TMOS
ARC CENTRE OF EXCELLENCE FOR
TRANSFORMATIVE META-OPTICAL SYSTEMS

Tuning of Metasurfaces in Three Dimensions

Yana Izdebskaya

In collaboration with:

Z. Yang, V. Shvedov, A. Komar, M. Liu, D. N. Neshev, and I.V. Shadrivov

ARC Centre of Excellence for Transformative Meta-Optical Systems (TMOS)

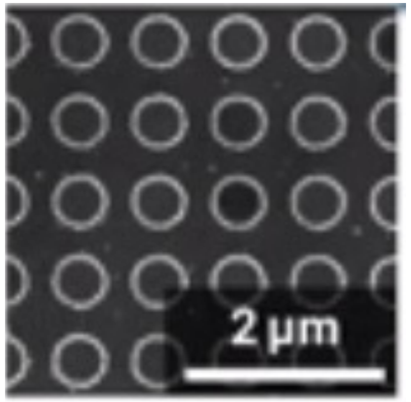
The Australian National University

Australian National University
THE UNIVERSITY OF MELBOURNE
UTS
THE UNIVERSITY OF WESTERN AUSTRALIA
RMIT UNIVERSITY
Australian Government
Australian Research Council

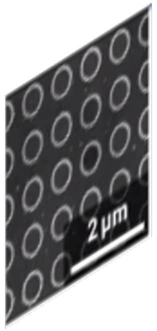
Outline:

- Motivation and introduction
- Tunable metasurfaces using liquid crystal
- Liquid crystal tunable metasurfaces by using magnetic field
- Tuning of metasurfaces in fully 3D

Optical metasurfaces



2D subwavelength arrangement of designed nanoscale building blocks



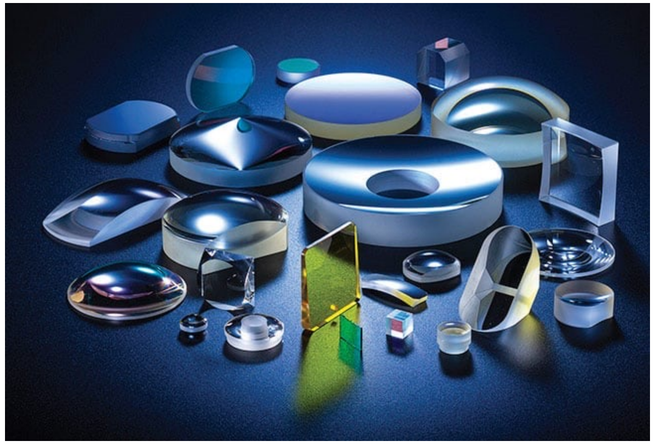
Known input light field

Desired output light field

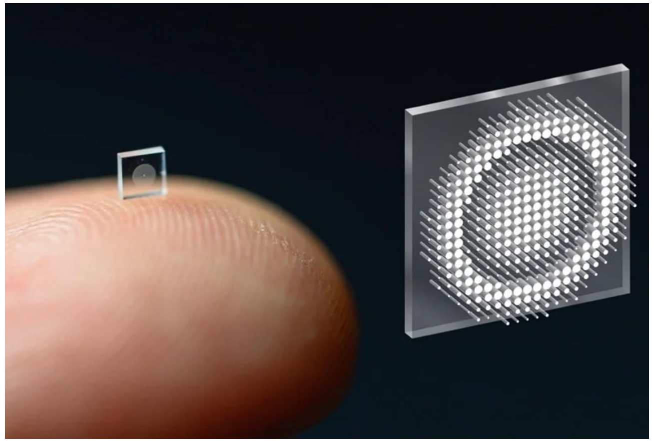
(with desired amplitude, phase, polarization, and direction of propagation)

Bulky optical components

Traditional lenses, holograms, beam deflectors, beam shapers, polarizers, beam generators, etc



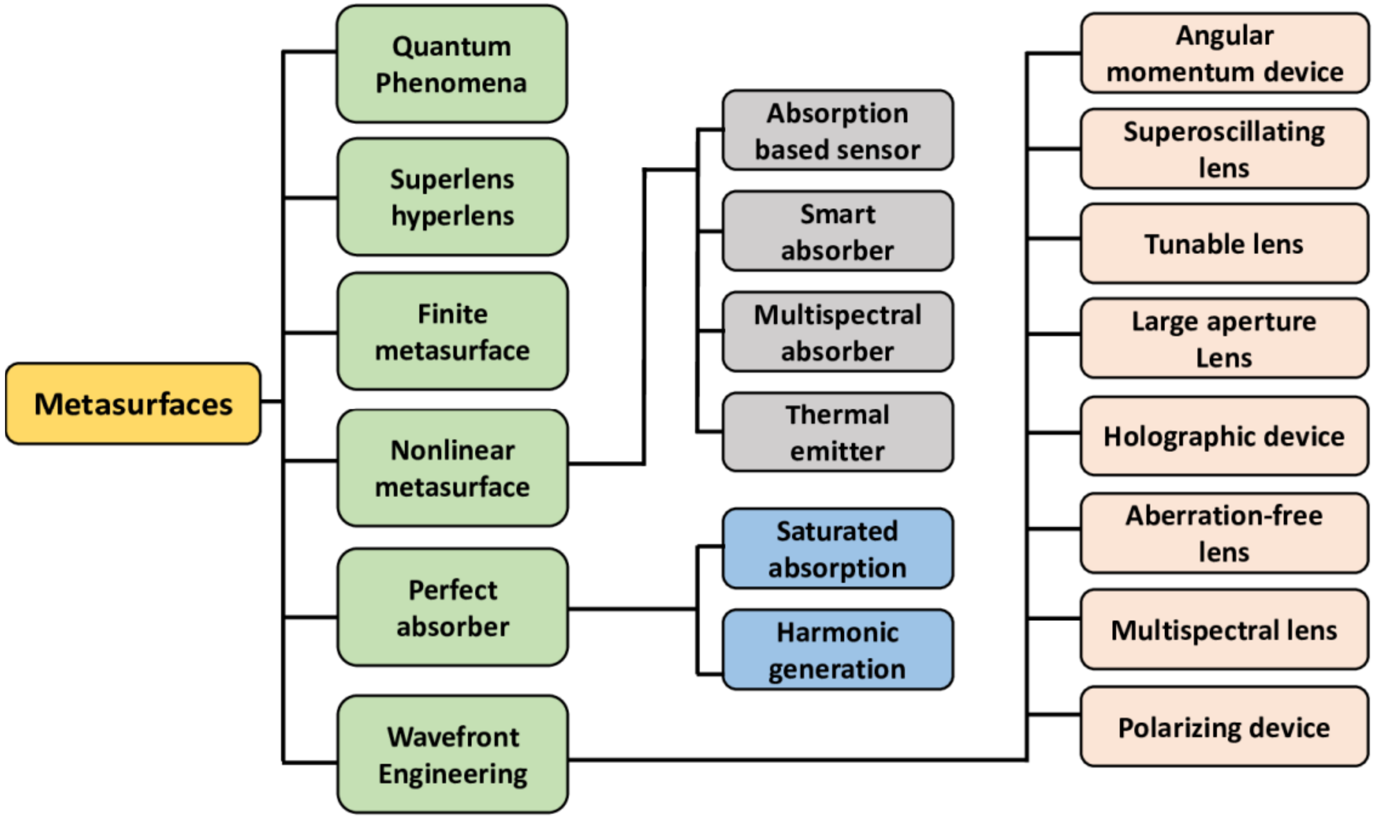
Flat optical meta-devices

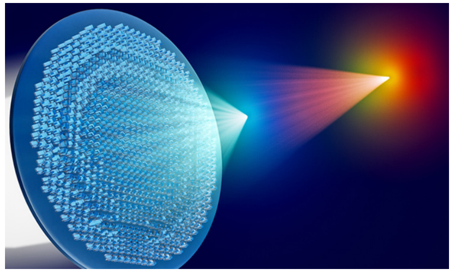


Metalenses, metaholograms, beam deflectors, beam shapers, polarizers, beam generators and etc (in nanoscale)

