Metamaterials and liquid crystals unite to make photonics a better technology

Vassili Fedotov
Optoelectronics Research Centre &
Centre for Nanostructured Photonic Metamaterials
University of Southampton, UK

Friday 19 September 15:45, Session 3, Photonics Day 2014 (Southampton, UK)

Metamaterials

ORC & Centre for Photonic Metamaterials

Oleksandr Buchnev

Vassili Fedotov

Nikolay Zheludev

+

Liquid crystals

Physics & Astronomy

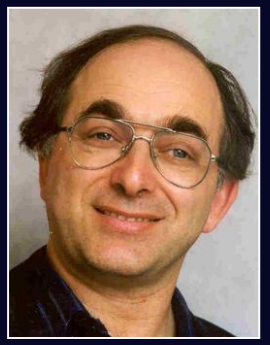
Malgosia Kaczmarek

ORC

Nina Podoliak

Mathematics

Giampaolo D'Alessandro



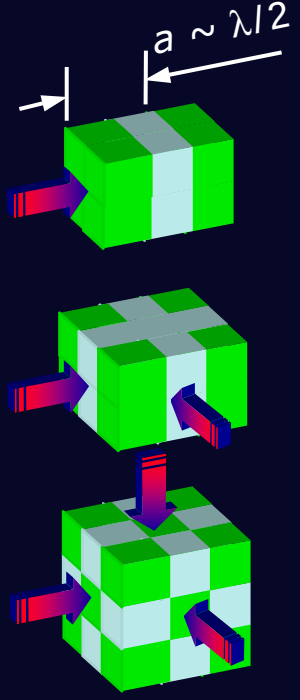
Timothy Sluckin

Artificially engineered materials (metamaterials)

Diffraction & interference
(**traditional way**)

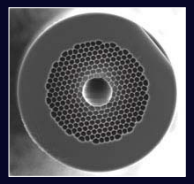
Controlling light at sub-wavelength (nano) scale: **Revolution!**

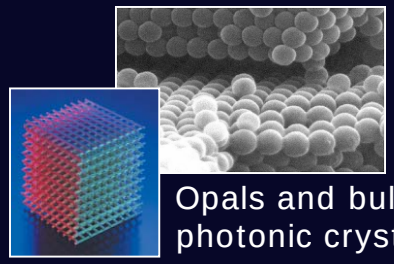
Photonic crystals



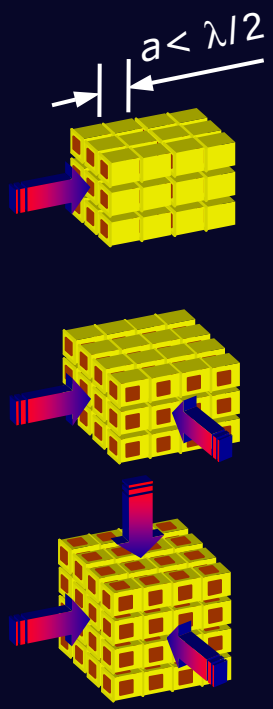

Anti-reflection coating


Dielectric mirrors

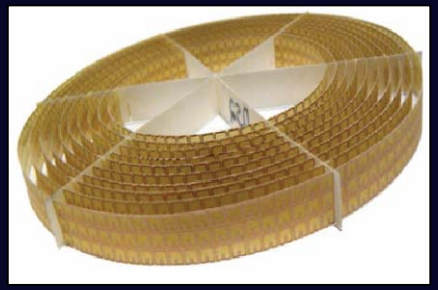

Holy fibres


Opals and bulk photonic crystals

Metamaterials (no diffraction)

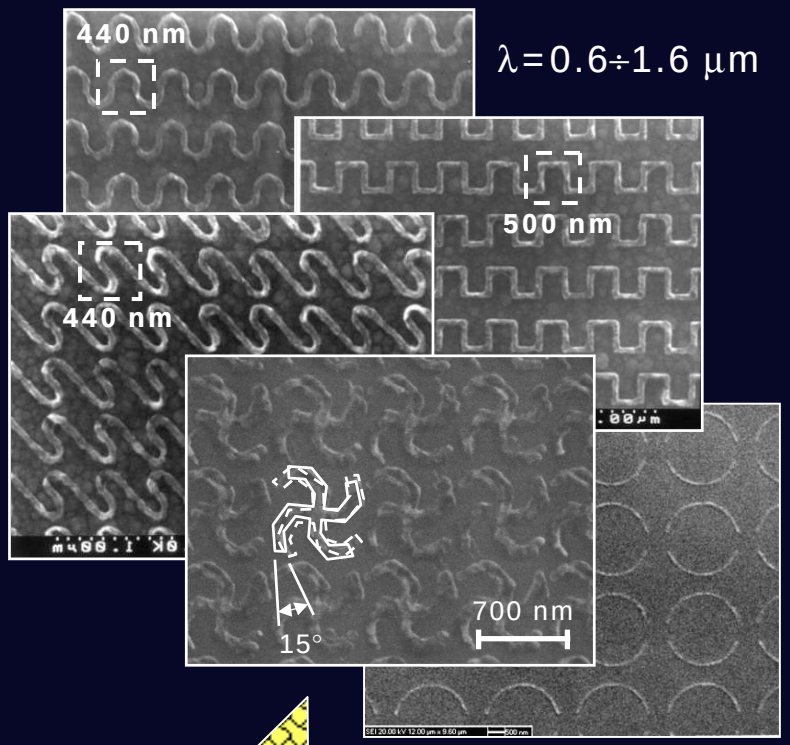


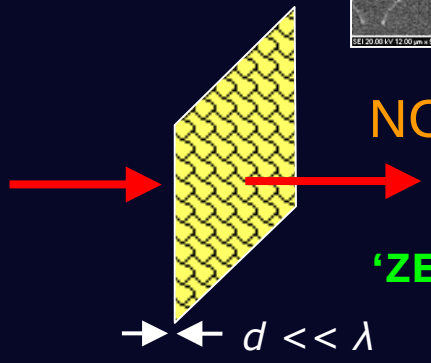

Negative refraction


Metamaterial cloak

Planar metamaterials:
new paradigm for photonics

Compatible with nanofabrication technologies!





