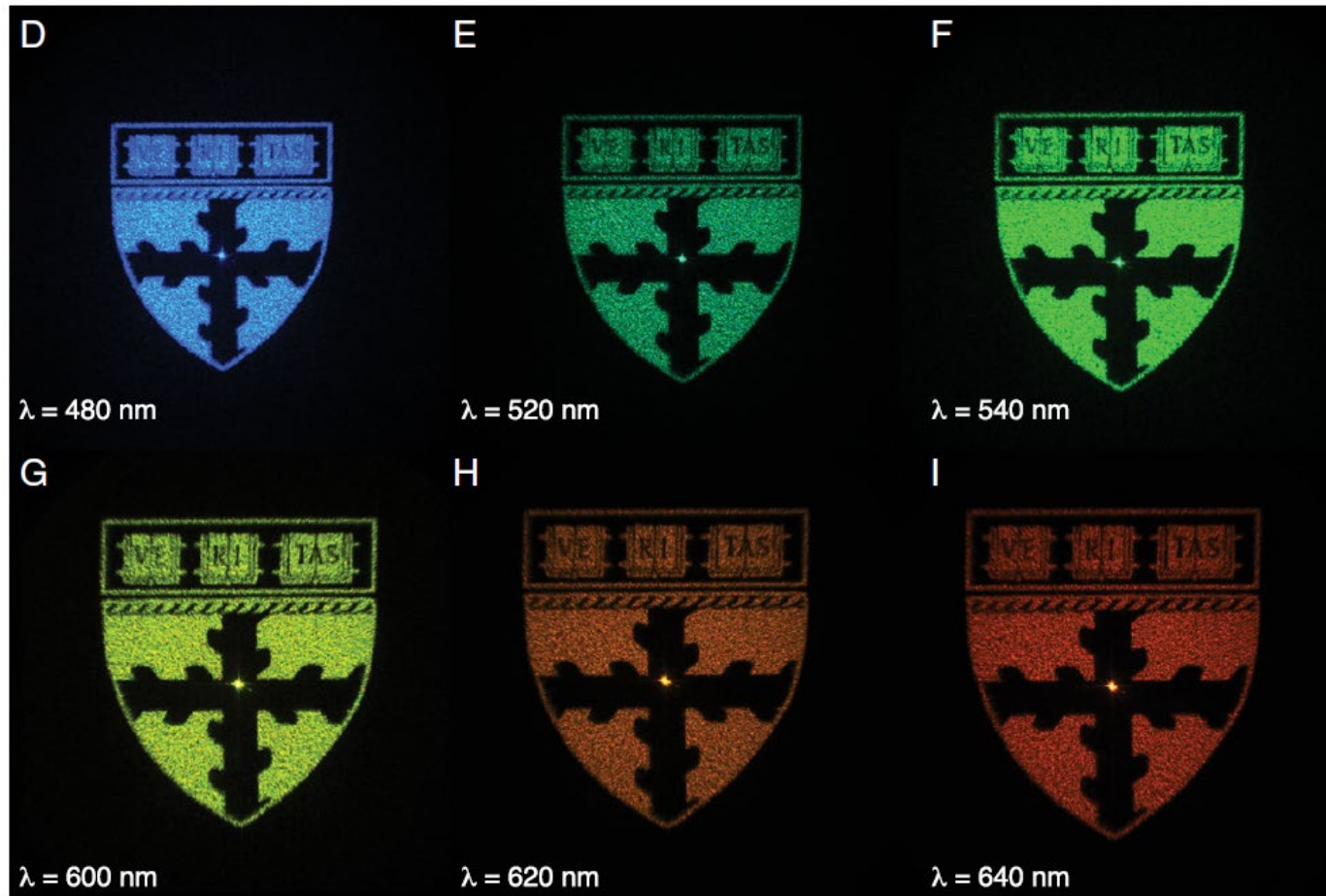
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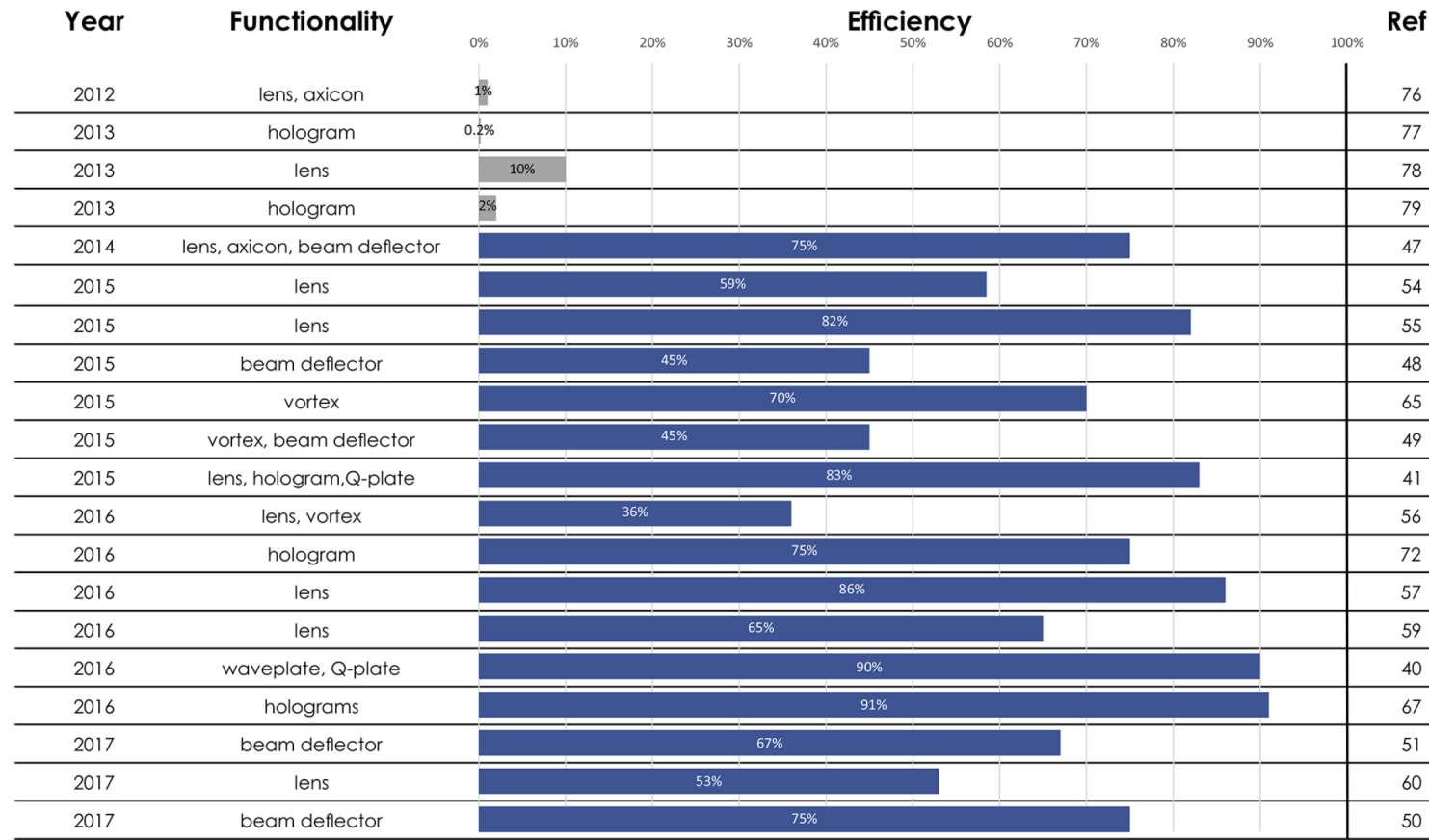
Fabrication of nanofin

- A very smooth surface is required, here fabrication in TiO_2



Metasurfaces governed by Mie resonances

- Such dielectric metasurfaces appear to have superior optical properties (at least in terms of efficiency) than plasmonic metasurfaces



ACS Photonics vol. 4, p. 2638 (2017)

Polarimetry

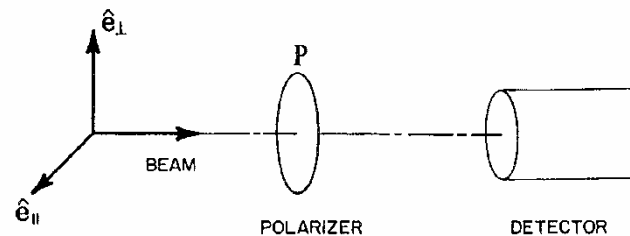
- Polarimetry provides significant information on materials, objects and their interaction with light
- The polarization of light is described by the Stokes vector, which requires four different measurements

$$S_0 = a_x^2 + a_y^2 = I = E_{\parallel} E_{\parallel}^* + E_{\perp} E_{\perp}^*$$

$$S_1 = a_x^2 - a_y^2 = Q = E_{\parallel} E_{\parallel}^* - E_{\perp} E_{\perp}^*$$

$$S_2 = 2a_x a_y \cos \varphi = U = E_{\parallel} E_{\perp}^* + E_{\perp} E_{\parallel}^*$$

$$S_3 = 2a_x a_y \sin \varphi = V = j(E_{\parallel} E_{\perp}^* - E_{\perp} E_{\parallel}^*)$$