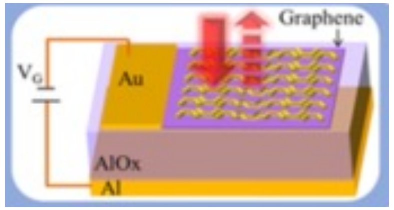
Tunable Metasurfaces

TMOS
ARC CENTRE OF EXCELLENCE FOR TRANSFORMATIVE META-OPTICAL SYSTEMS

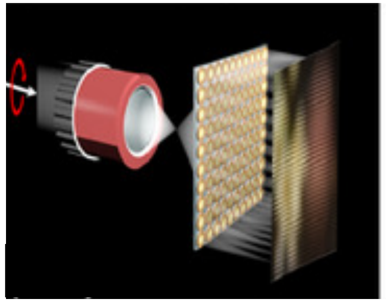




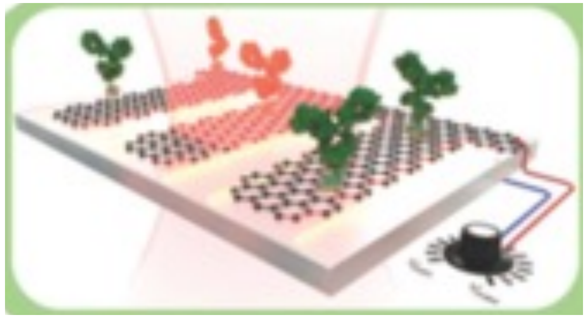
Tunable lenses



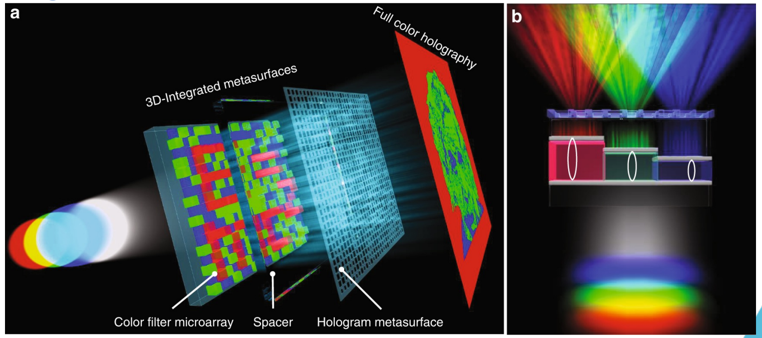
Tunable absorber



Light field imaging and sensing

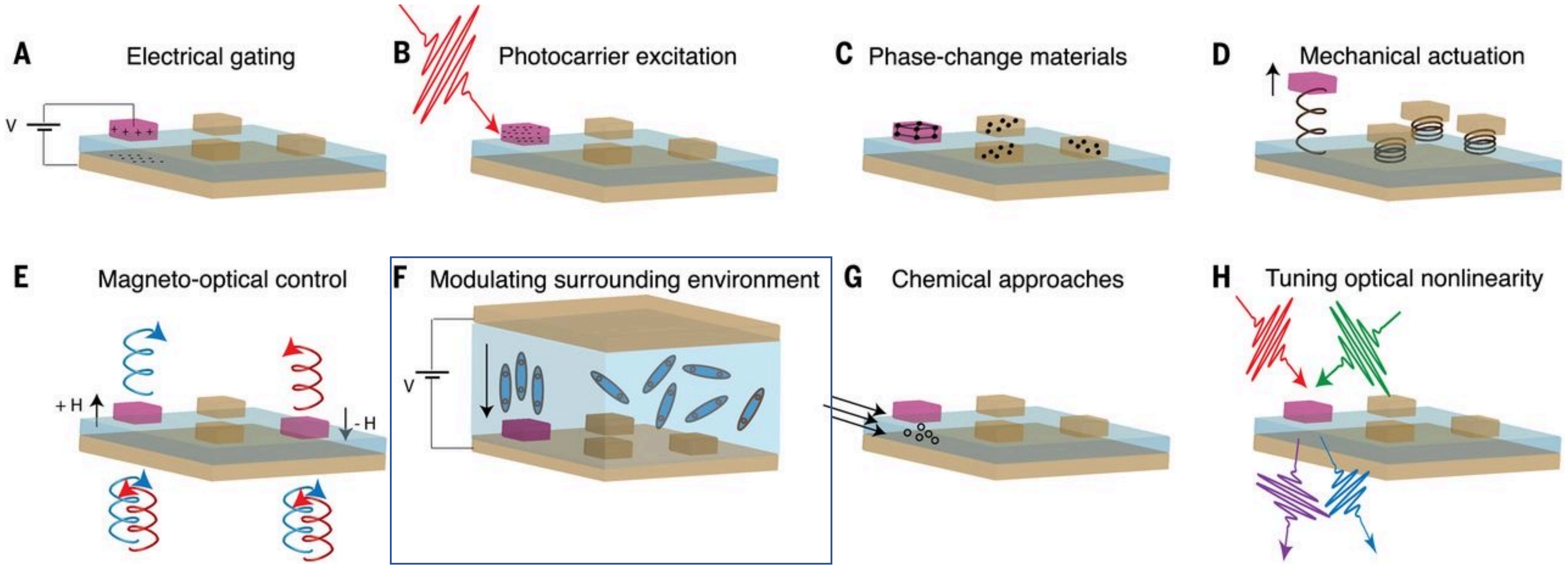


Tunable biosensor



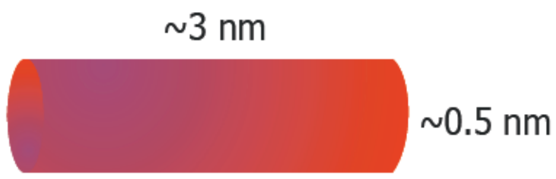
Meta-holograms

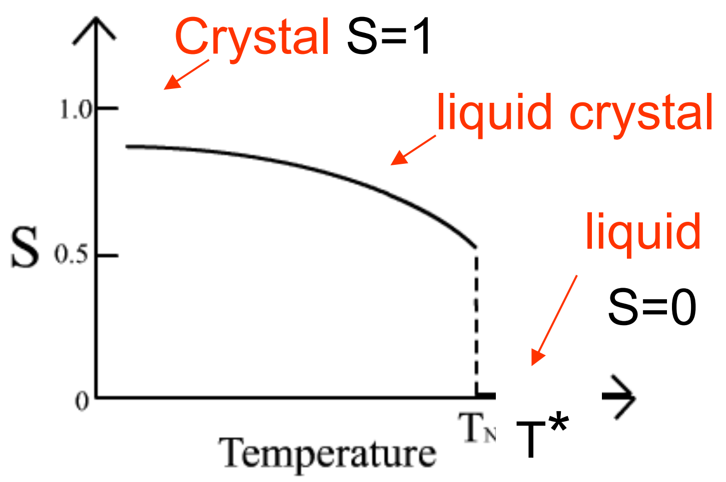
Different Metasurface Modulation Approaches



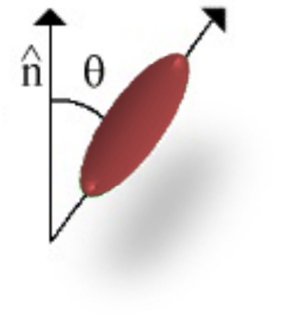
A. Shaltout, Science, 364, 6441 (2019).

Liquid Crystals





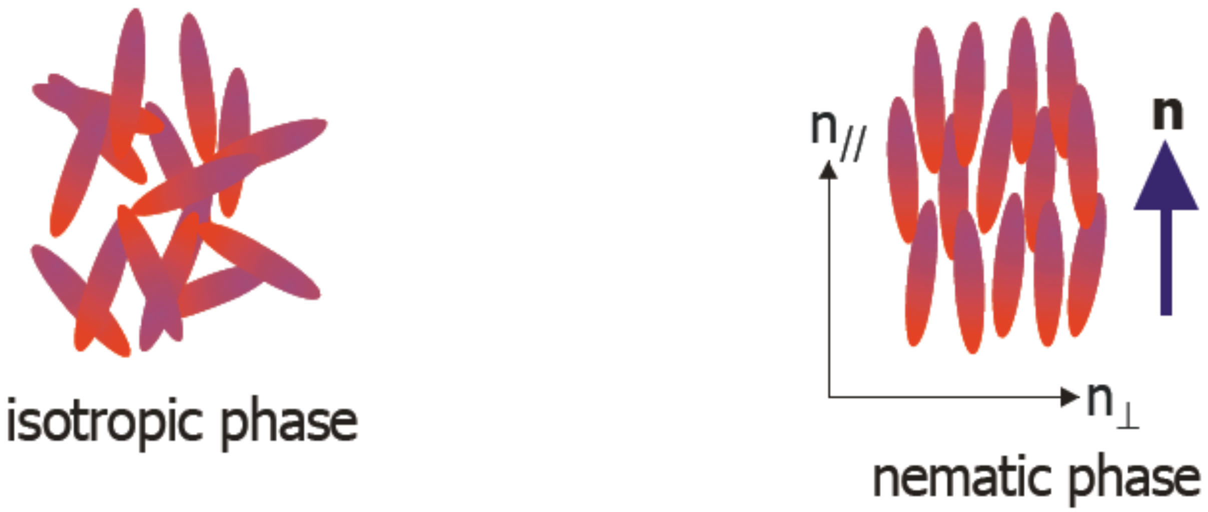
T* – liquid crystal to liquid phase transition temperature