NO diffraction!

media of
'ZERO dimension'

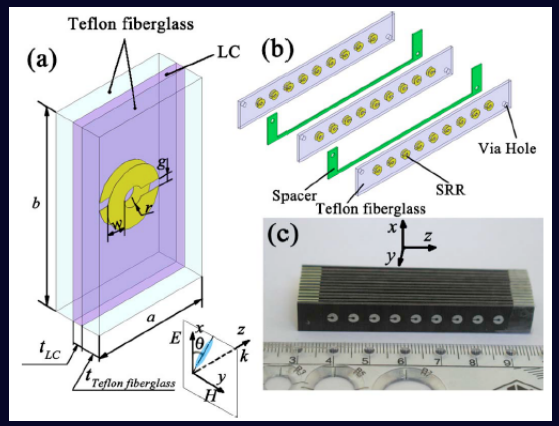
$d << \lambda$

WHAT CAN BE ACHIEVED?

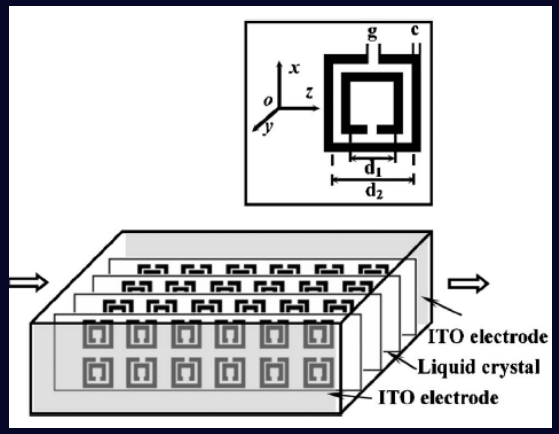
- Spectral filter (RF & MW FSS)
- Polarizer/waveplate
- Retarder & accelerator
- Circular polarizer/rotator
- Lens, prism & wavefront engineering
- Optical SC (magnetic mirror)
- Loss amplification (perfect absorber)
- Asymmetric transmission
- 'Slow light'
- Sensors
- Optical activity w/o chirality
- Enhanced nonlinearity of metals
- Subwavelength imaging
- …

Active control: LC-metamaterial hybrids

Electric/ Magnetic field (RF & metamaterials)



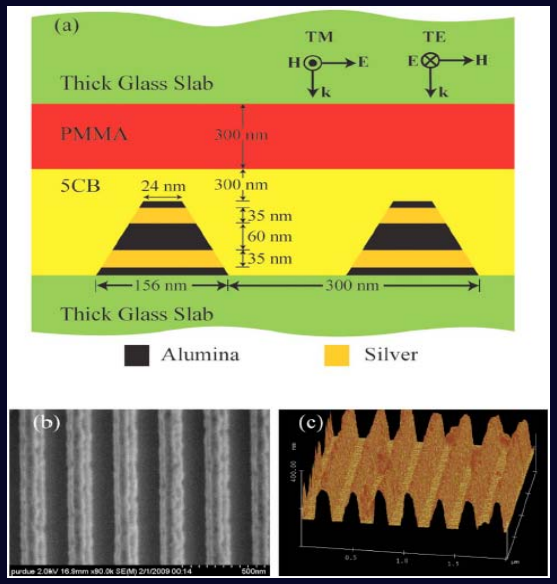
F. Zhang et al., APL 92, 193104 (2008)



Q. Zhao et al., APL 90, 011112 (2007)

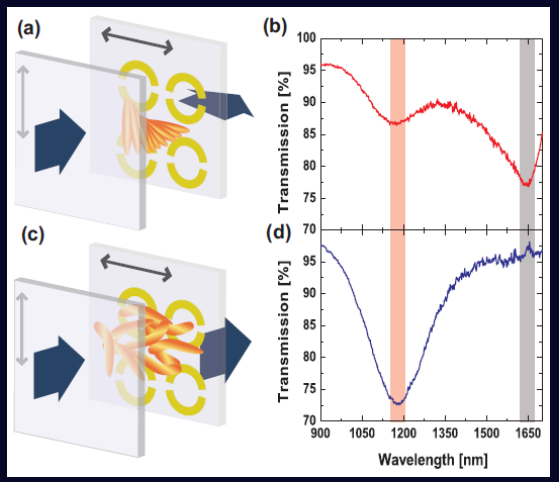
Next major step

Temperature (Near-IR metamaterials)

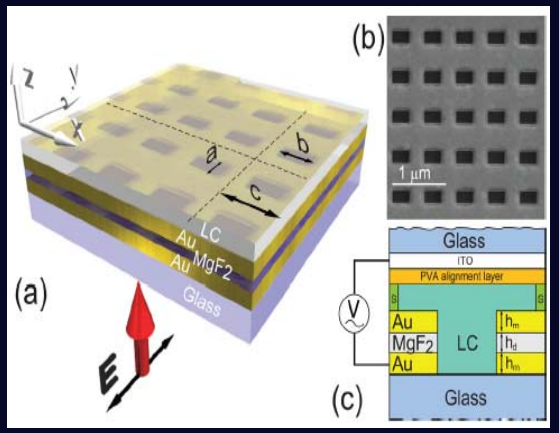


S. Xiao et al. APL 95, 033115 (2009)

Optical switching & nonlinearity (Near-IR metamaterials)