I : irradiance

$$I^2 \geq Q^2 + U^2 + V^2 \quad \text{in general}$$

$$I^2 = Q^2 + U^2 + V^2 \quad \text{for polarized light}$$

$$Q = U = V = 0 \quad \text{for unpolarized light}$$

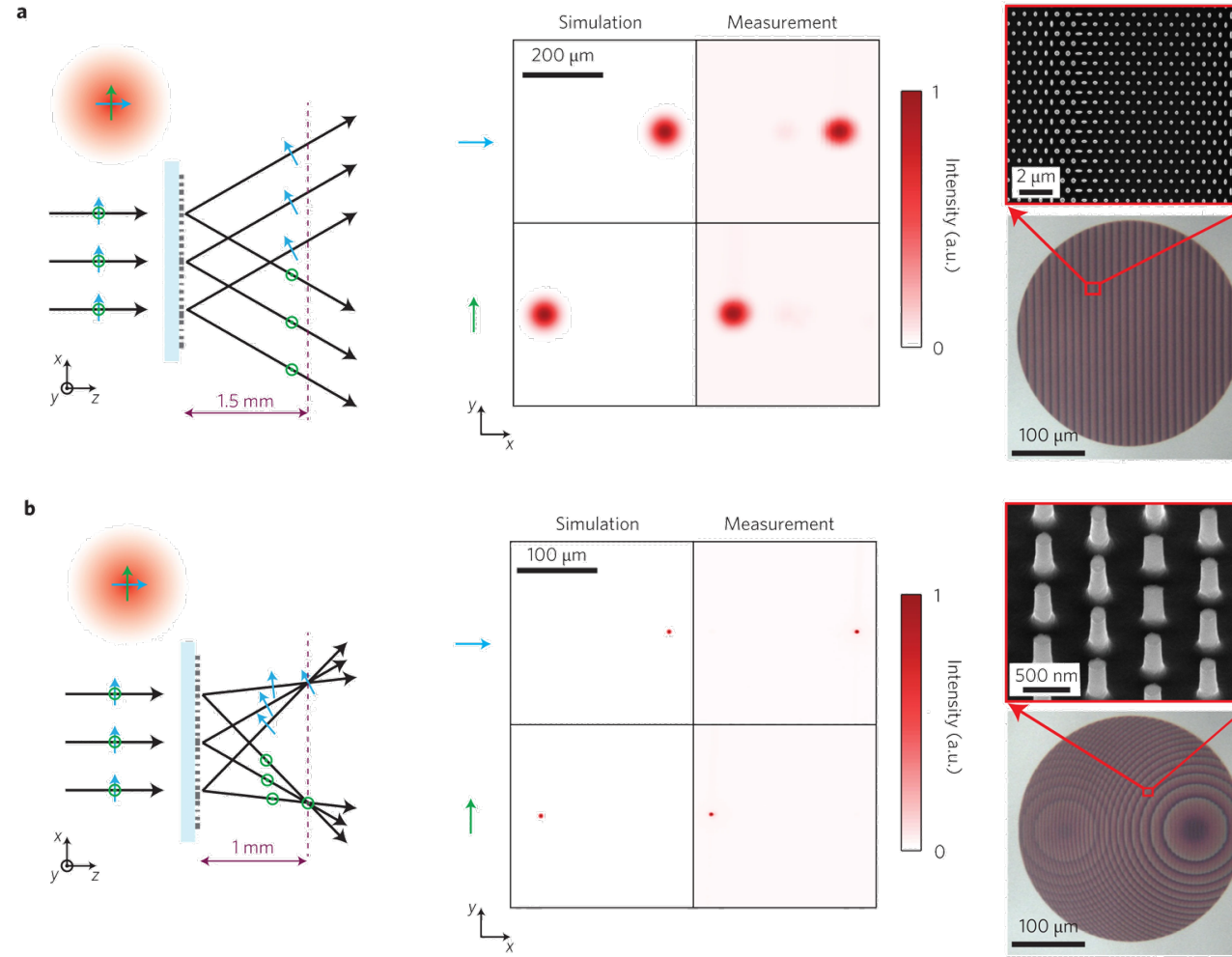
degree of polarization : $\sqrt{Q^2 + U^2 + V^2} / I$ (between 0 and 1)

degree of linear polarization : $\sqrt{Q^2 + U^2} / I$ (between 0 and 1)

degree of circular polarization : V / I (between 0 and 1)

Polarimetry

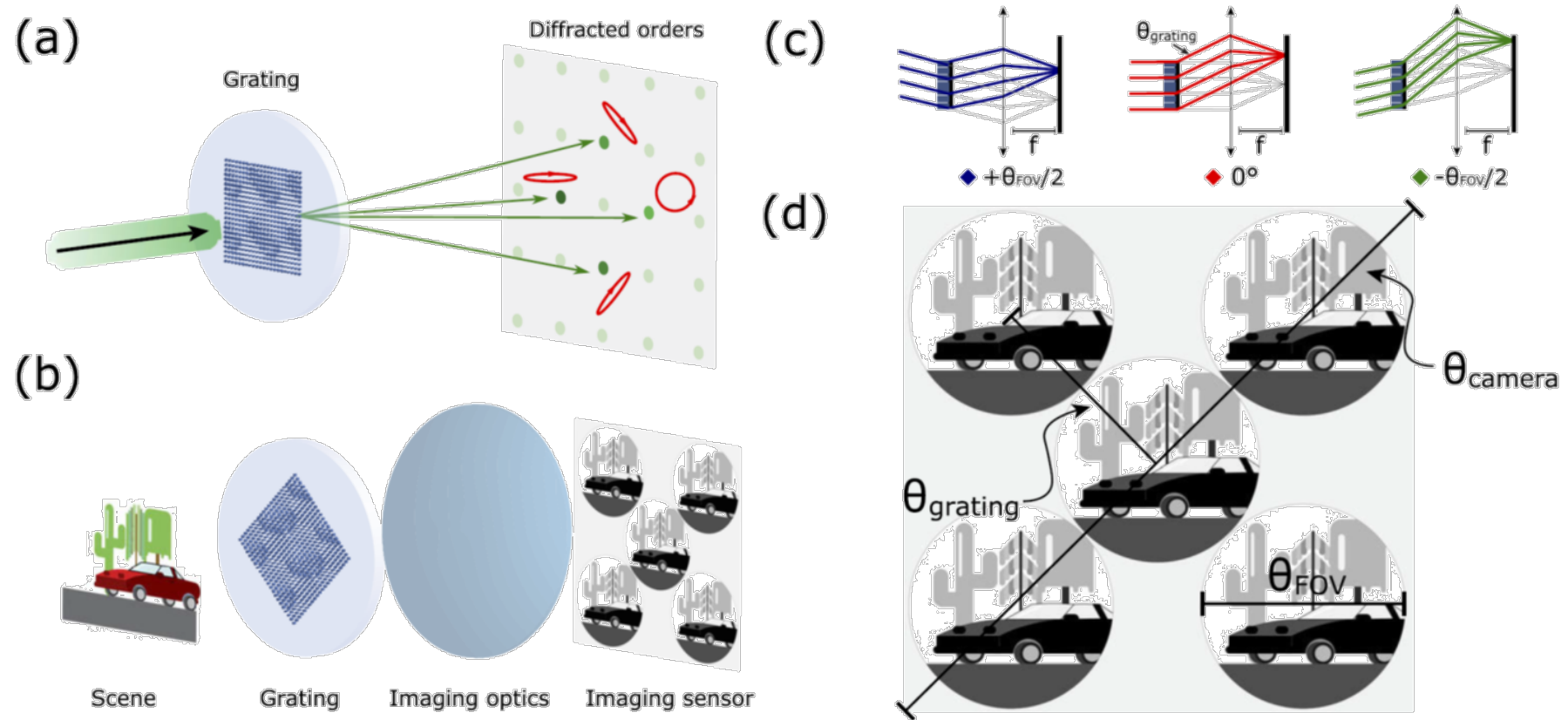
- Metasurfaces have the potential to retrieve the entire polarization state in a single measurement



Nature Nanotechnology vol. 10, p. 937 (2015)

Polarimetry

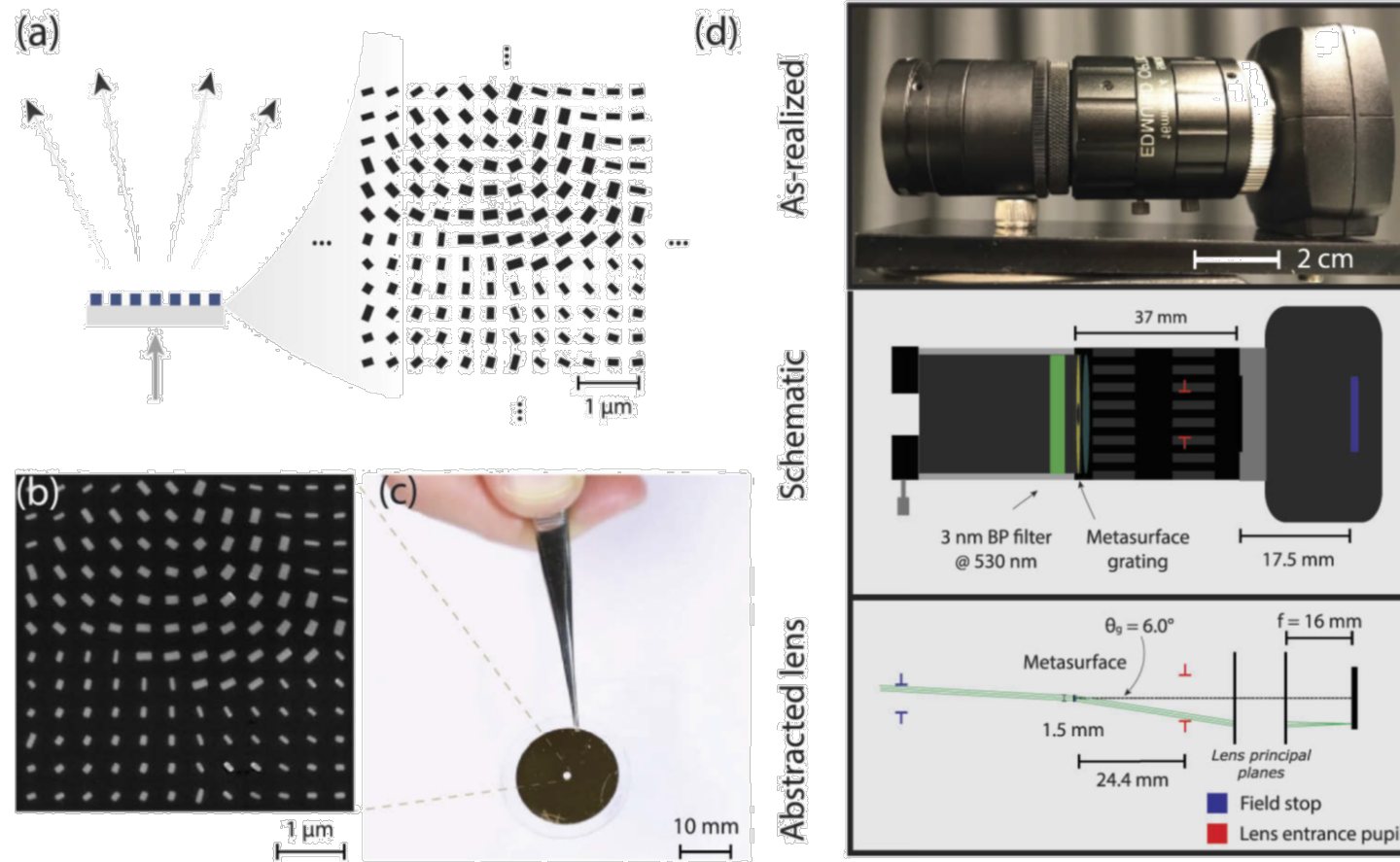
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Optics Express, vol. 30, p. 9389 (2022)