$S = \langle (3\cos^2\theta - 1)/2 \rangle$

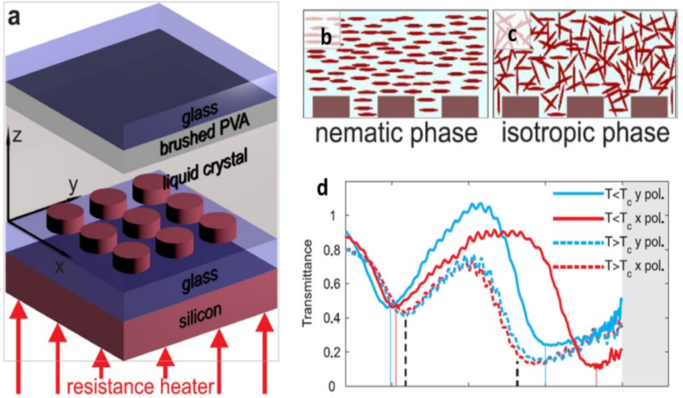
The order parameter S
of a liquid crystal range from 0.3 to 0.9

high response to
external stimuli



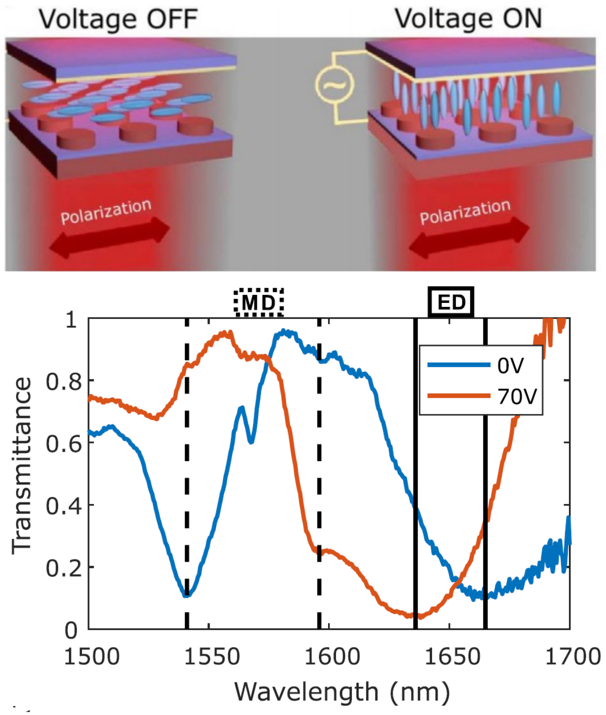
Tuning of Dielectric Metasurfaces with Liquid Crystal

Thermal Tuning



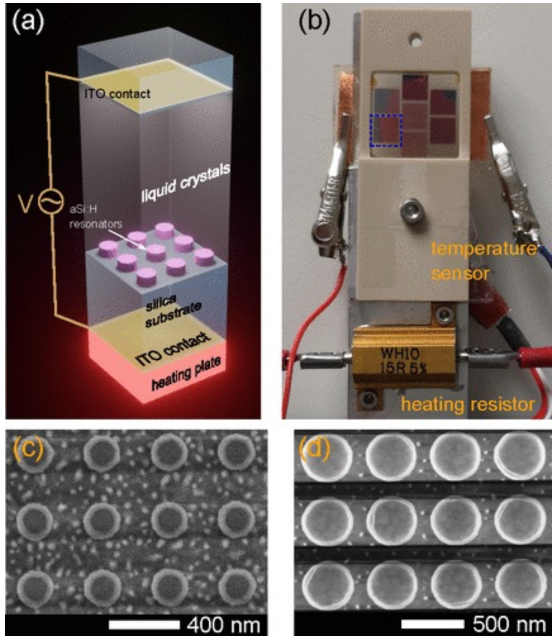
J. Sautter, et al., ACS nano ***9****, 4308 (2015).*

Electrical Tuning



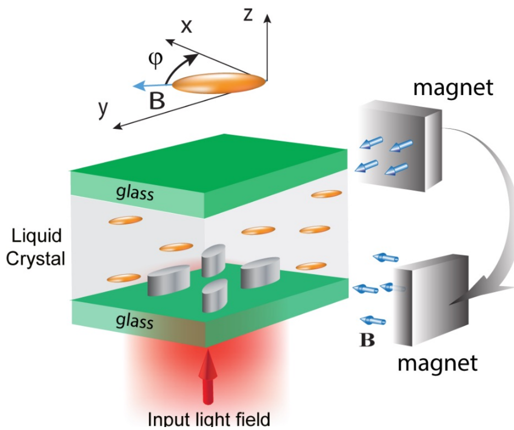
A. Komar, et al., Appl. Phys. Lett ***110****, 071109 (2017).*