B. Kang et al., OE 18, 16492 (2010)



A. Minovich et al., APL 100, 121113 (2012)

No efficient *electrical* tuning of photonic metamaterials…

What you are going to see in this talk…

Efficient electrical control in photonic LC-metamaterial hybrids through:

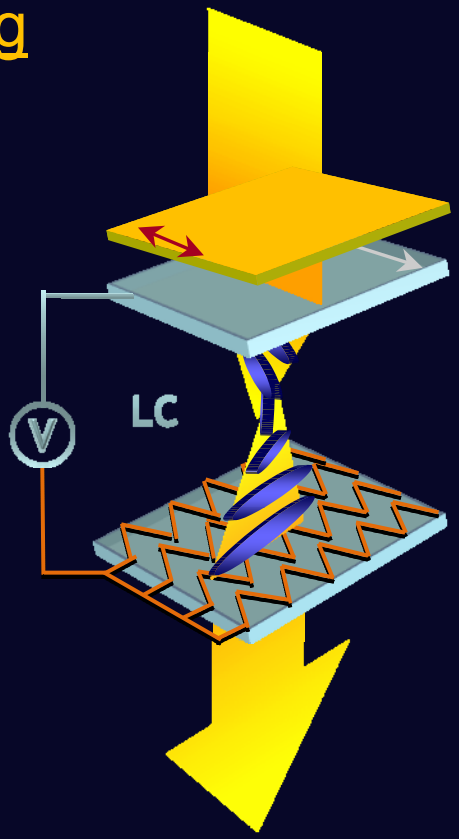
- MICRO-scale LC-volume switching:
  high contrast modulation