Polarimetry

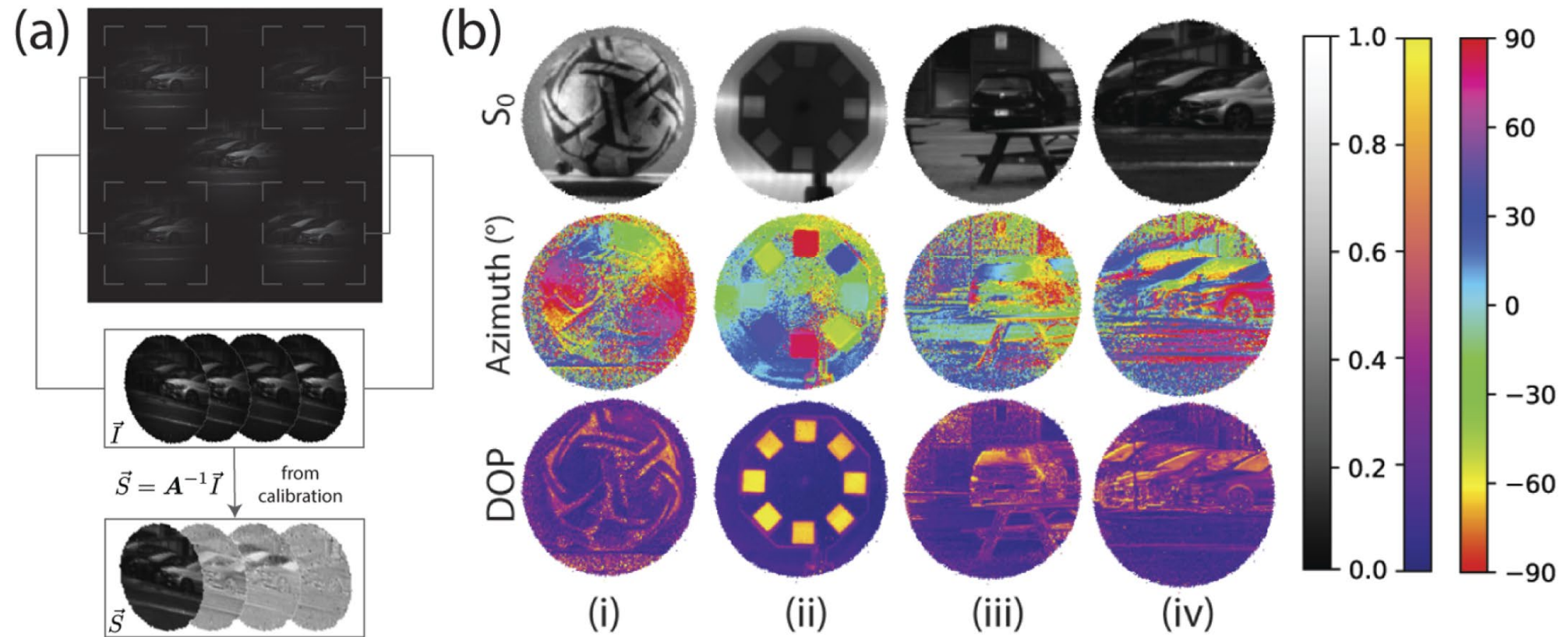
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Optics Express, vol. 30, p. 9389 (2022)

Polarimetry

- Metasurfaces have the potential to retrieve the entire polarization state in a single measurement



Optics Express, vol. 30, p. 9389 (2022)

Selected Topics in Advanced Optics

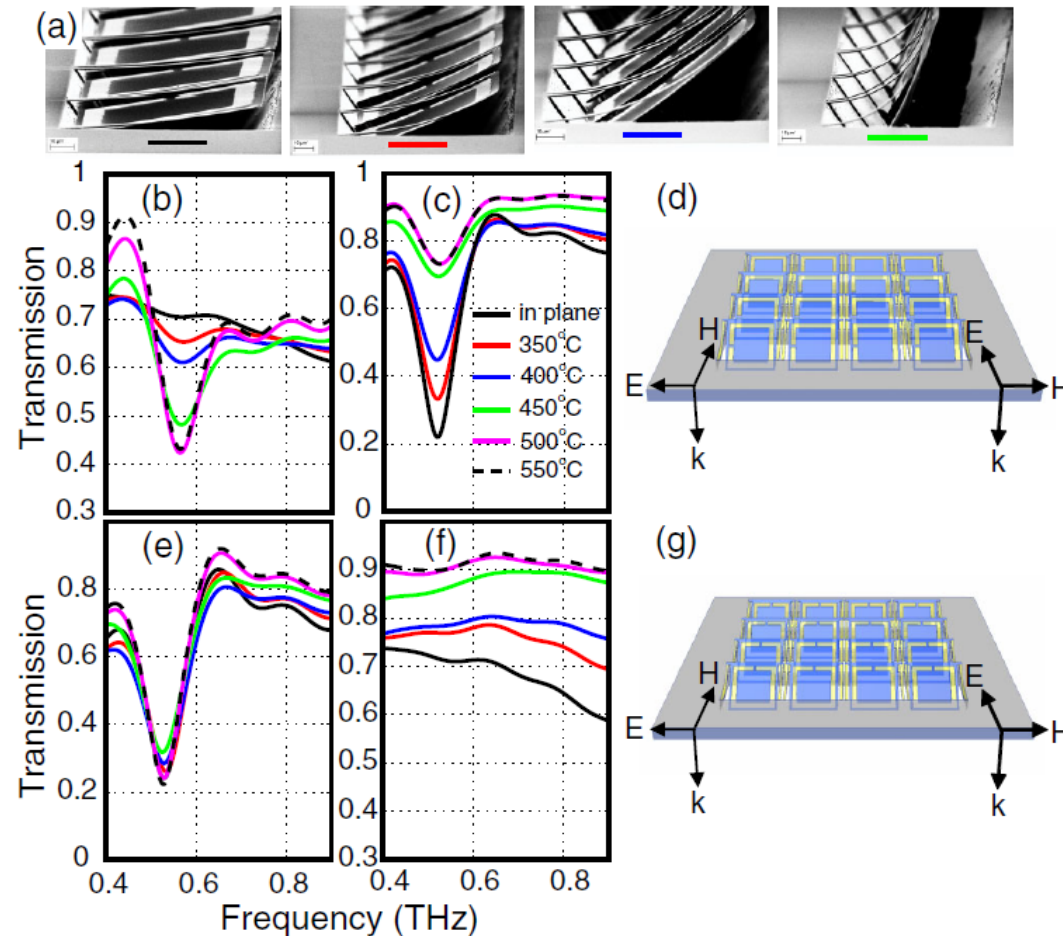
Week 13 – part 3

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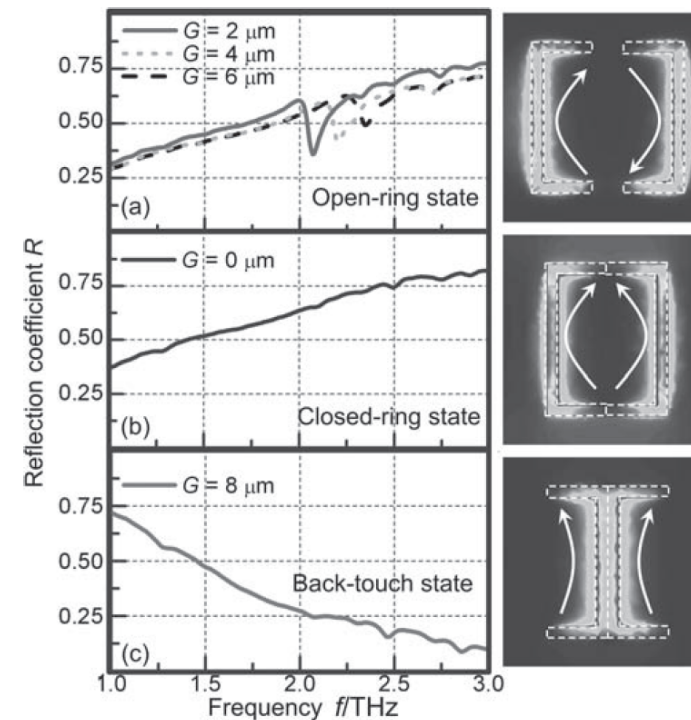
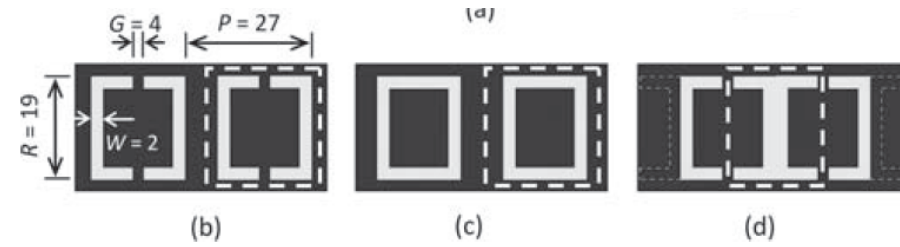
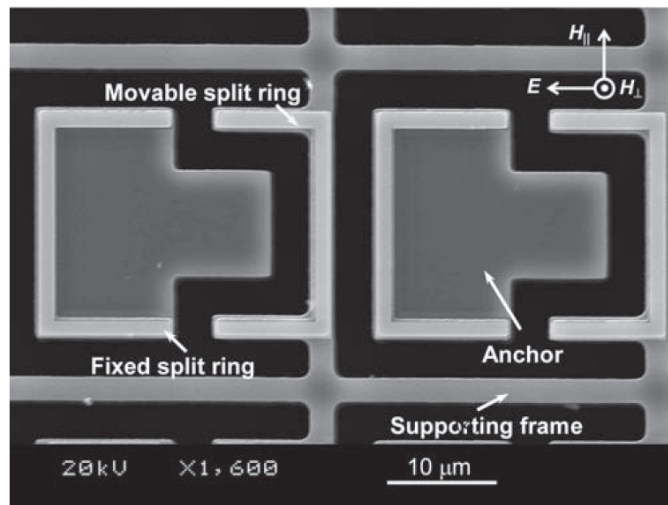
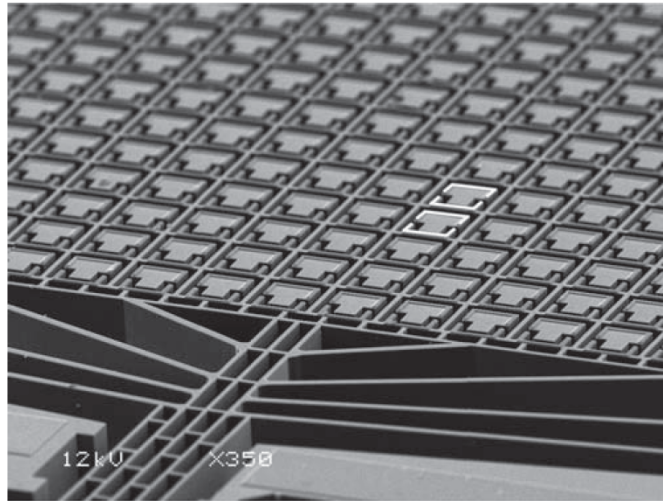
Reconfigurable metasurfaces

- Reconfigurable split-rings based on active cantilevers made from bimetaterials and responding to a thermal stimulus