Thermo- Electrical Tuning



C. Zou, et al., *ACS Photonics*, **8**, 1775, (2021)

Magnetic Tuning



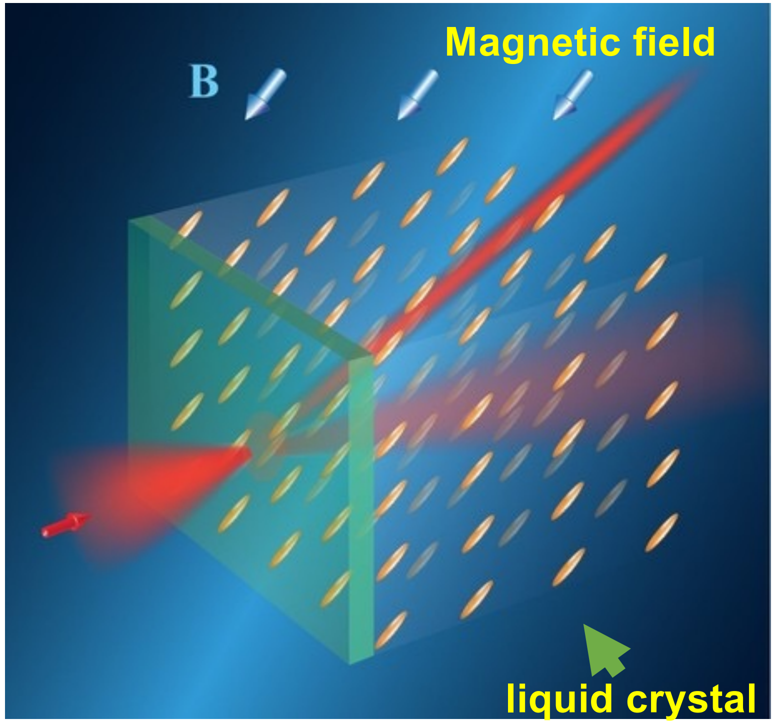
Doesn't require

LC pre-alignment

Y. Izdebskaya, et. al Nanophotonics, ***11****, 17 (2022)*

Control Liquid Crystal with External Magnetic Field

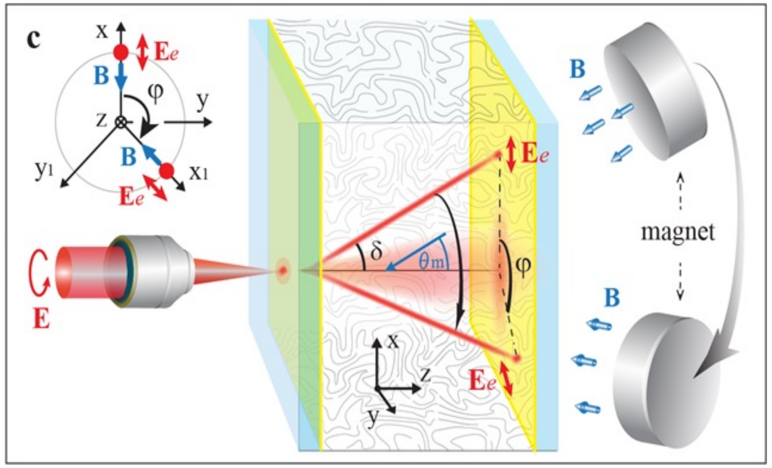
3D control of NLC molecular orientation



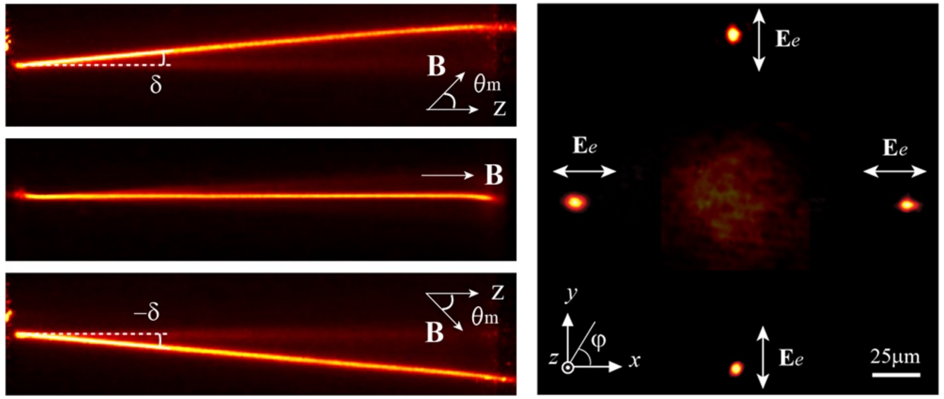
Y. Izdebskaya, et al., Nat. Commun. 8, 1 (2017)