- NANO-scale in-plane LC switching (first time):
  spectral tuning

near-IR

Hybrid LC-metamaterial optical cell

Volume switching



Polarizer

ITO glass

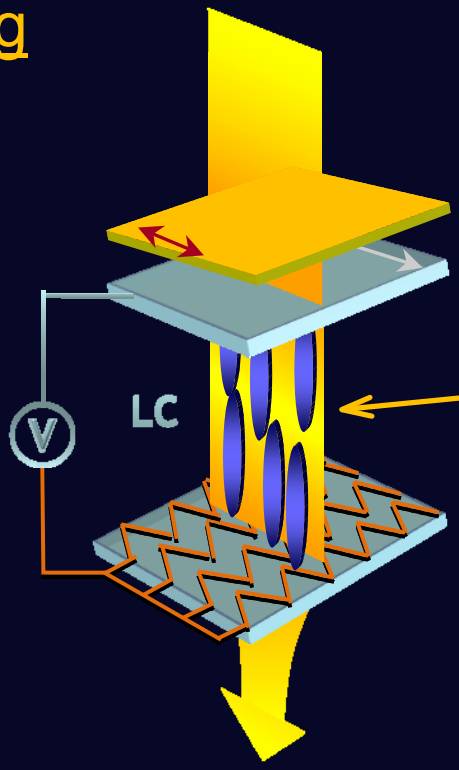
Planar metamaterial

$2L\,(n_e - n_0) > \lambda$

Cell thickness, $L \sim 4\text{-}20\mu m$

Hybrid LC-metamaterial optical cell

Volume switching



LC volume switches from twisted to homeotropic state

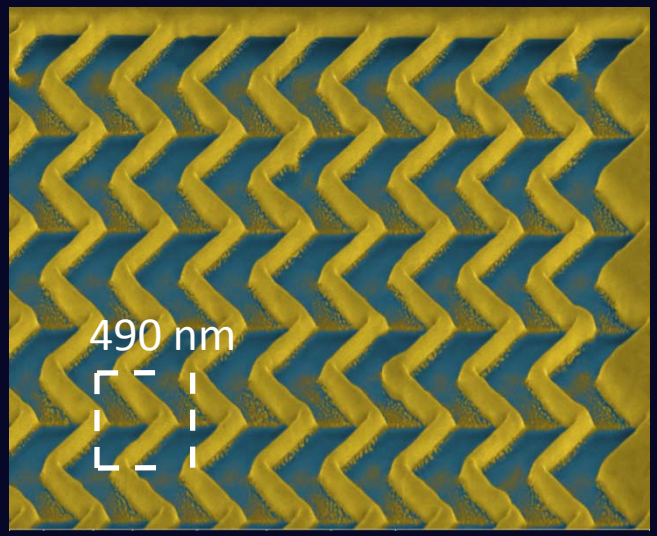
$$2L\,(n_e - n_0) > \lambda$$

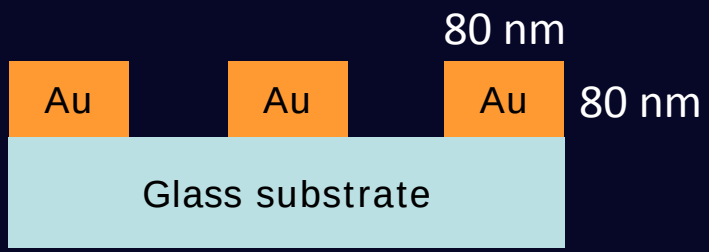
Cell thickness, L ~ 4-20μm

Near-IR plasmonic zig-zag metamaterial

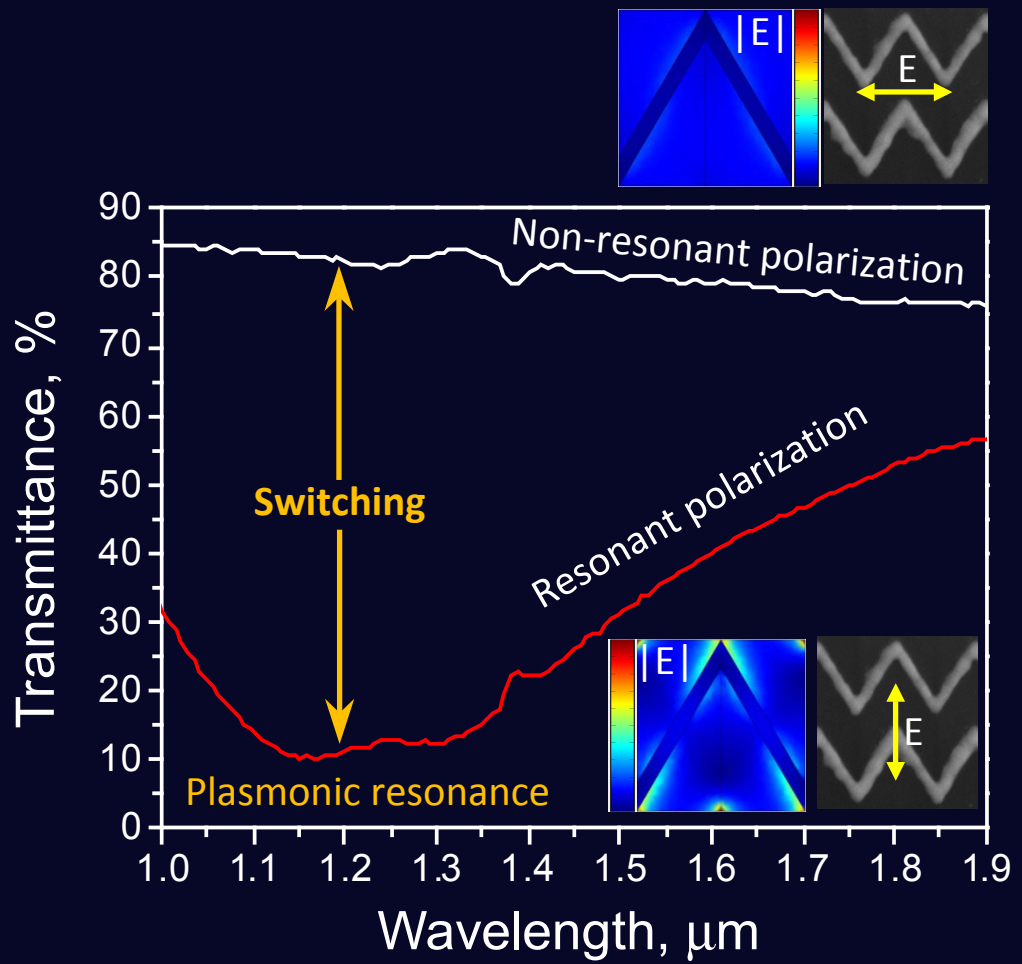
- Metamaterial array 25 x 25 μm
- 2600 zig-zag resonant elements
- Focused ion beam milling of Au film

Buchnev et al., Opt. Express **21**, 1634 (2013)





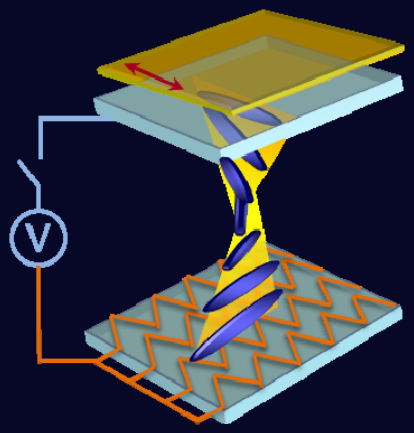
Metamaterial cross-section



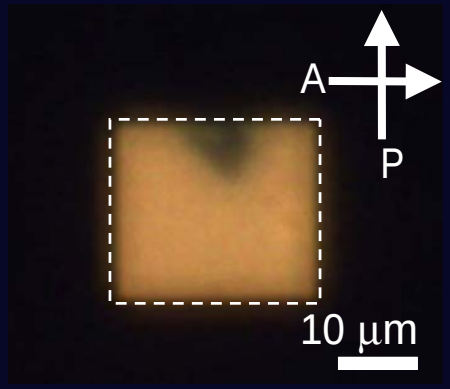
Electrical control of metamaterial transmission