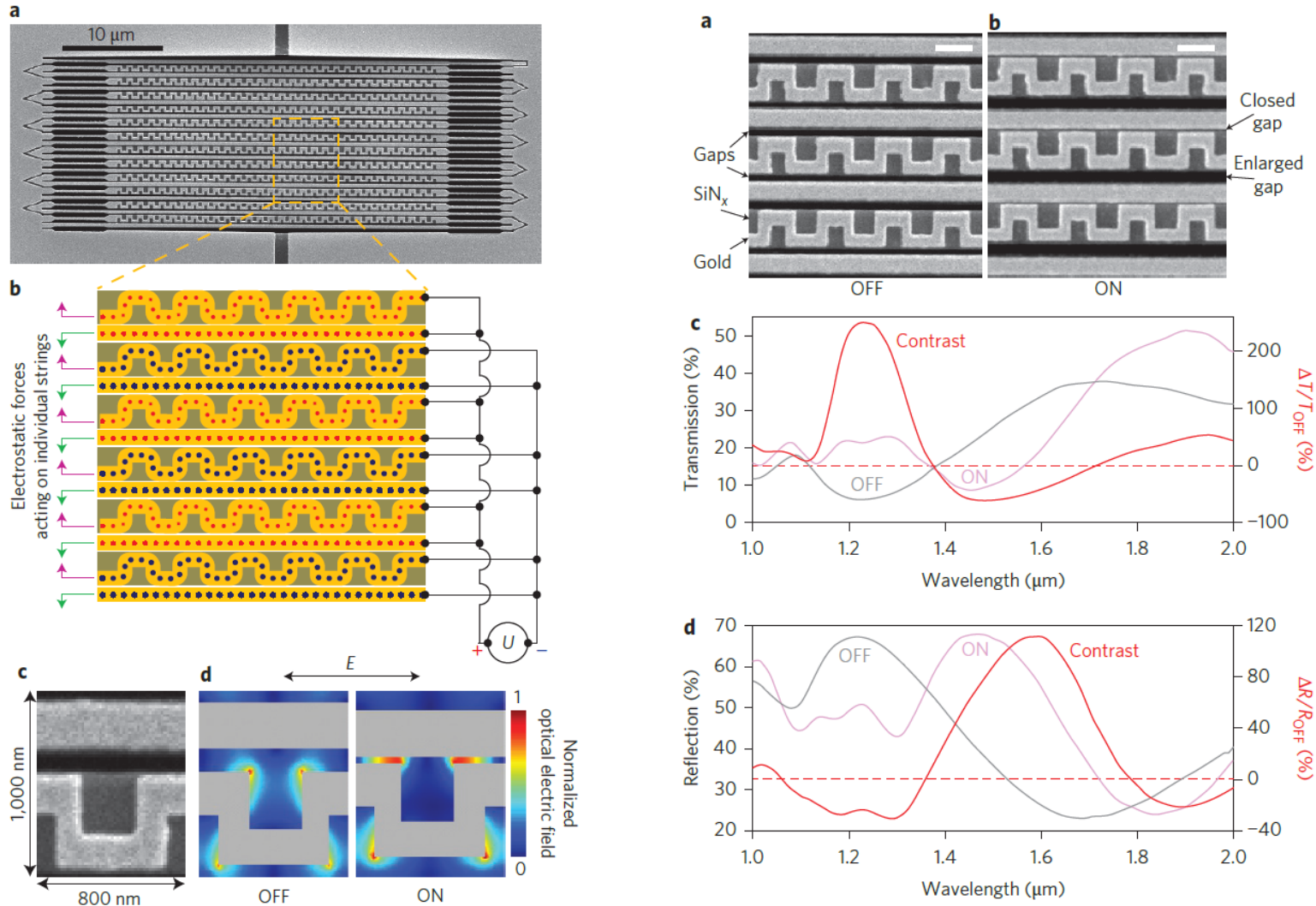
Reconfigurable metasurfaces

- Switchable magnetic metamaterials using micromachining



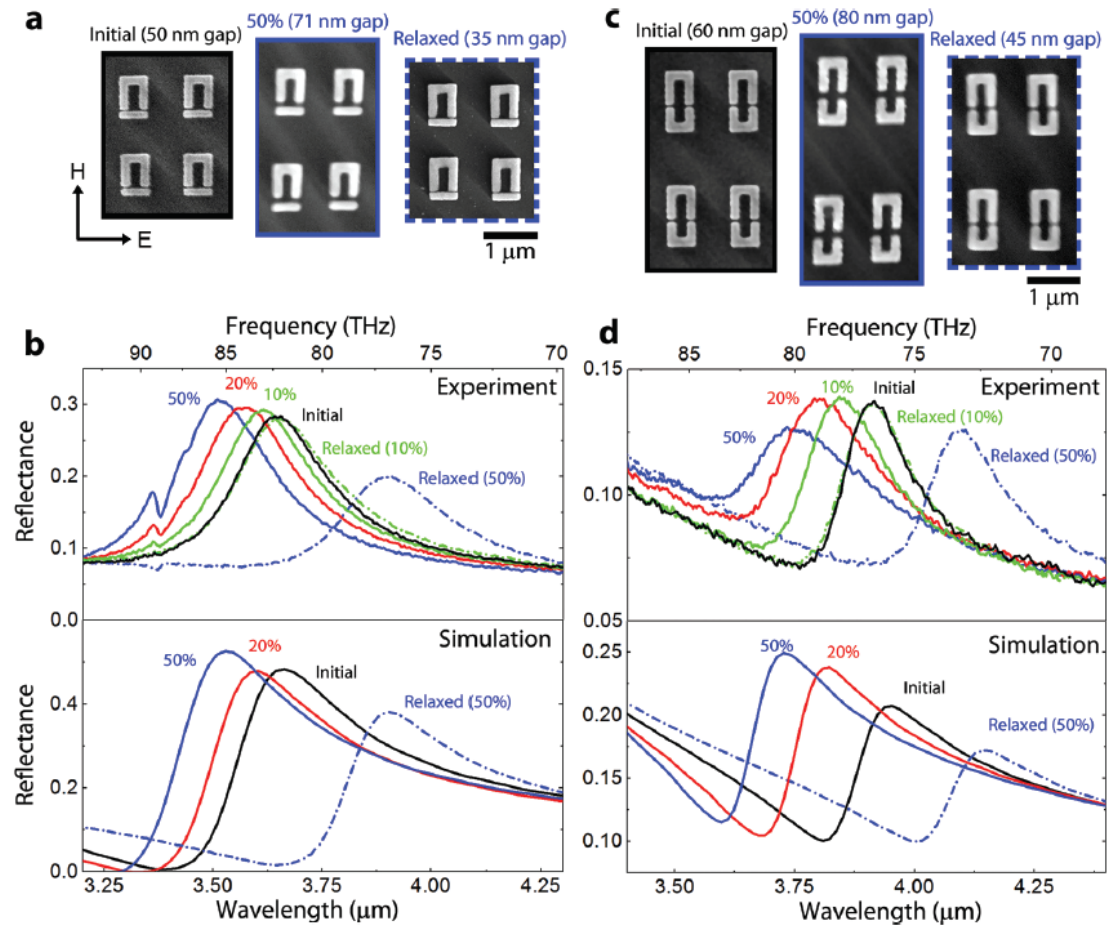
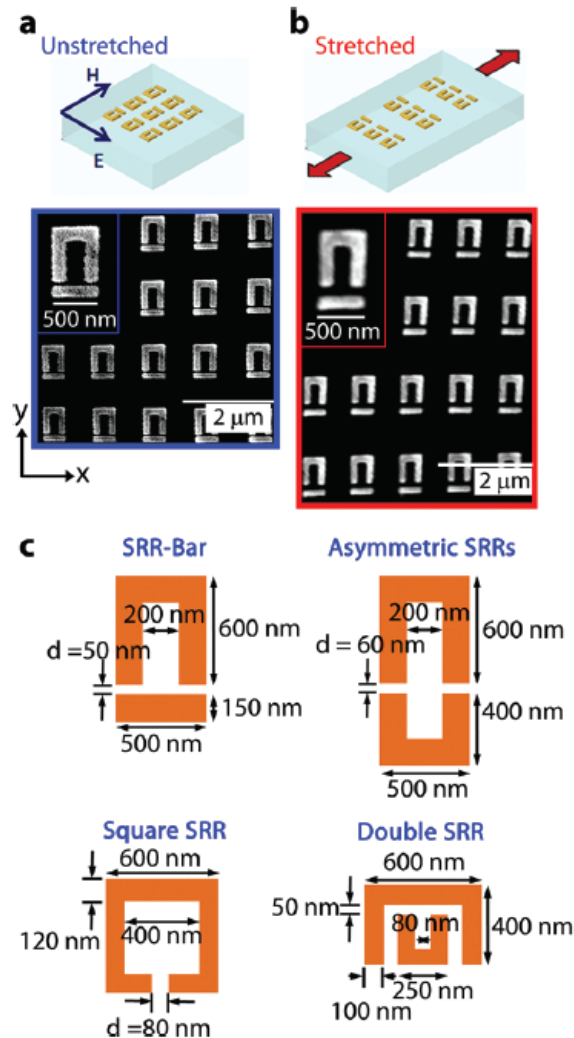
Reconfigurable metasurfaces