LC molecules have magnetic momentum due to moving electrical charges

Steering optical waveguides with magnets in 3D

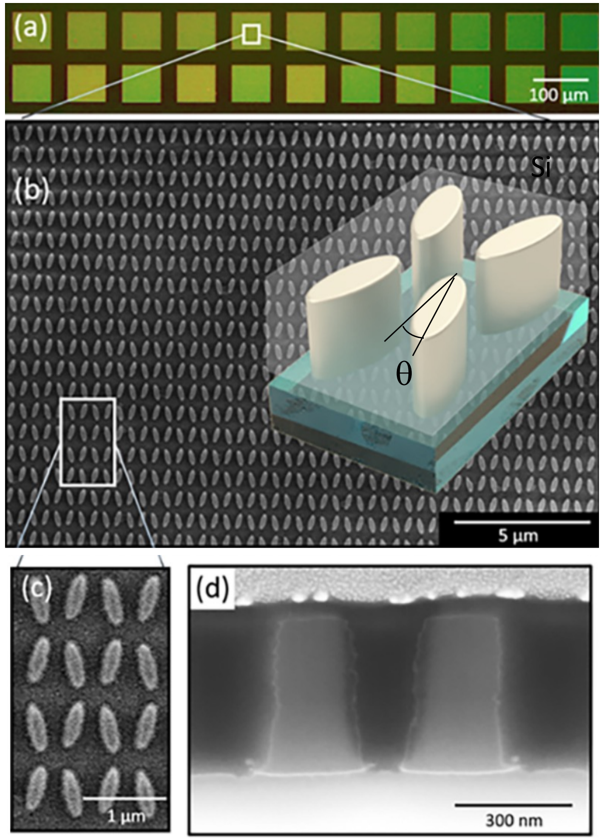


Experimental results

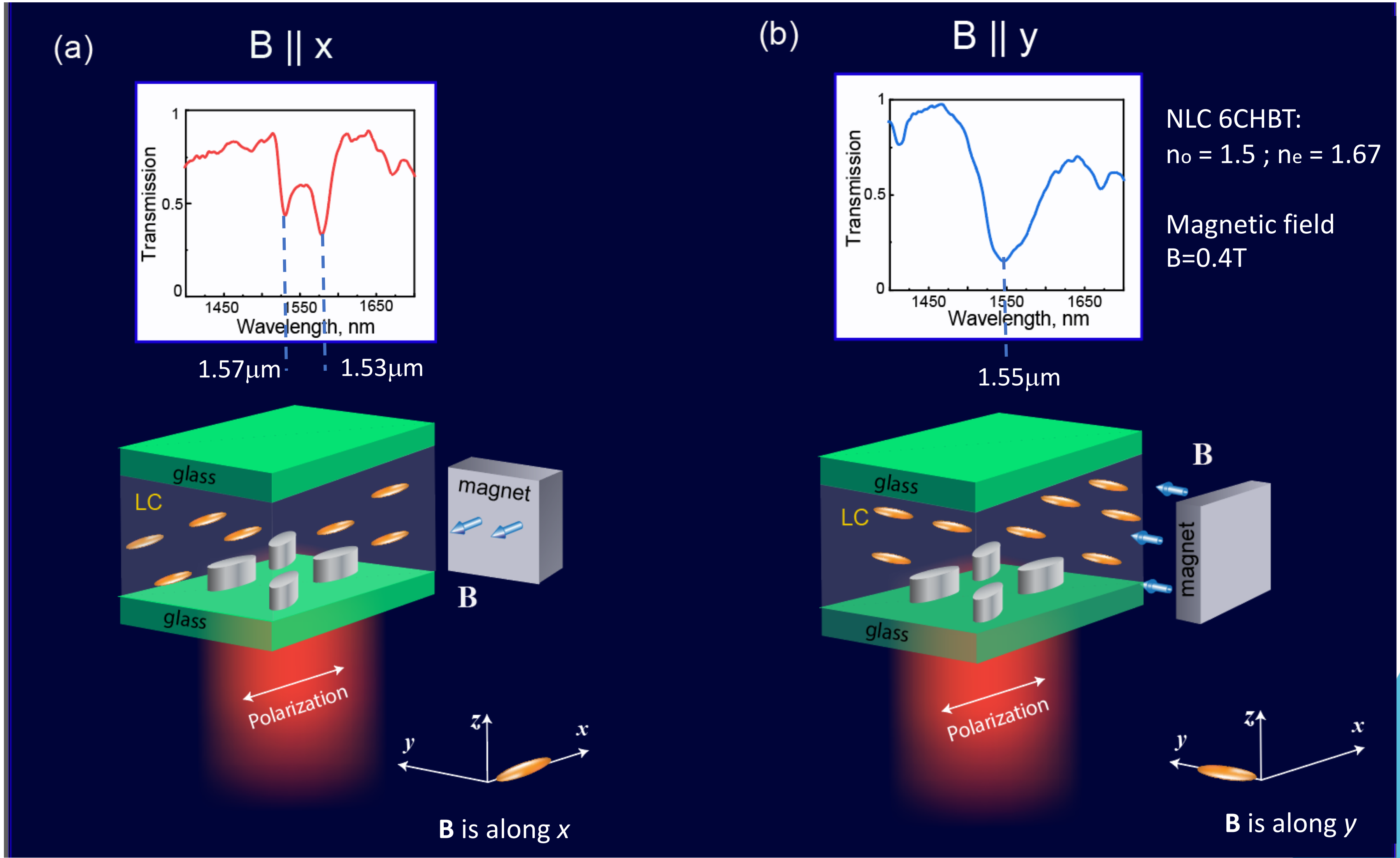


Magnetic Tuning of Metasurfaces with Liquid Crystal

Metasurface is composed of zigzag arrays of silicon elliptical-cylinders

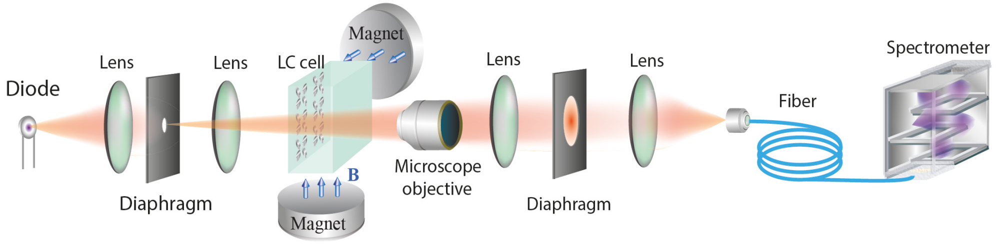


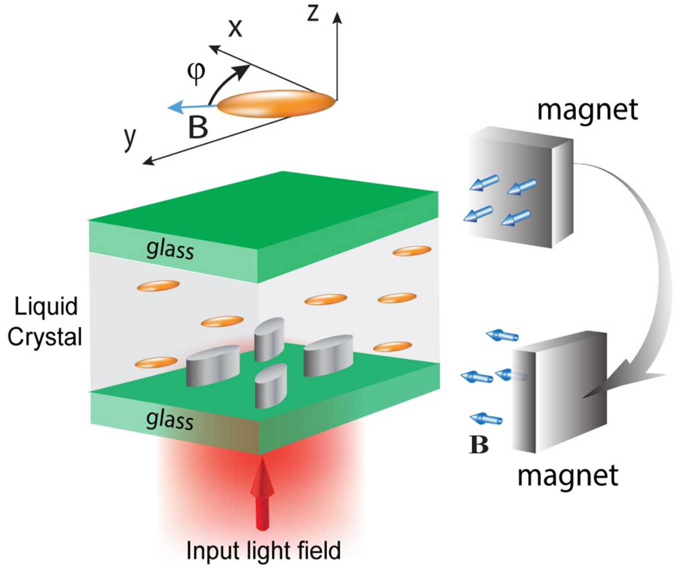
M. Liu, D.Y. Choi, *Nano Lett.* **18**, *8062 (2018)*



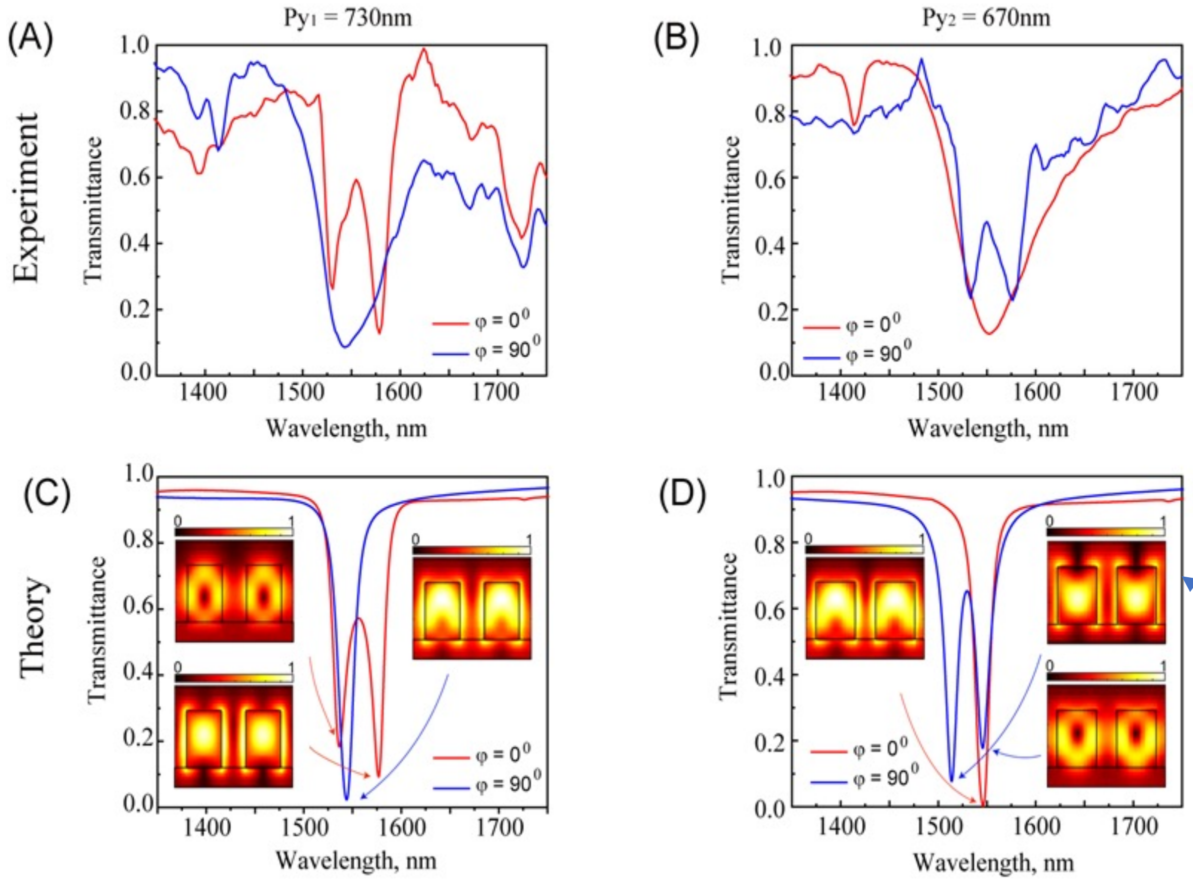
Experimental and Numerical results

Transmittance setup





Transmittance spectra of resonances for two metasurfaces with different array periods



the inverted dynamics

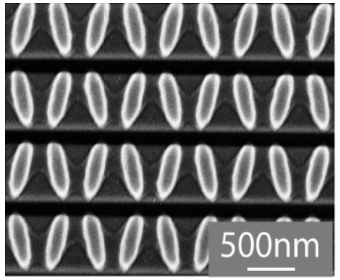
The amplitude of electric field profiles of resonances

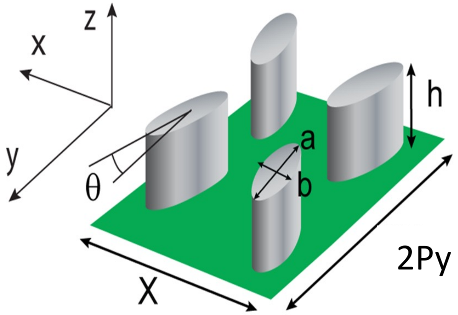
Y. Izdebskaya, Z. Yang, M. Liu, D.-Y. Choi, A. Komar, D. N. Neshev, and I. V. Shadrivov, Nanophotonics, **11**, 17, (2022)

Transmittance spectra for different periods Py of metasurface

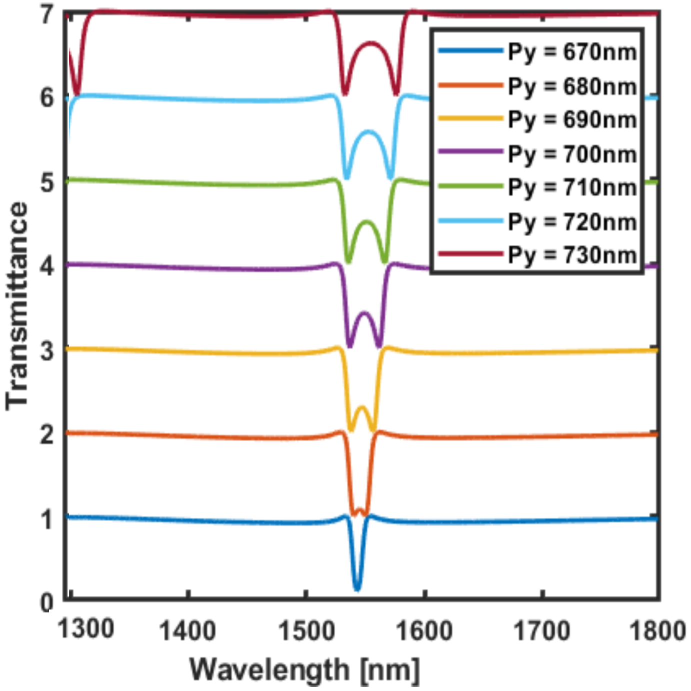
Similar dynamics of overlapping and splitting resonances can be achieved by mechanically changing the array period of metasurface