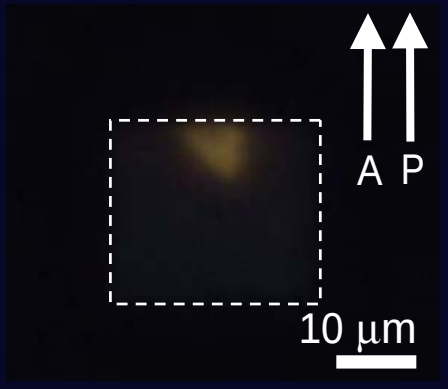
Hybrid LC cell

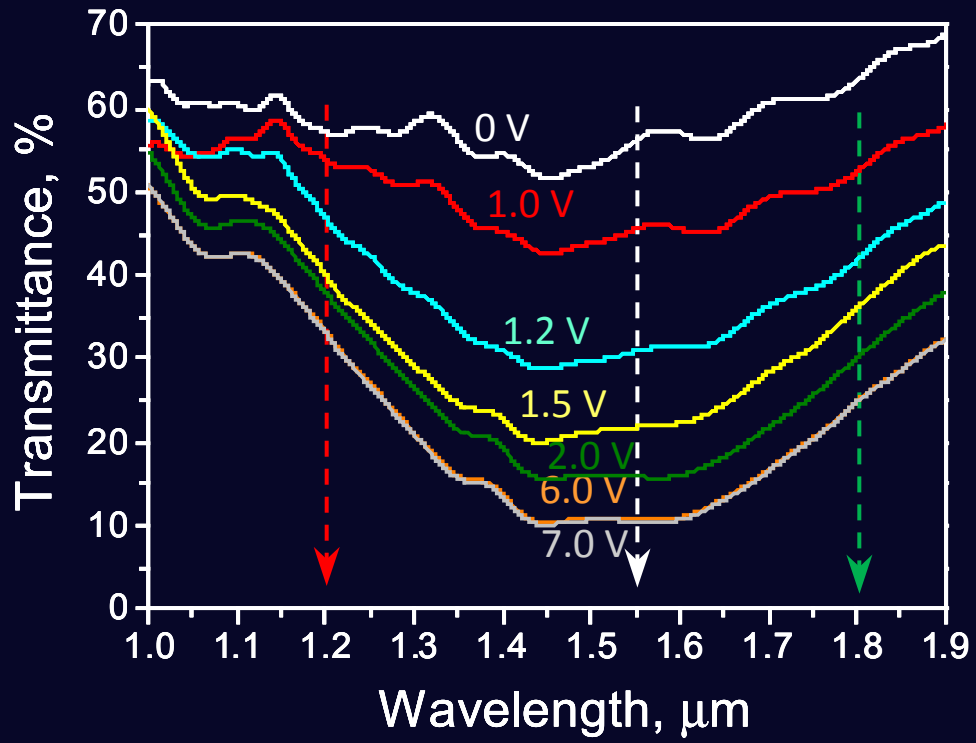
Liquid crystal: E7
Cell thickness: 15μm
Voltage: < 7V

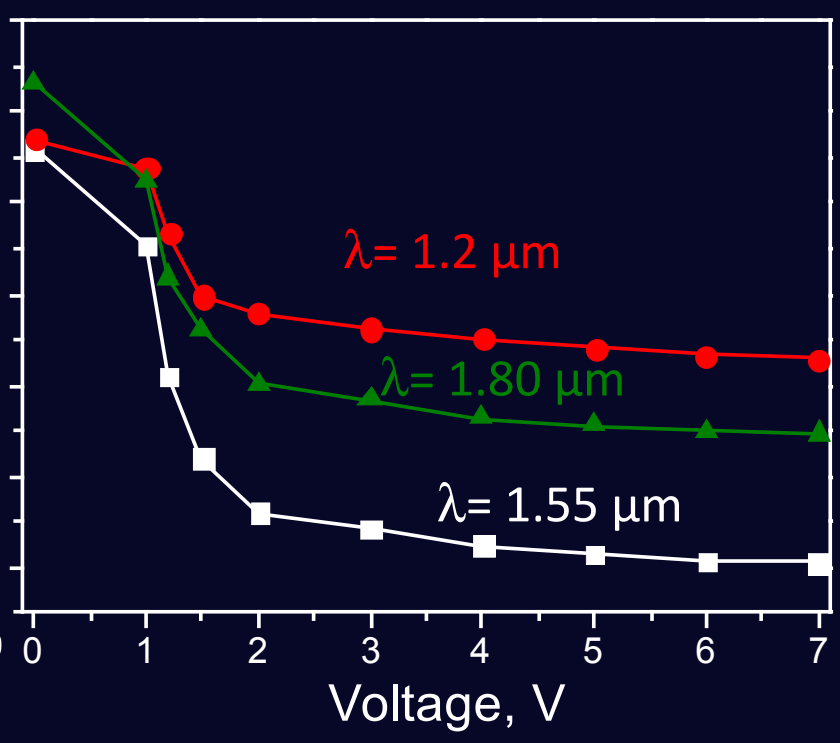


Twisted state (polarization microscopy)