- An electromechanically reconfigurable plasmonic metamaterial



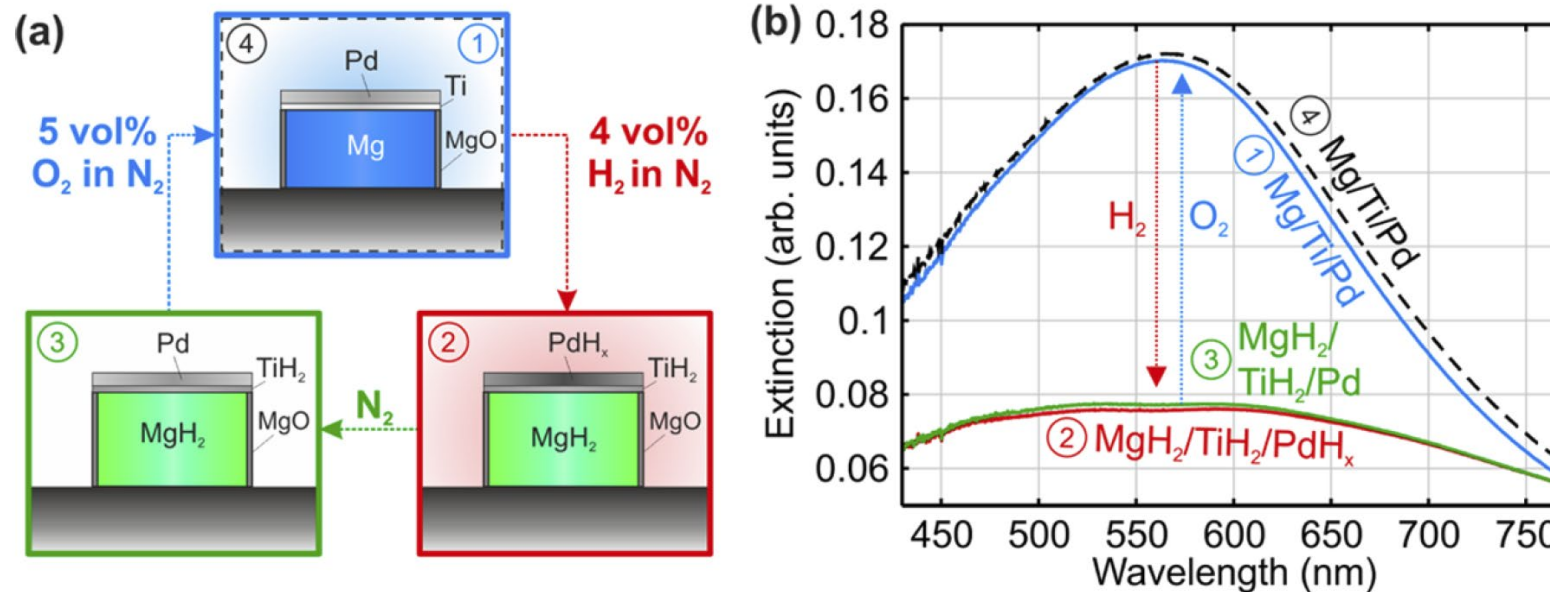
Reconfigurable metasurfaces

- Stretchable metasurface



Responsive metasurface

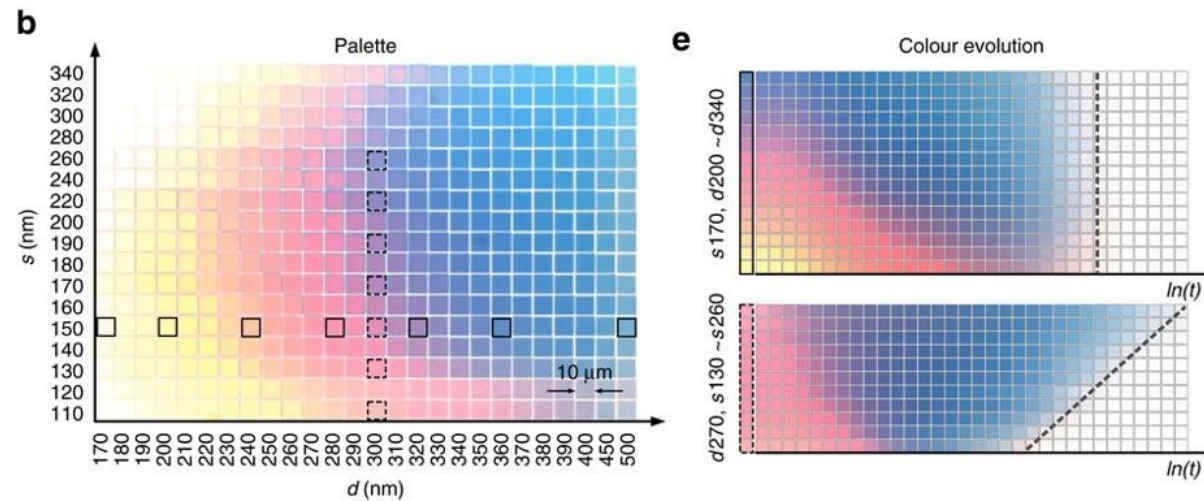
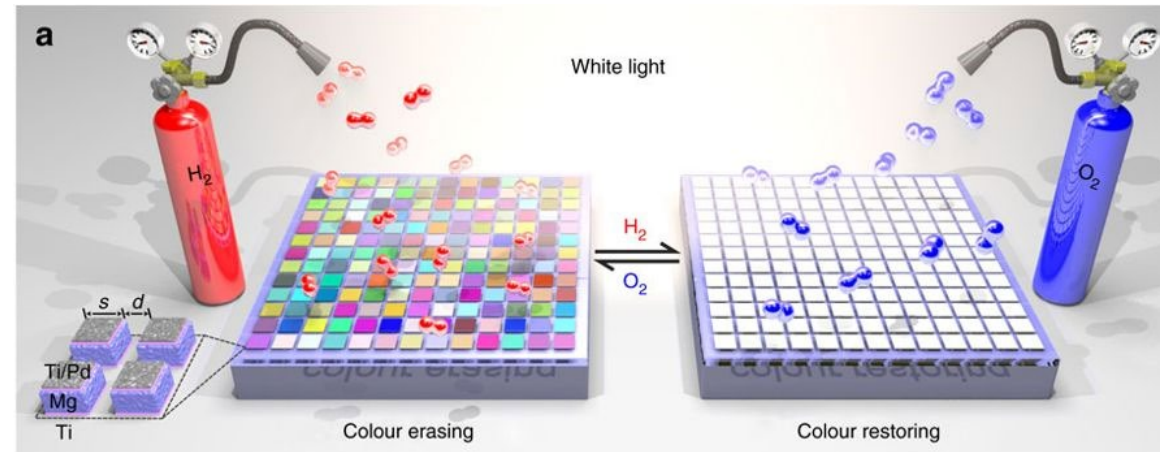
- Mg reacts to hydrogen and changes its optical response
- Switching of magnesium particles to magnesium hydride and vice versa with the aid of a 10 nm catalytic Pd layer and a 5 nm Ti buffer



Nano Letters vol. 15, p. 7949 (2015)

Responsive «metasurface» built from Mg nanostructures

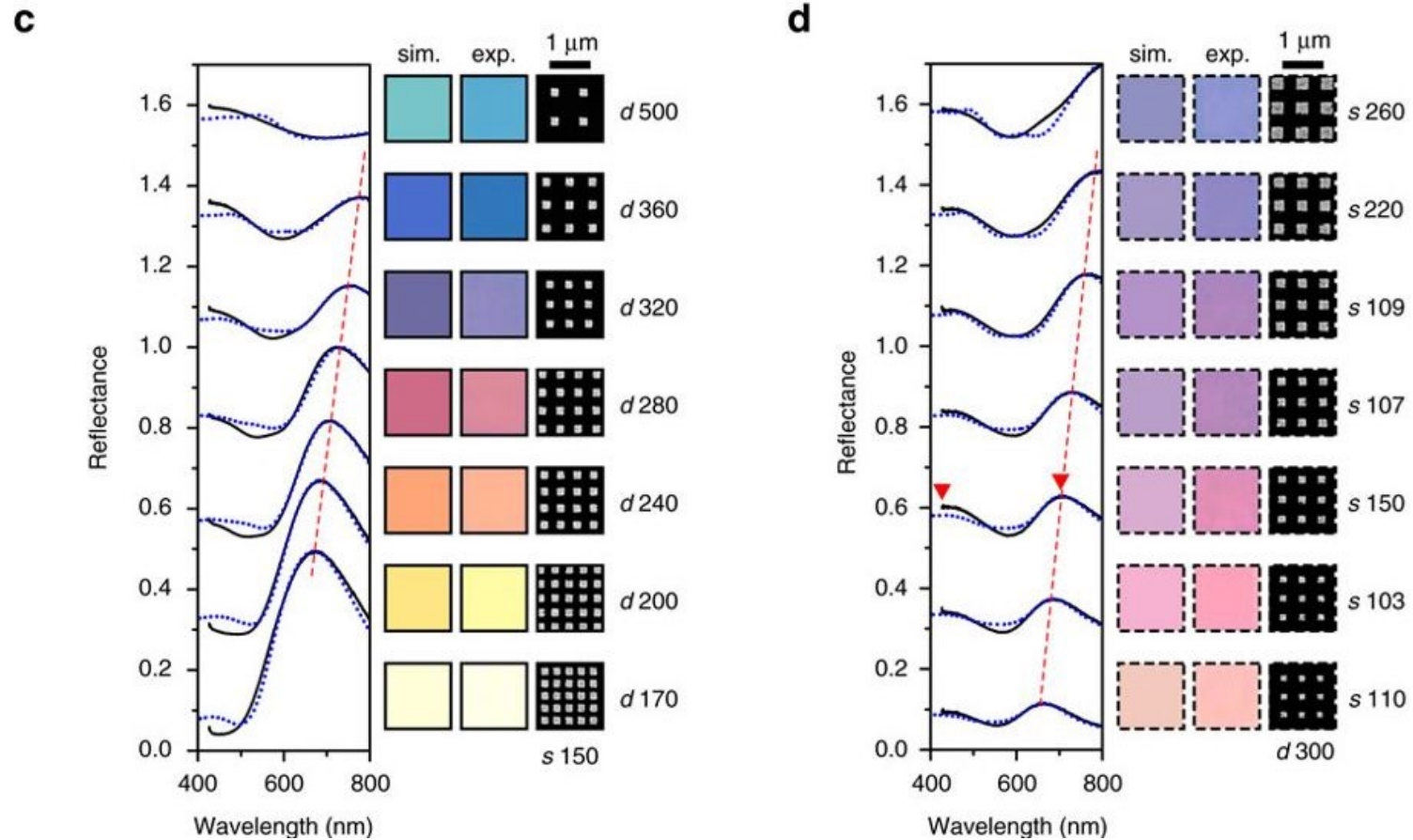
- The optical response changes with the H_2 or O_2 content



Nature Communications vol. 8, p. 14606 (2017)

Responsive «metasurface» built from Mg nanostructures

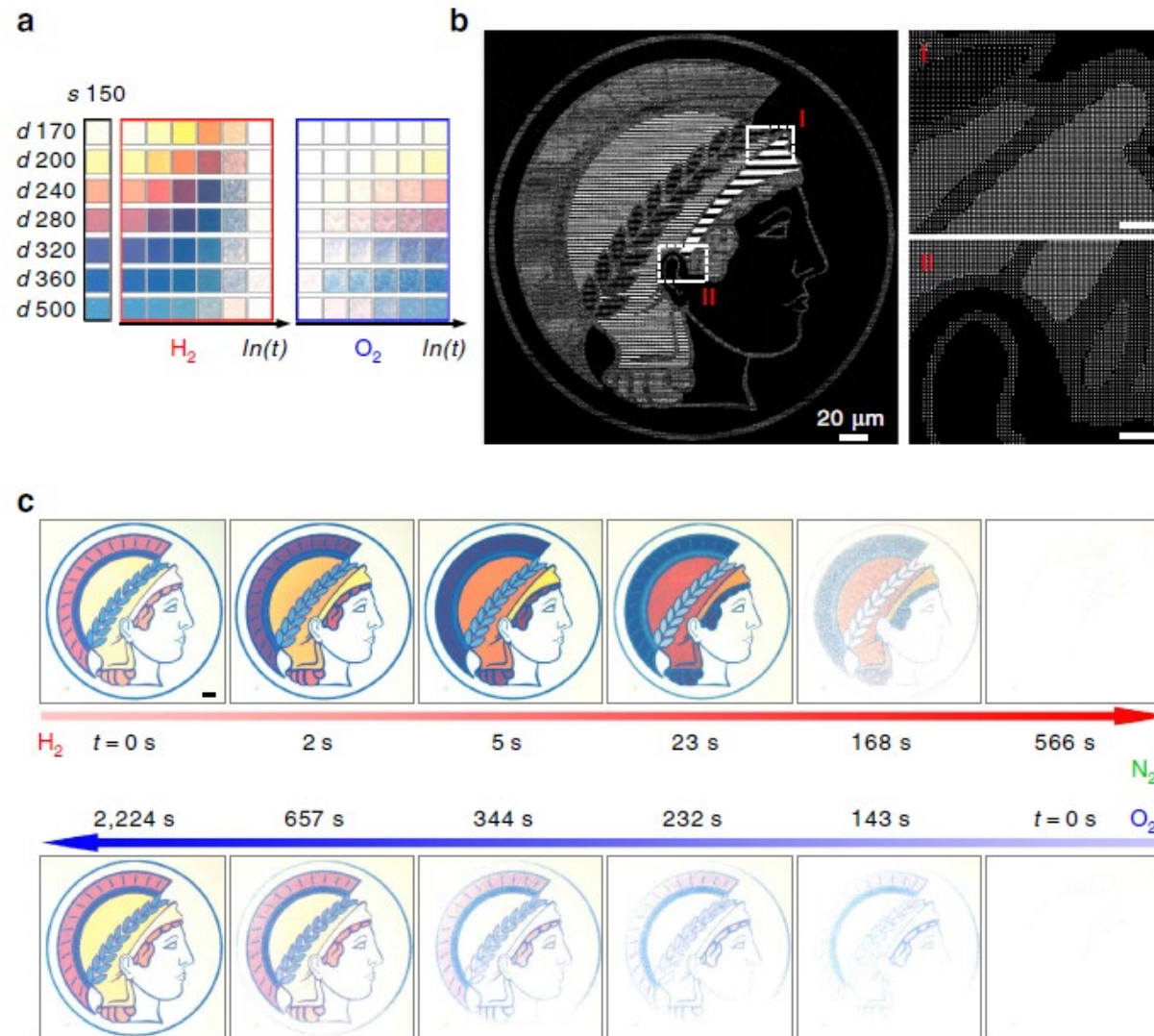
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Nature Communications vol. 8, p. 14606 (2017)