A zig-zag dielectric metasurface

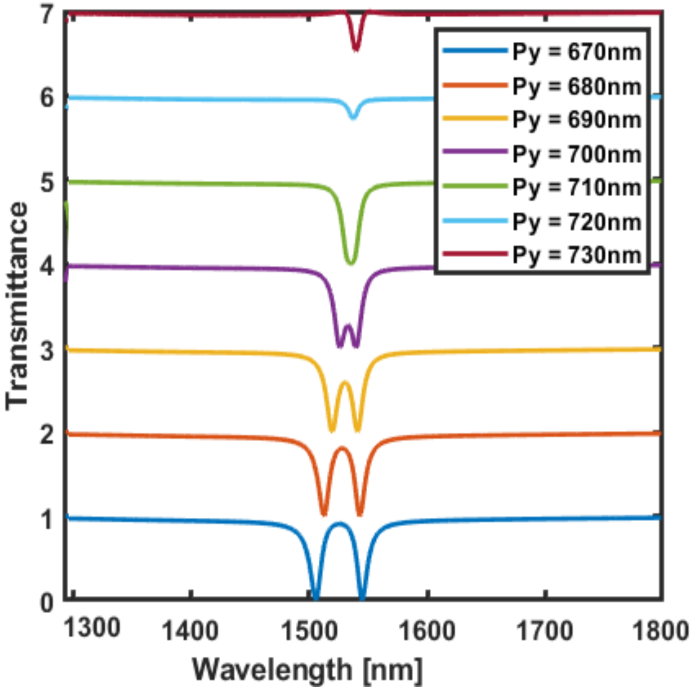




B || x



B || y



Gradual tuning of the resonances

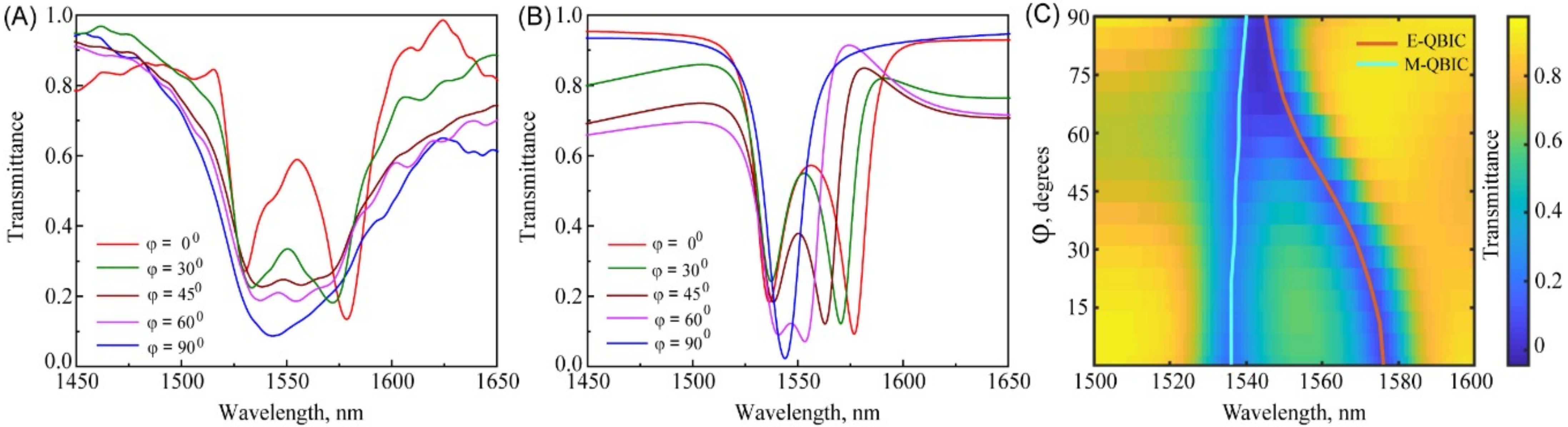
- Doesn't require LC pre-alignment
- No limitation in the geometry and thickness of LC cells
- Gradual tuning of both electric and magnetic modes for any polarization

Transmittance spectra for different angles φ of the magnetic field **B** in *x*–*y* plane

Calculated transmittance spectra of the metasurface from Figure (B) versus the systematic magnetic field orientation φ

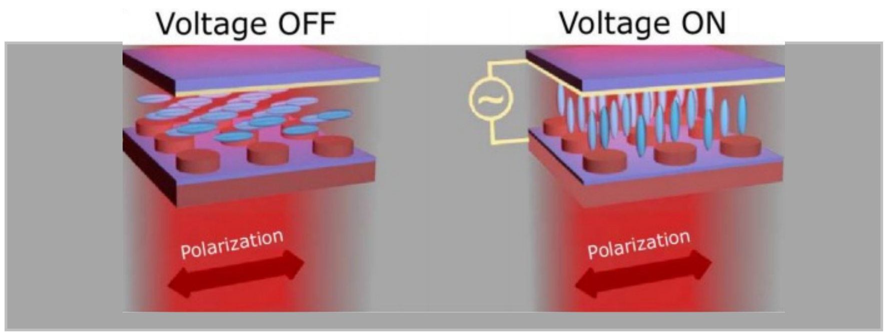
Experiment

Theory

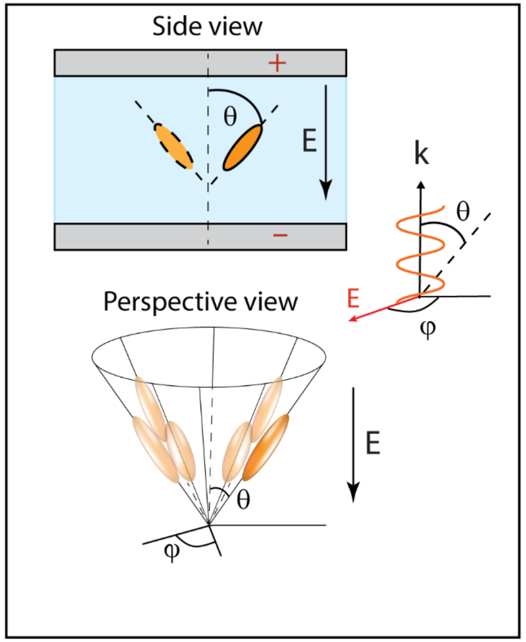


Difference Between Electric and Magnetic Tuning

Electrical tuning

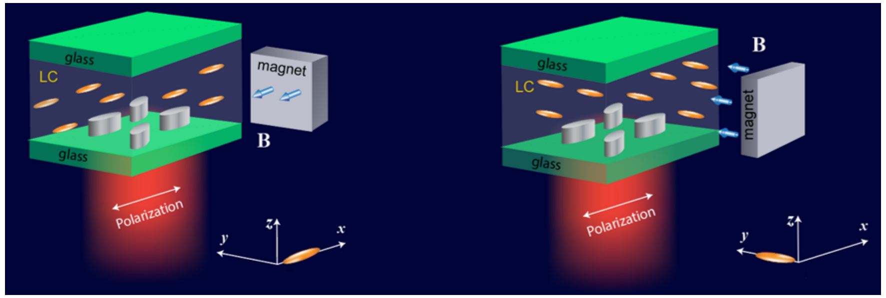


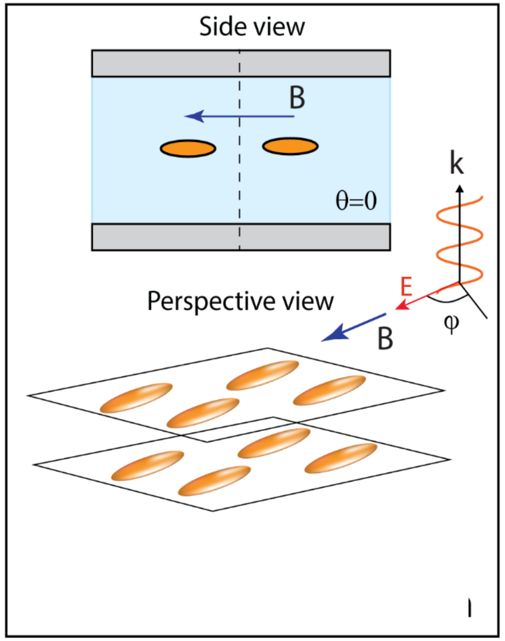
(Voltage is between ON and OFF)