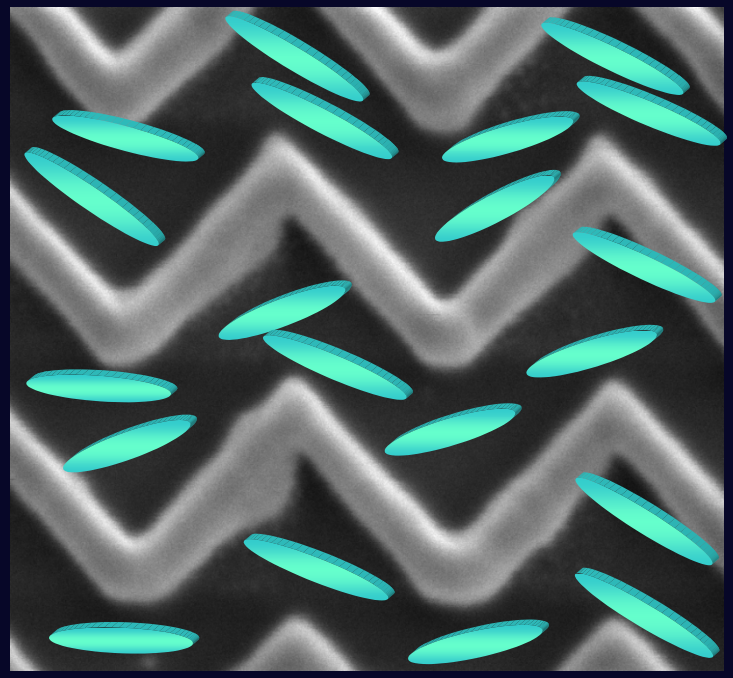






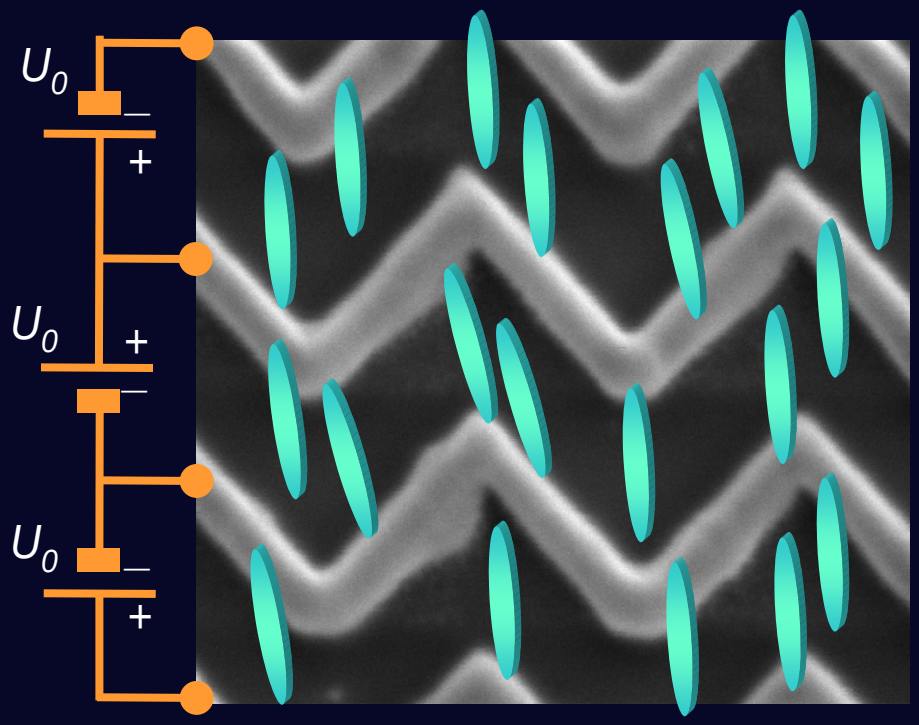
Engaging in-plane LC switching at nano-scale

Spectral tuning $\rightarrow$ in-plane switching of LC



Engaging in-plane LC switching at nano-scale

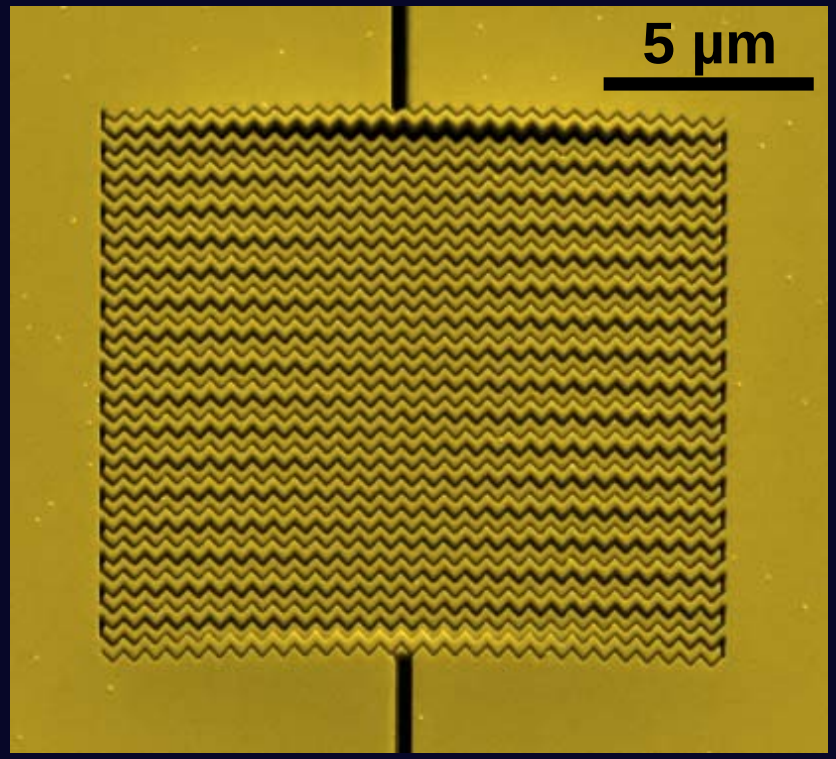
Spectral tuning → in-plane switching of LC

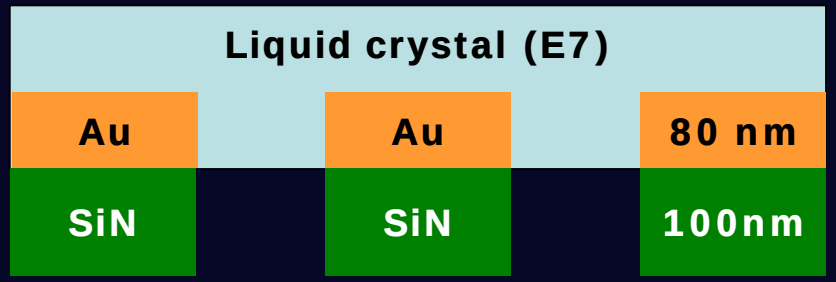


Problem: LC anchoring is too strong

Solution: remove substrate!