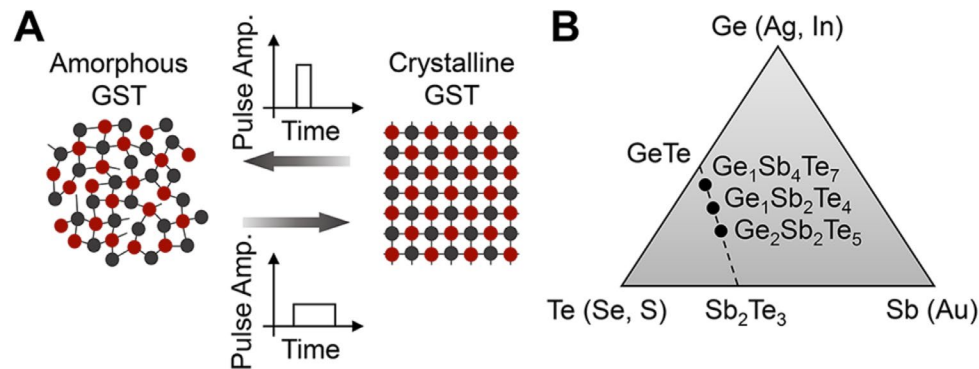
Responsive «metasurface» built from Mg nanostructures

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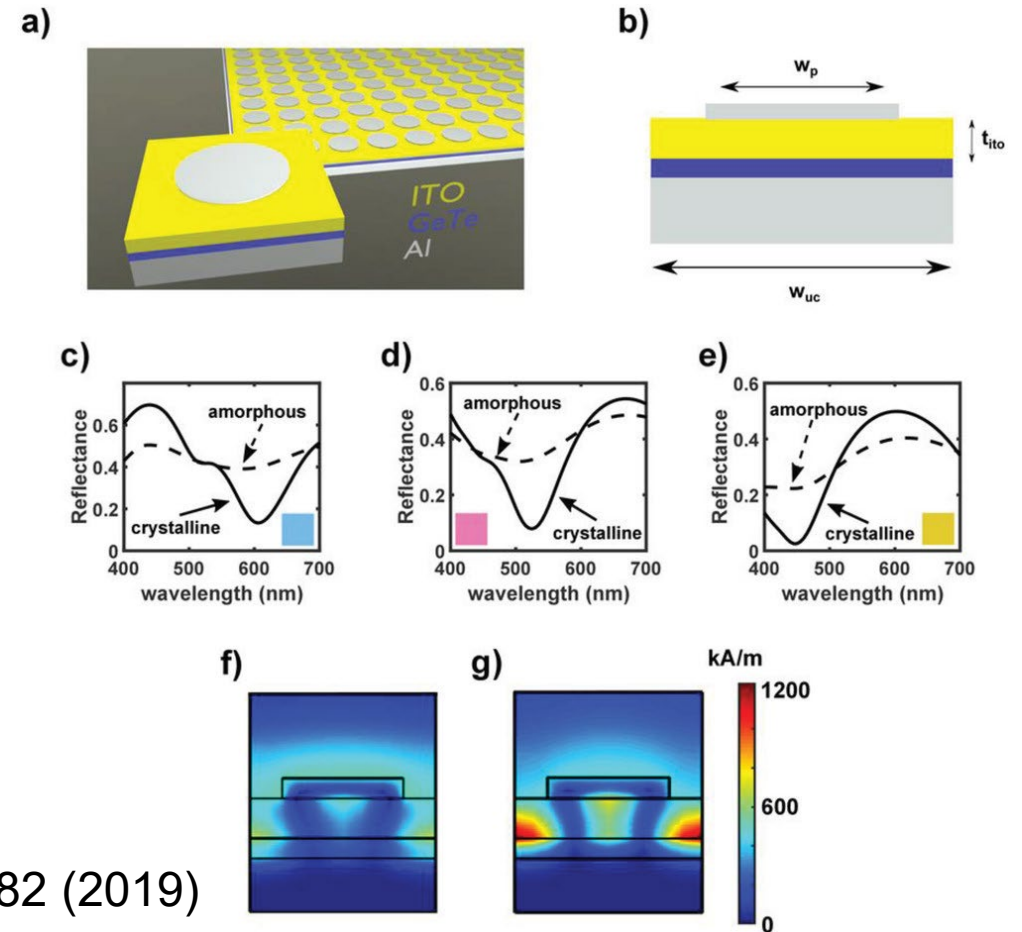


Tunable metasurfaces

- Chalcogenide phase-change materials ($\text{Ge}_2\text{Sb}_2\text{Te}_5$, GeTe , ...)
- Change from amorphous to crystalline upon temperature cycles or pulsed illumination



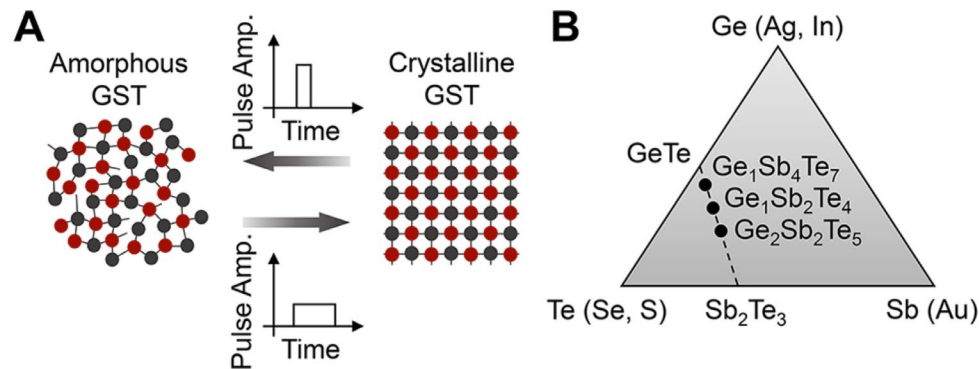
Nanophotonics vol. 9, p. 39 (2020)



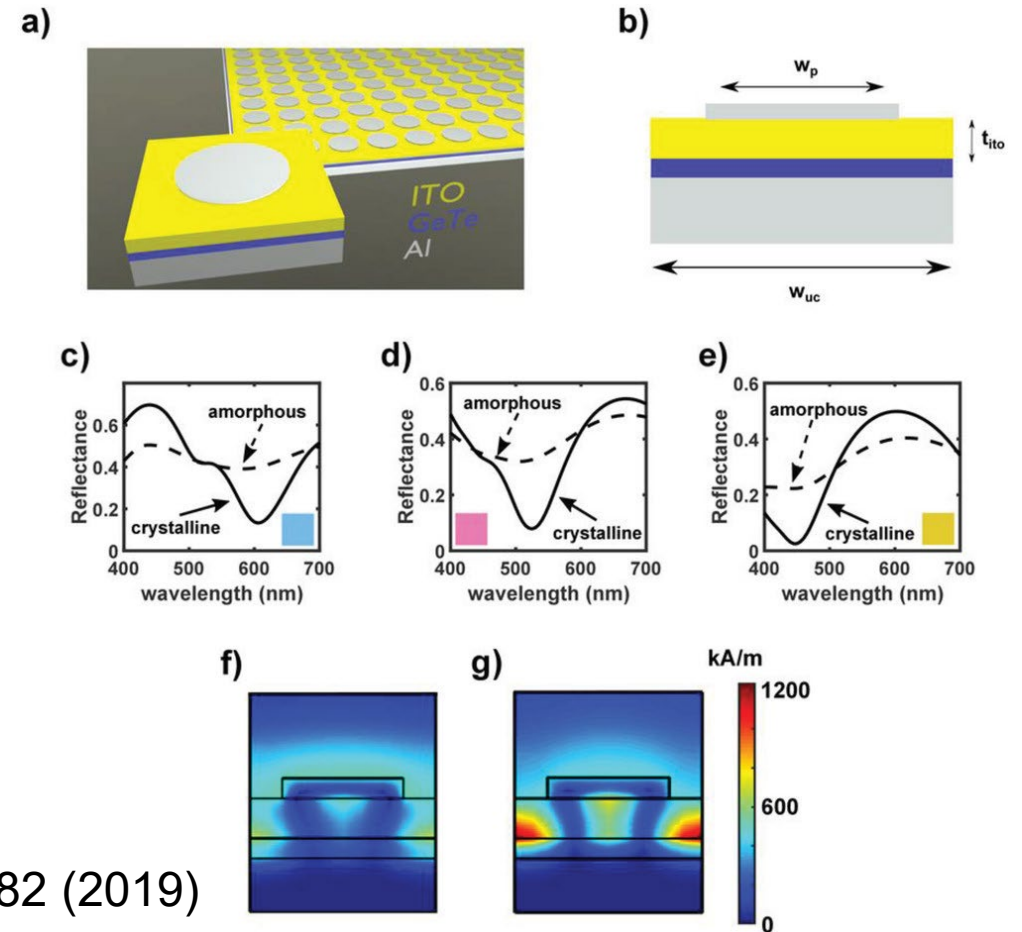
Advanced Optical Materials vol. 7, p. 1801782 (2019)