If Voltage is between ON and OFF molecules orientation are not strongly defined

Magnetic tuning

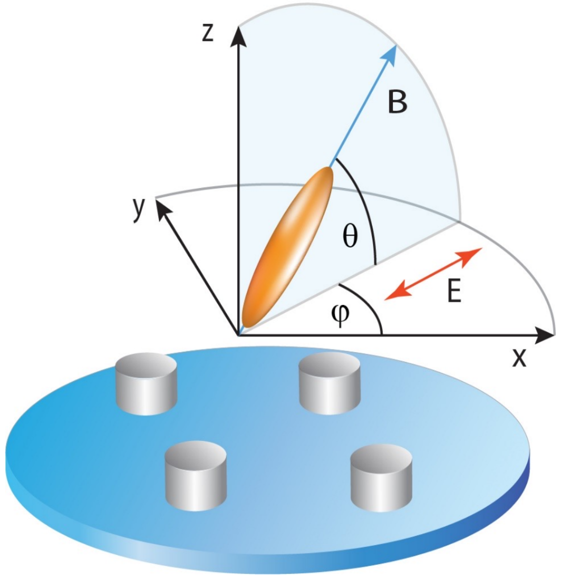




Molecular orientation is always oriented along the magnetic field **B**

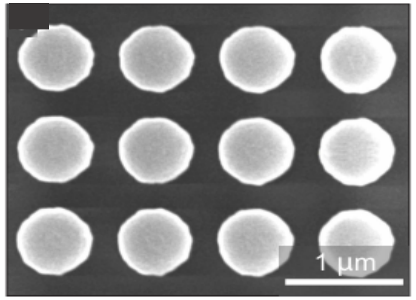
3D Magnetic tuning of metasurface

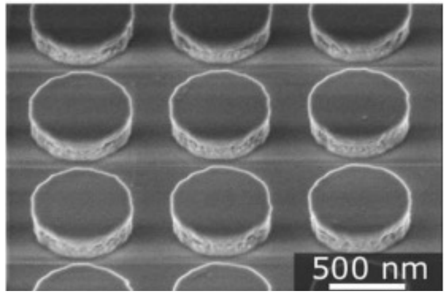
Concept of 3D tuning of LC metasurfaces



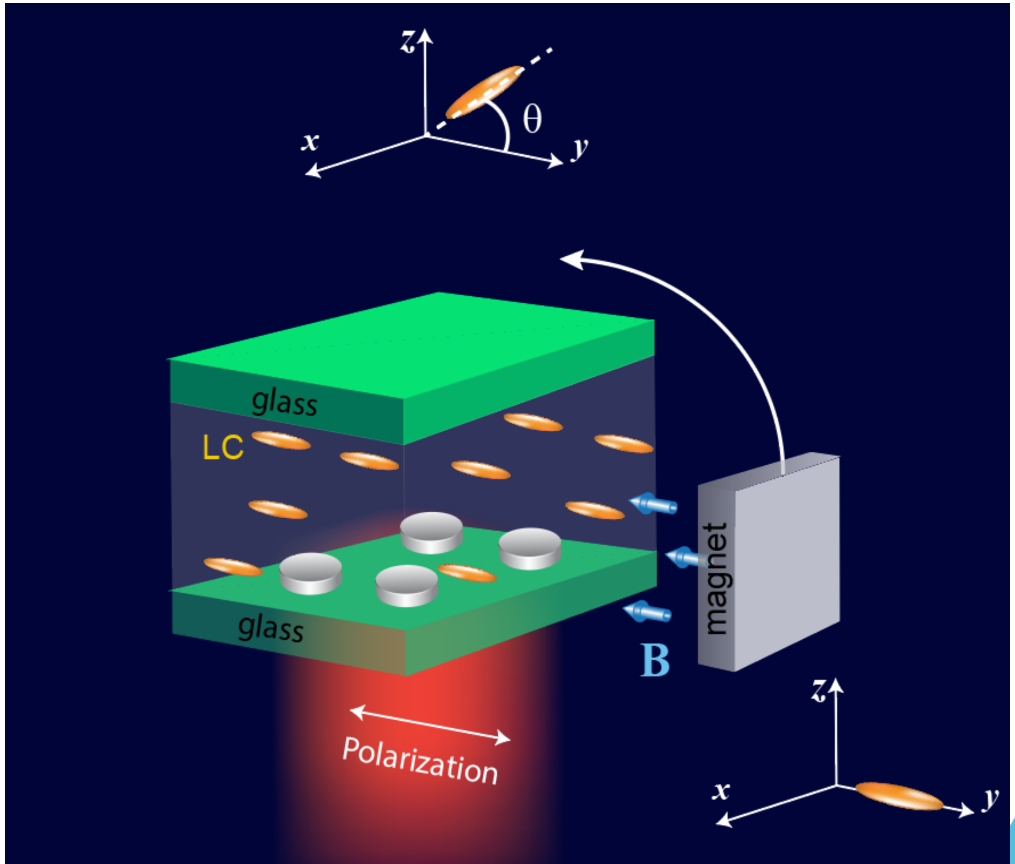
- φ – azimuthal angle
- θ – polar angle
- Polarization

The silicon nanodisk metasurface
Nanodisks have a height of h = 220 nm and a diameter of d = 606 nm





Rotation in plane (xy-z)



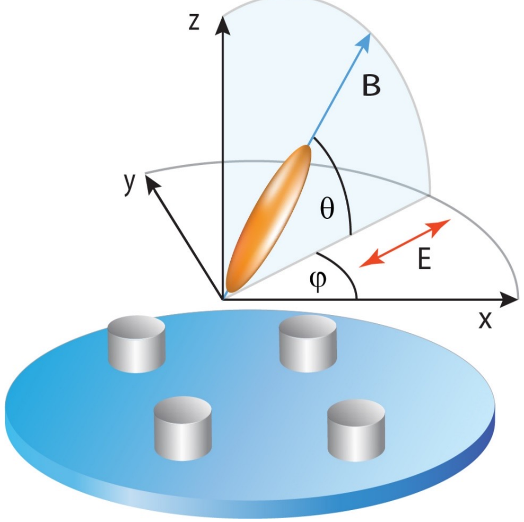
NLC 6CHBT: n_o = 1.5 ; n_e = 1.66

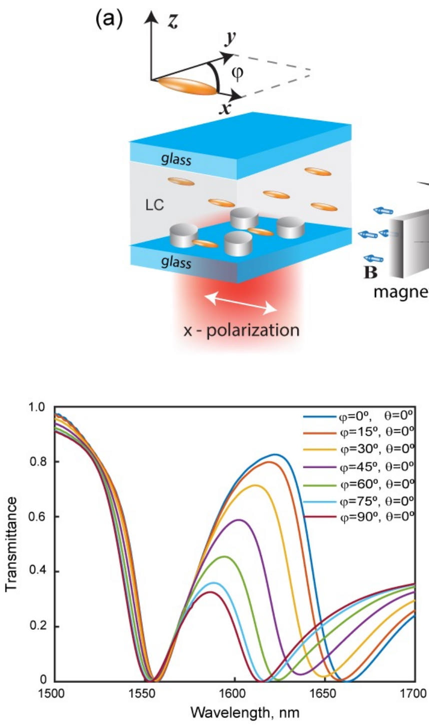
Magnetic field B=0.4T

3D Tuning of Metasurfaces (Numerical results)