Negative zig-zag metamaterial

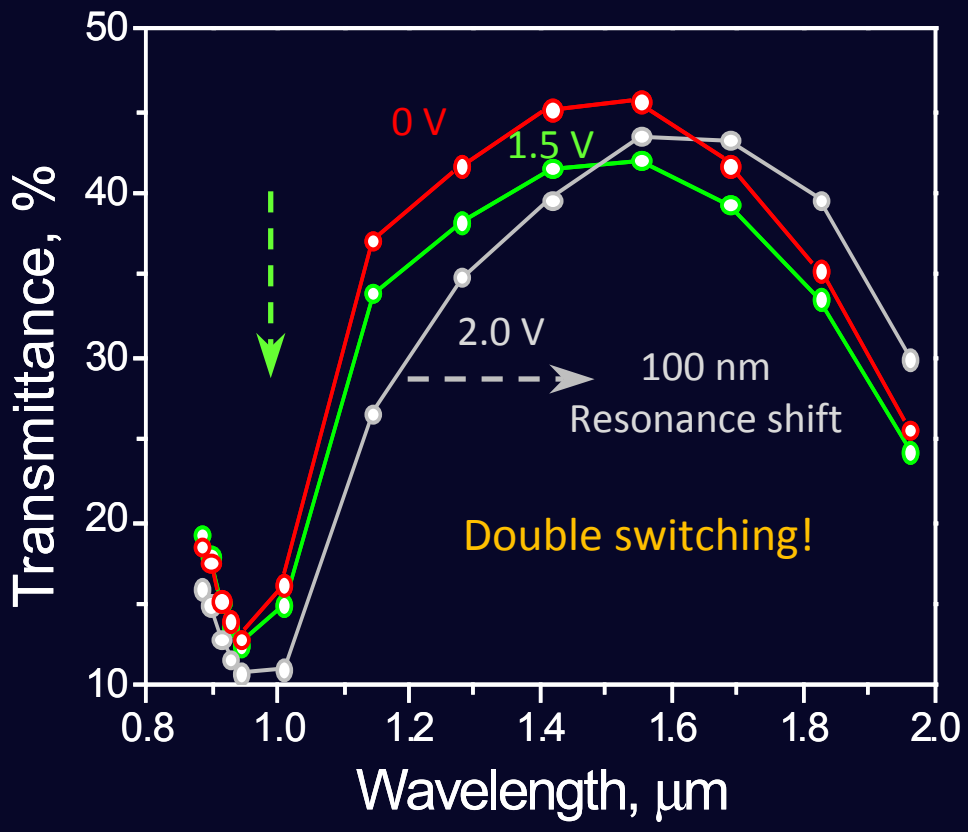


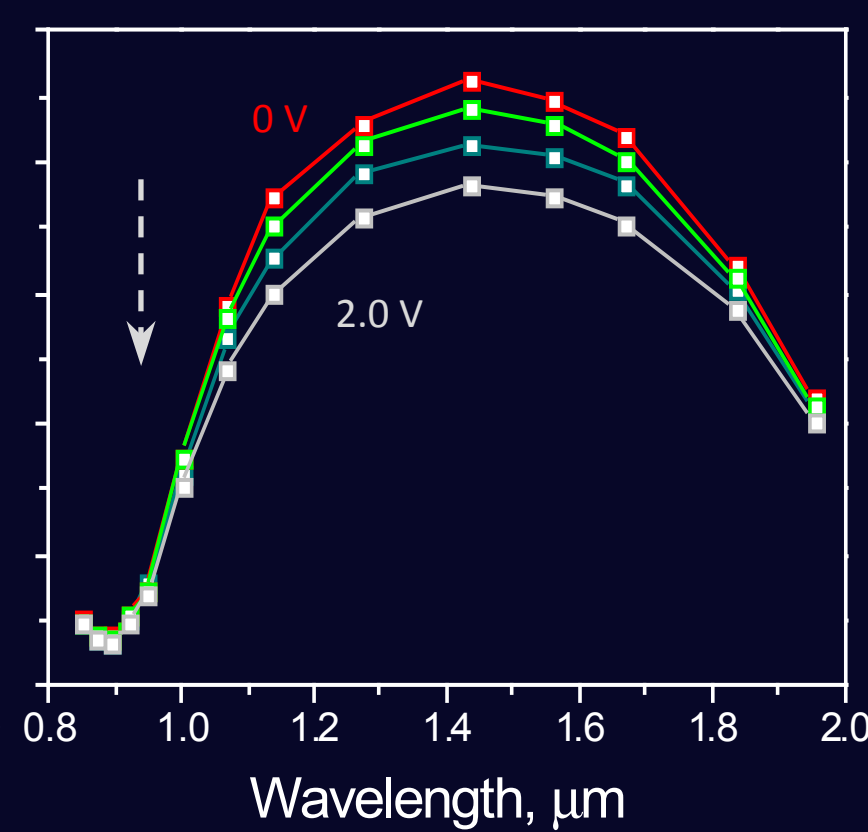


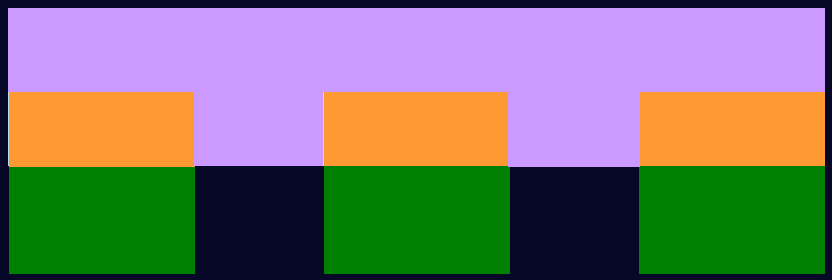
Electrical tuning of LC metamaterial spectrum