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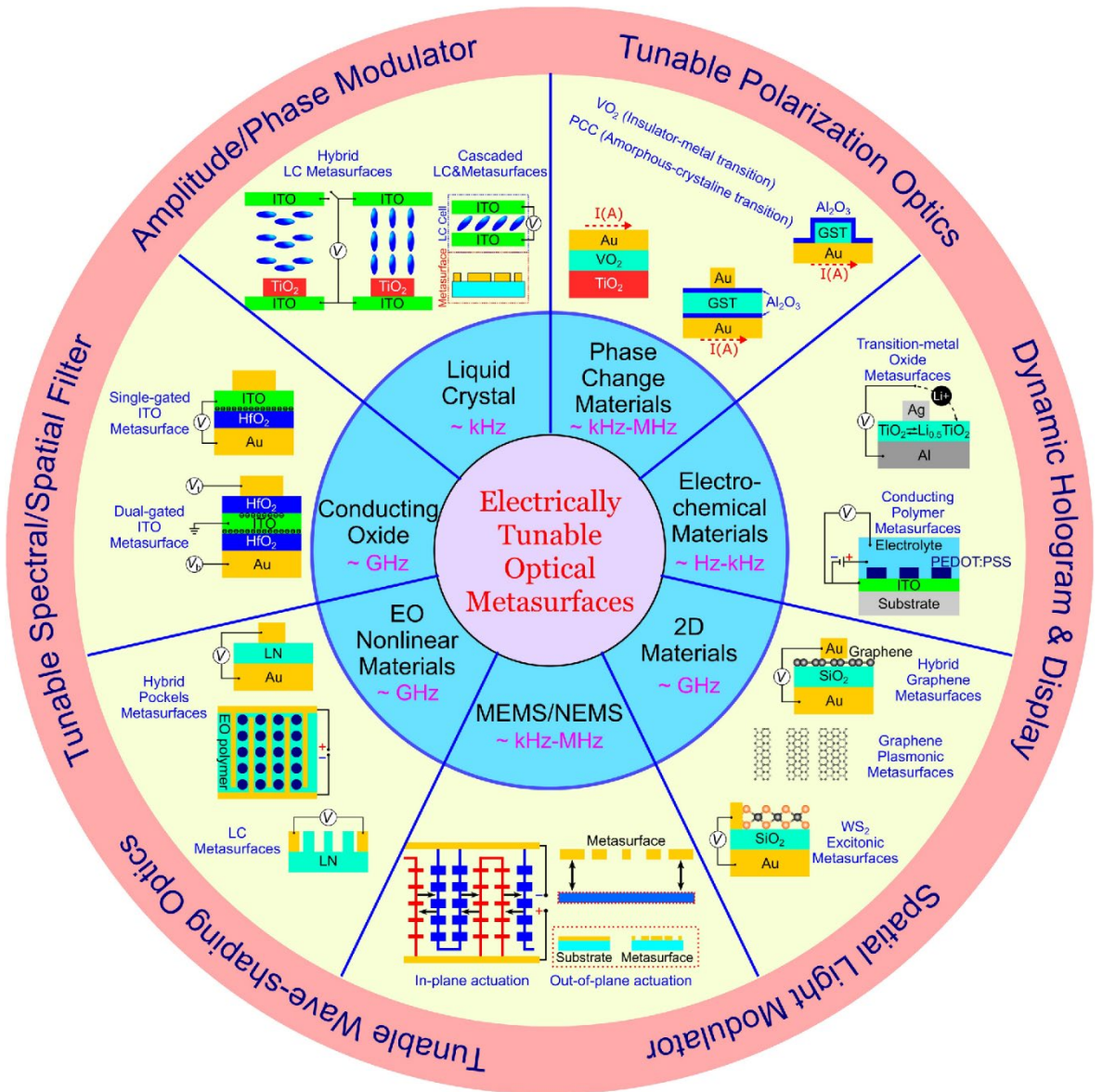
Nanophotonics vol. 9, p. 39 (2020)



Advanced Optical Materials vol. 7, p. 1801782 (2019)

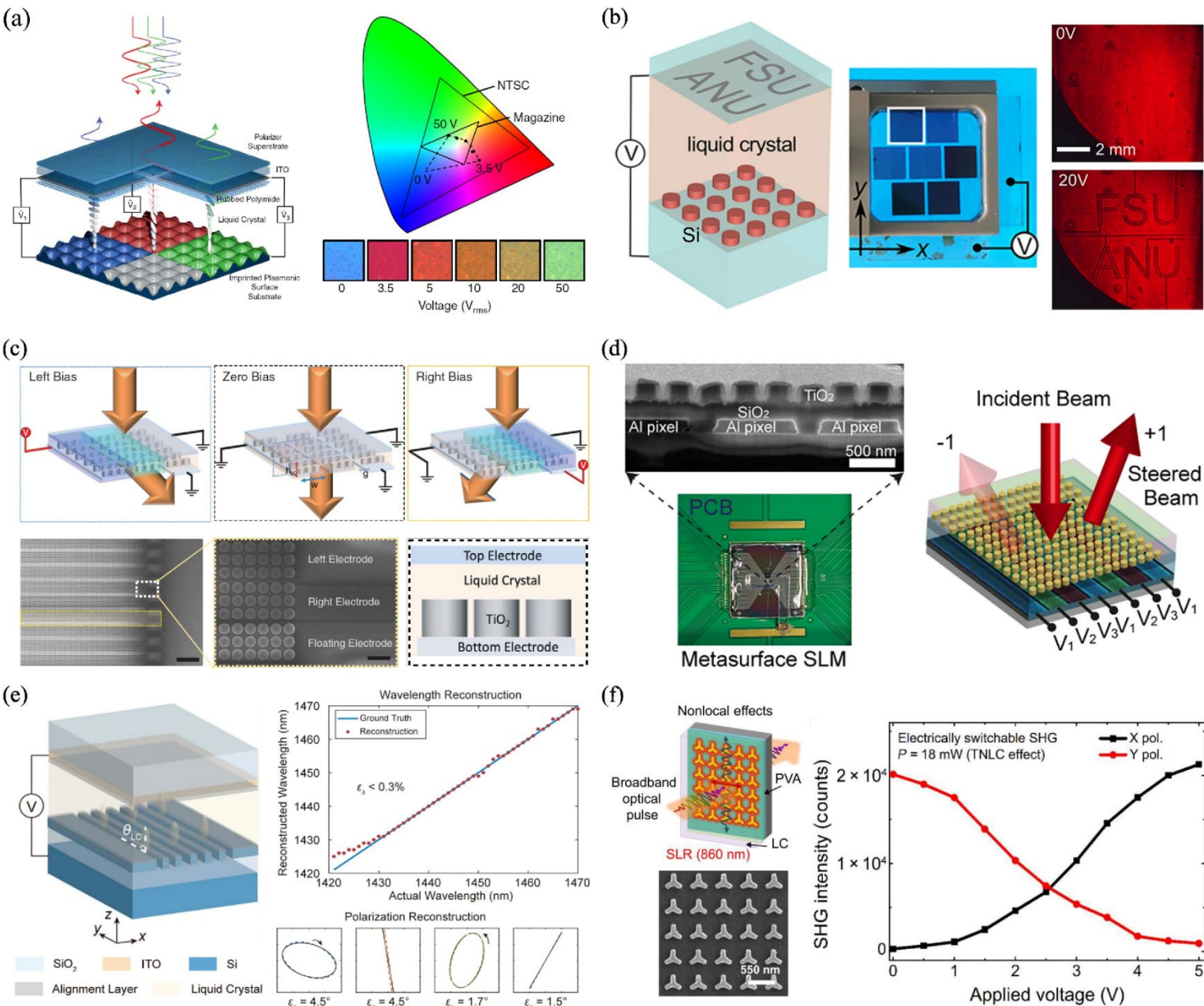
Electrically tunable metasurfaces

- Emergence of a plurality of tuning mechanism for metasurfaces, providing numerous degrees of freedom