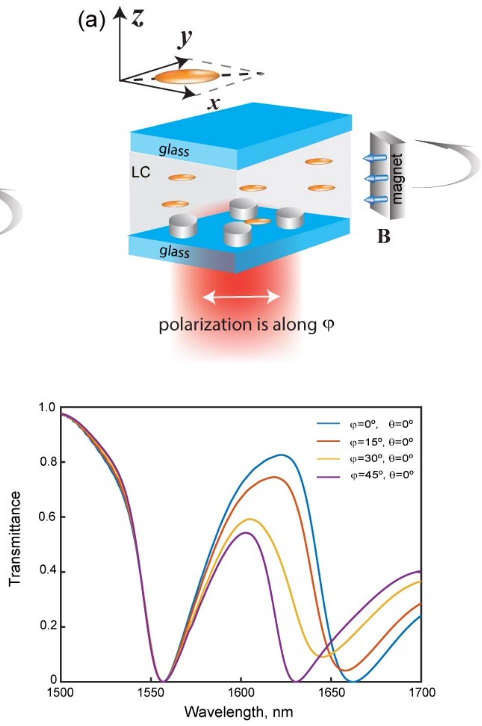
TMOS
ARC CENTRE OF EXCELLENCE FOR TRANSFORMATIVE META-OPTICAL SYSTEMS

Concept of 3D tuning of LC metasurfaces

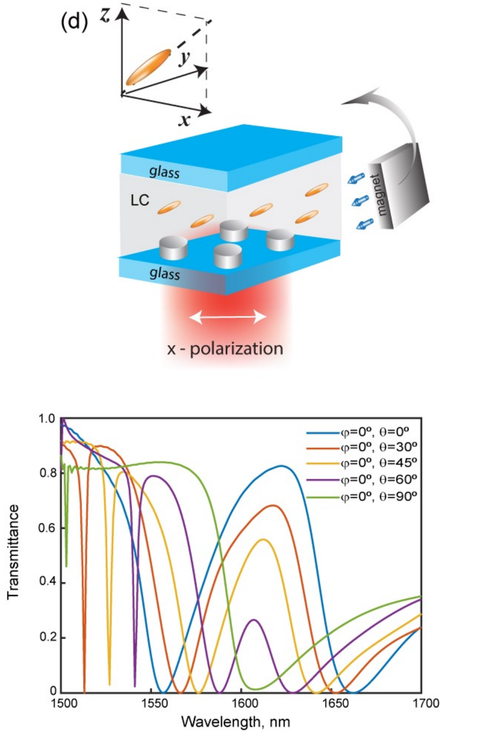




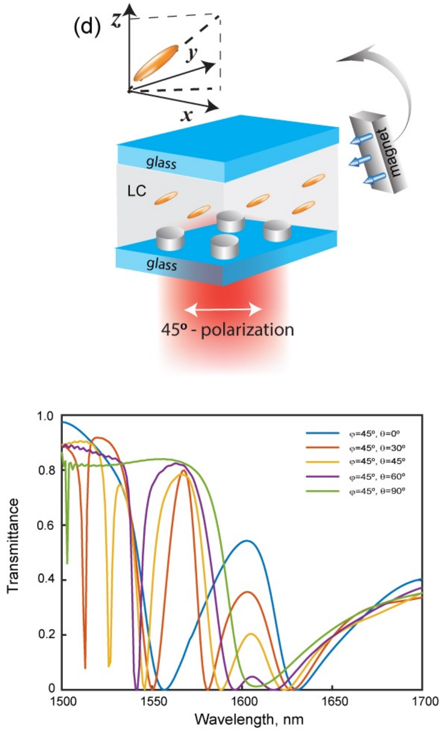
LC rotates from 0 to 90 degrees (Θ = 0) in the x-y plane, and the polarization is along the x direction



LC rotates from 0 to 45 degrees (Θ = 0) in the x-y plane and the polarization is along the φ direction

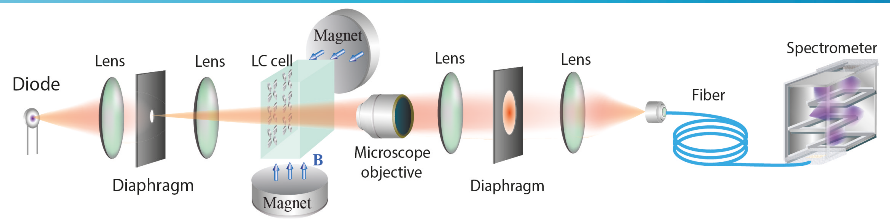


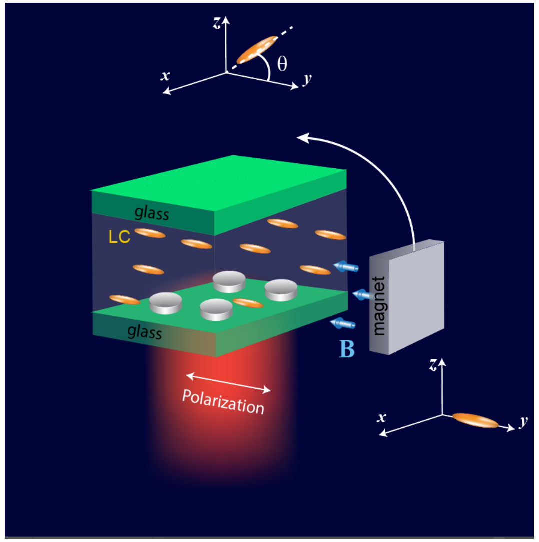
LC rotates from 0 to 90 degrees in the x-z plane (φ = 0), and the polarization is along the x direction



LC rotates from 0 to 90 in a vertical plane tilted at φ = 45 to the x-z plane. The polarization is along the φ = 45 direction

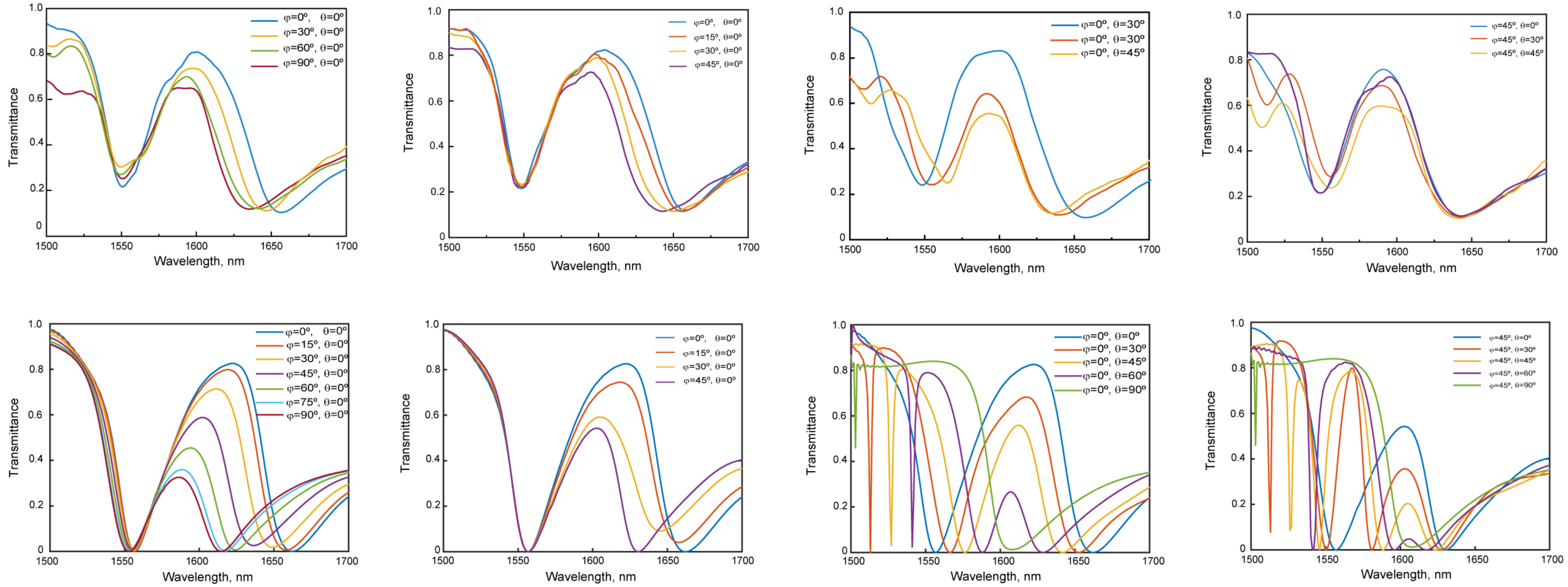
3D Tuning of Metasurfaces (Experimental results)





Experiment

Theory



LC rotates from 0 to 90 degrees (Θ = 0) in the x-y plane, and the polarization is along the x direction

LC rotates from 0 to 45 degrees (Θ = 0) in the x-y plane and the polarization is along the φ direction

LC rotates from 0 to 90 degrees in the x-z plane (φ = 0), and the polarization is along the x direction

LC rotates from 0 to 90 in a vertical plane tilted at φ = 45 to the x-z plane. The polarization is along the φ = 45 direction

Summary

- First demonstration of magnetic tuning of dielectric metasurfaces
- Magnetic tuning does not require LC pre-alignment
- No limitation in the geometry and thickness of LC cells
- By changing angle of magnetic field, we can shift resonances gradually
- First demonstration of tuning of metasurfaces in fully 3D
- Control different states of LC orientation and polarization
- By rotating LC molecules in 3D, we can tune resonances differently. Some regimes allow us to tune the electrical resonance, others - the magnetic resonance, or both

Acknowledgements

TMOS
ARC CENTRE OF EXCELLENCE FOR TRANSFORMATIVE META-OPTICAL SYSTEMS

- Ziwei Yang
- Mingkai Liu
- Andrey Komar
- Vladlen Shvedov
- Dragomir Neshev
- Ilya Shadrivov

TMOS
ARC CENTRE OF EXCELLENCE FOR
TRANSFORMATIVE META-OPTICAL SYSTEMS

Australian National University

ANZCOP

ANFF

Australian Government
Australian Research Council