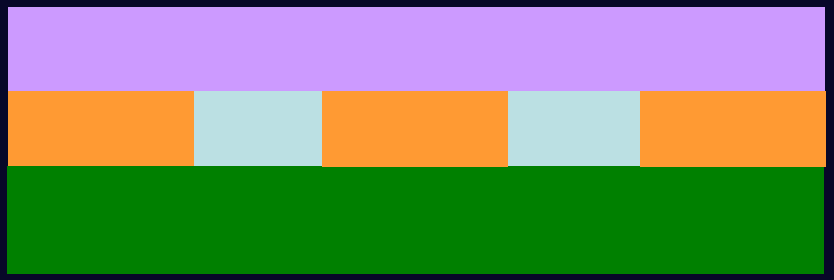
Sample: suspended metamaterial

Reference: metamaterial on substrate

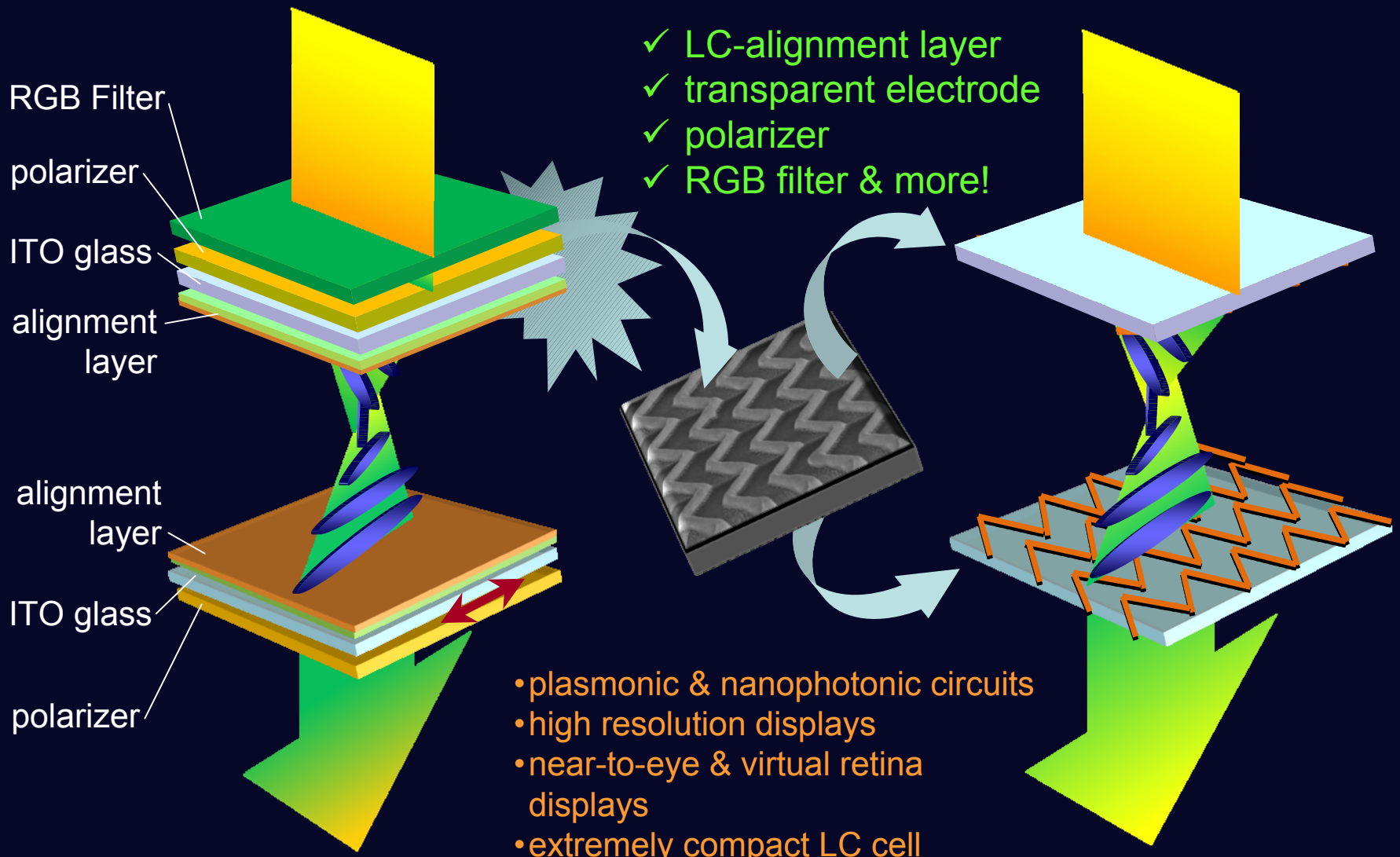




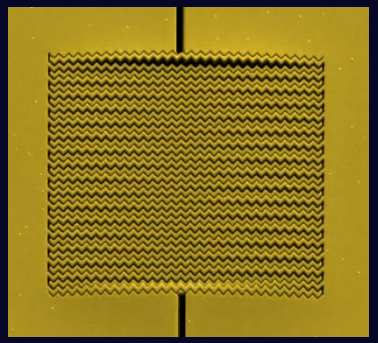




Improving LC devices using planar metamaterials



Summary

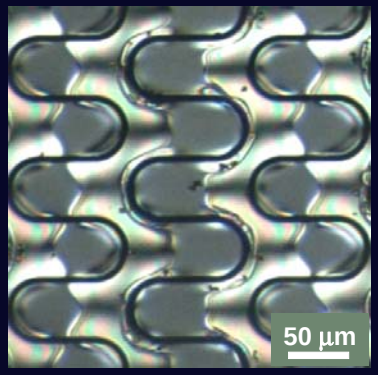


Near-IR

- efficient electrical control of LC-based plasmonic metamaterials
- transmission modulation: 5-fold change @ < 7 V
- 1st time spectral tuning: 7% shift @ only 2 V
- metamaterials to replace key elements of LC-cells

Terahertz

- large-area optically thin switches: 12 μm
- low operational voltage: 20 V
- transmission change: 20%
- phase change: 40 degrees



Watch our space

www.metamaterials.org.uk

Optics Express **21**, 1634 (2013)

Appl. Phys. Lett. 103, 141904 (2013)

University of Southampton Optoelectronics Research Centre

EPSRC Engineering and Physical Sciences Research Council

THE ROYAL SOCIETY

Light