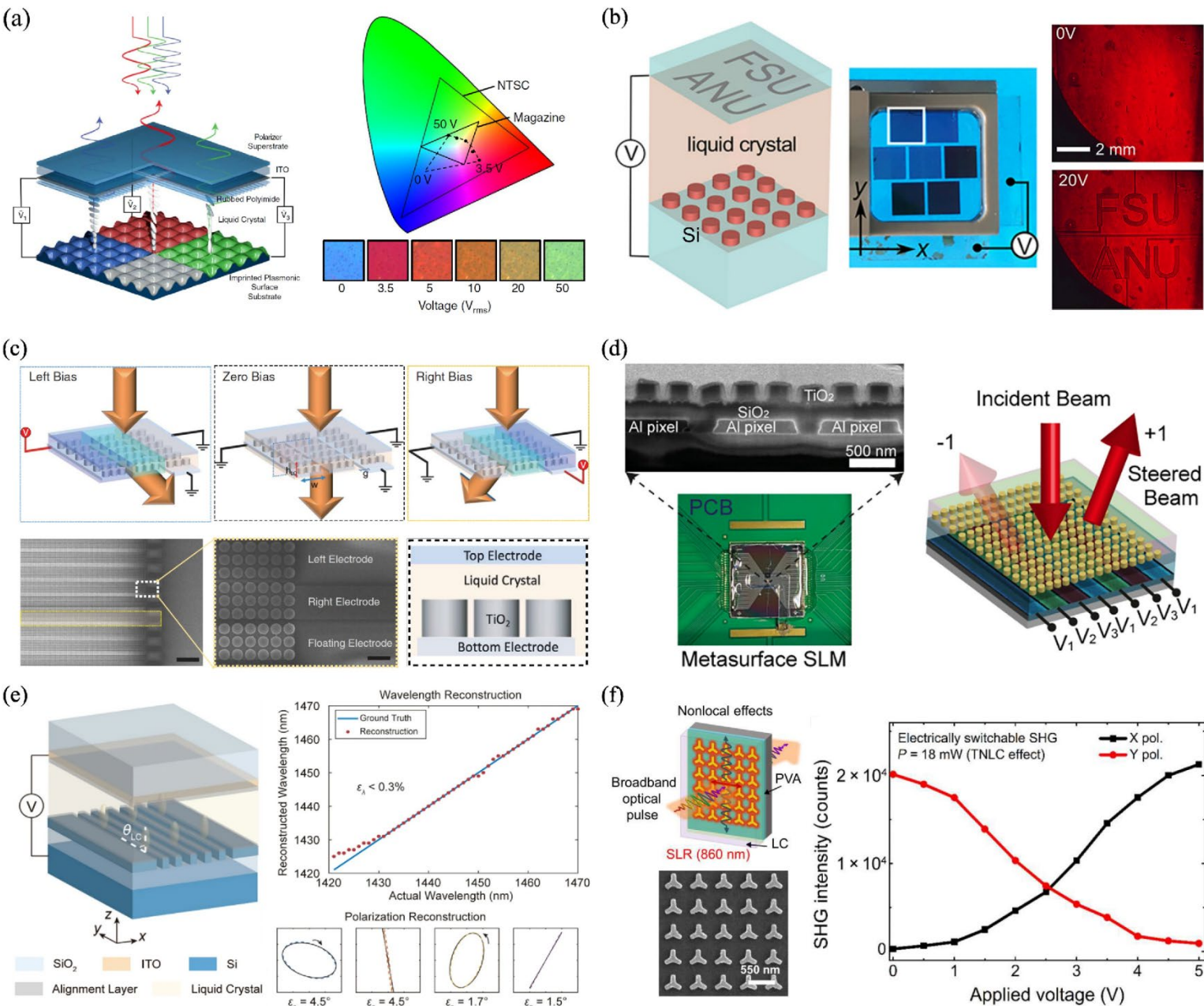
Electrically tunable metasurfaces

- Combination with liquid crystals



Electrically tunable metasurfaces

- Combination with liquid crystals

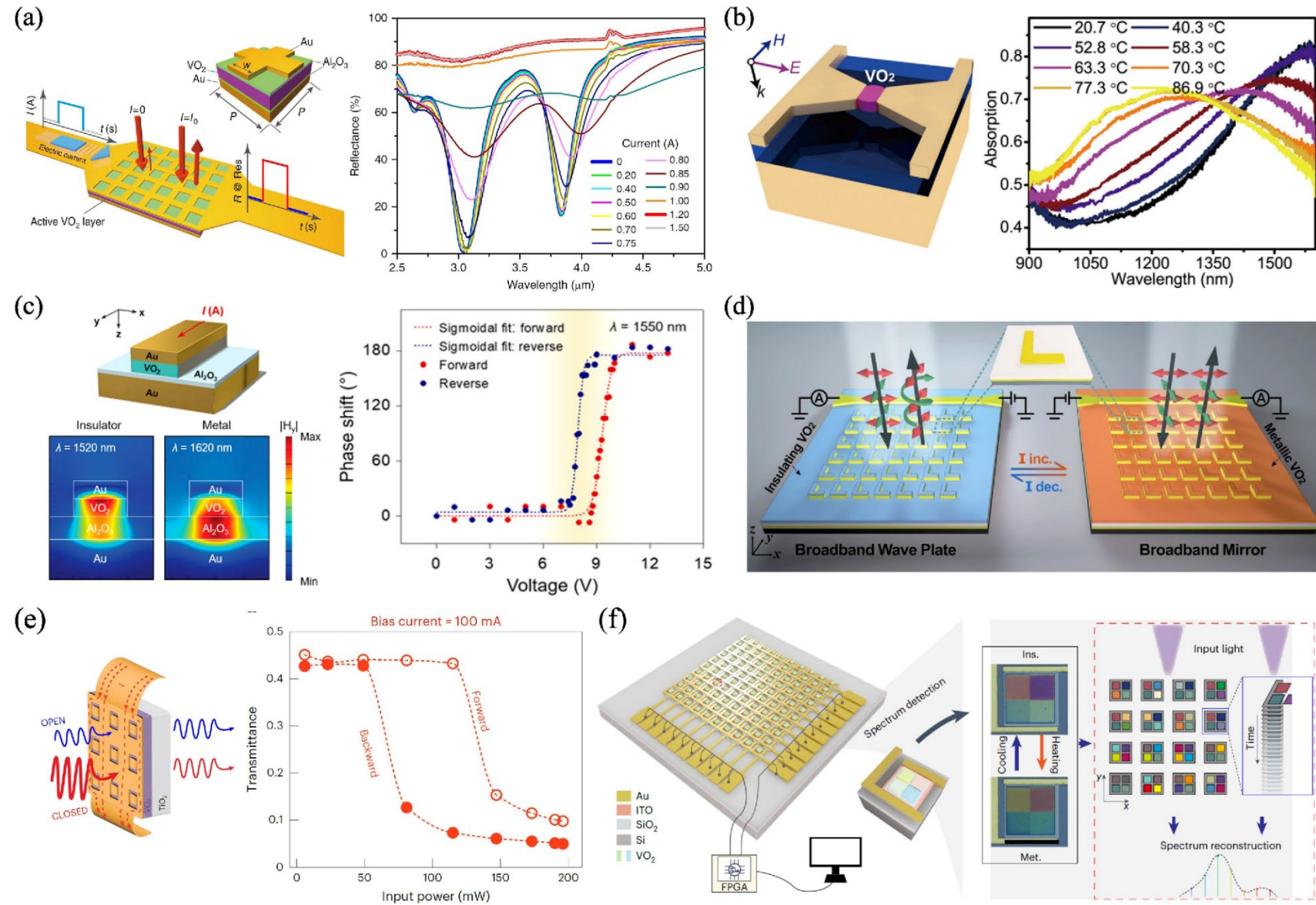


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Electrically tunable metasurfaces

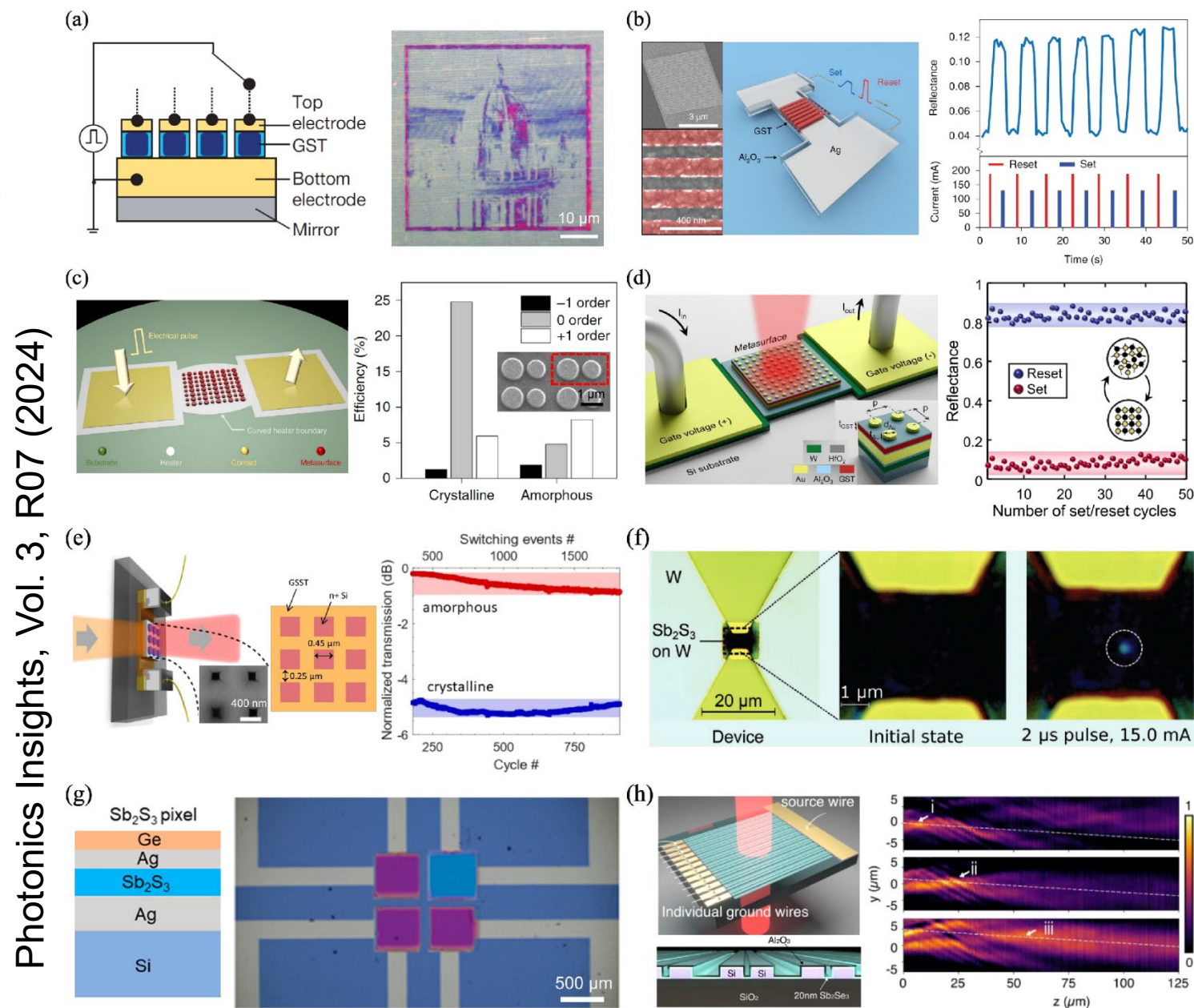
- Combination with VO₂

Photonics Insights, Vol. 3, R07 (2024)



Electrically tunable metasurfaces

- Combination with Chalcogenides



Selected Topics in Advanced Optics

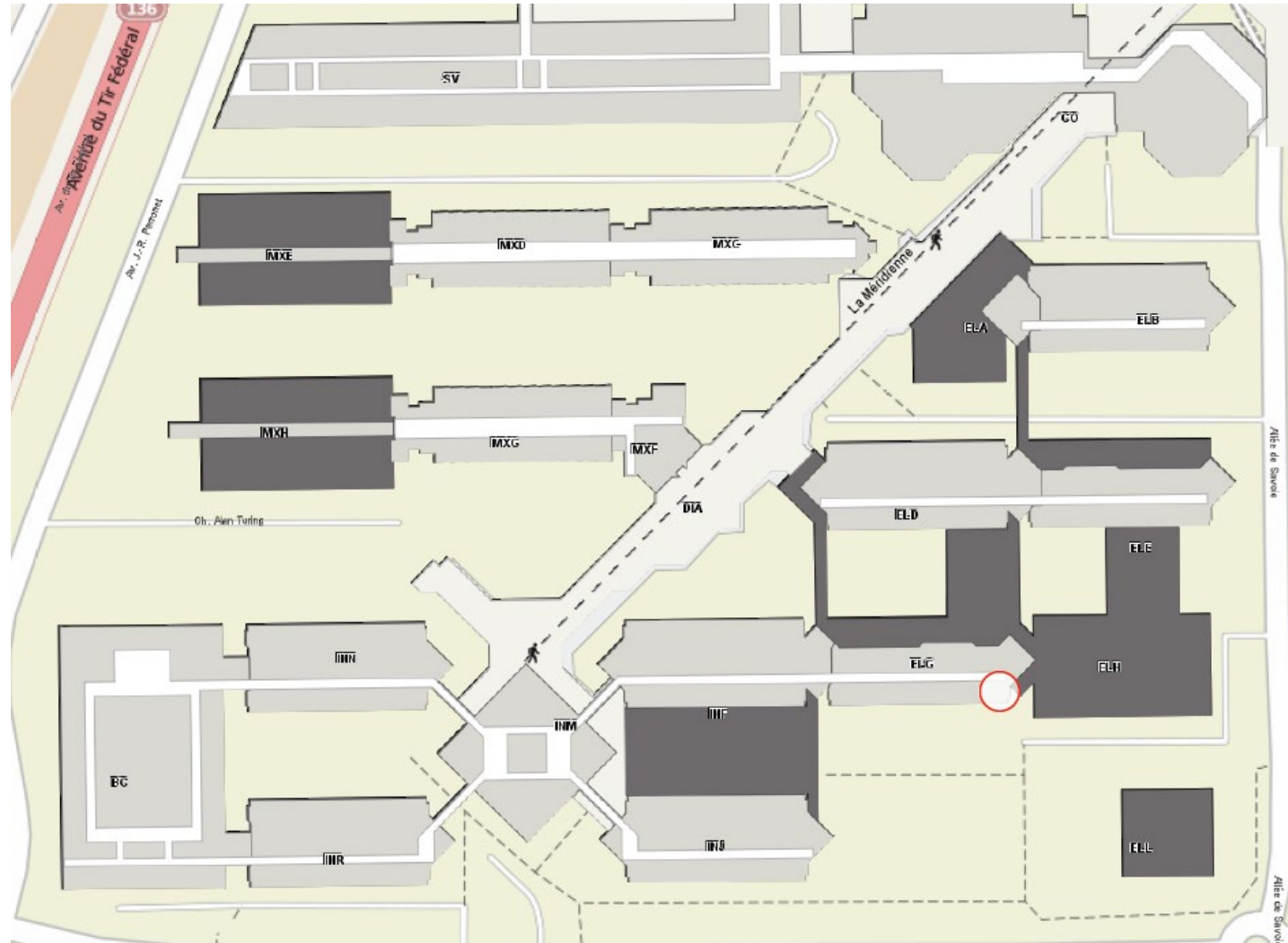
Week 13 – part 4

Olivier J.F. Martin
Nanophotonics and Metrology Laboratory



Lab visit

- Next week, meet us at 9:15 in ELG 240



Advanced Optics – Information for the exam

The examination will be conducted in the following manner:

- The candidate will enter the room, show her/his Camipro card
- The candidate will choose at random one of the following topics:
 - 1) Material properties and optical constants
 - 2) Light scattering
 - 3) Optics of metals & plasmonics
 - 4) Gratings, stratified media & photonic crystals
 - 5) Metamaterials and metasurfaces
- The candidate will then have about 20 minutes to prepare the topic with all possible documents (course, lecture notes, books, etc...)
- After this preparation time, the student will present for about 20 minutes the topic on the blackboard and answer questions. The entire material seen during the course and the exercises can be tested during the examination

Please select your time slot for the exam on moodle!