FACULTY OF ENGINEERING AND ARCHITECTURE

ELECTRONICS AND INFORMATION SYSTEMS DEPARTMENT
LIQUID CRYSTALS AND PHOTONICS RESEARCH GROUP

LIQUID CRYSTALS AND LIGHT EMITTING MATERIALS FOR PHOTONIC APPLICATIONS

Kristiaan Neyts April 2018 Lecture series at WAT in Warsaw

GHENT UNIVERSITY

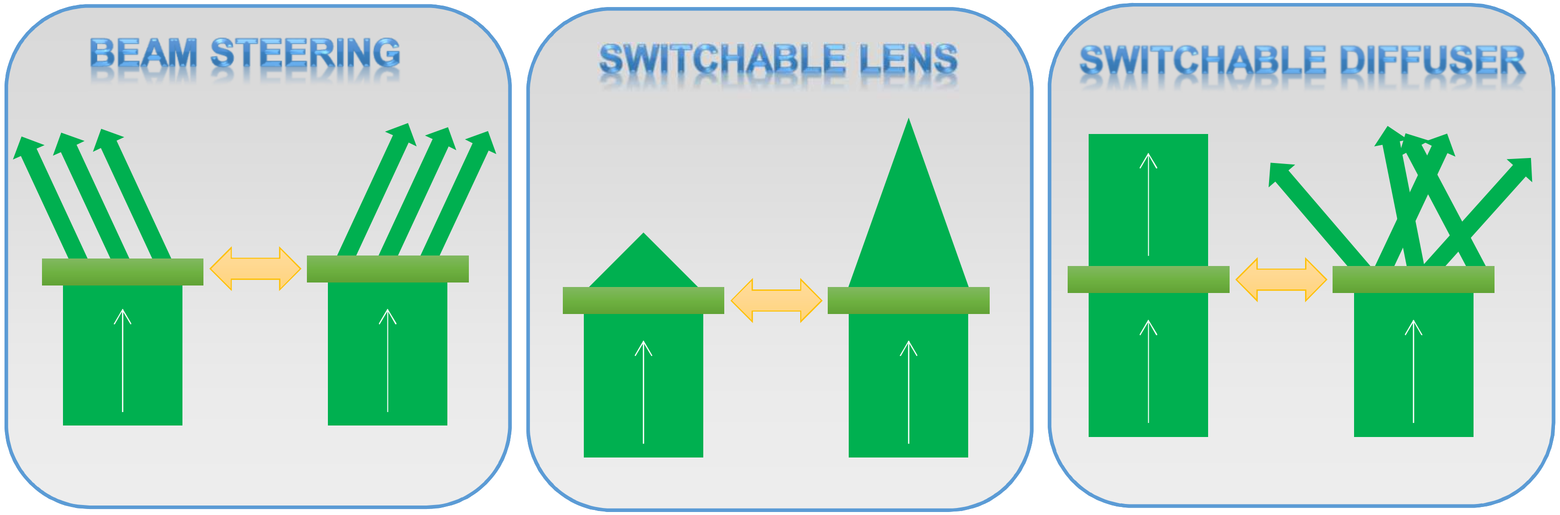
nb-photonics
Center for Nano- and Biophotonics
Ghent University

Liquid Crystals and Photonics

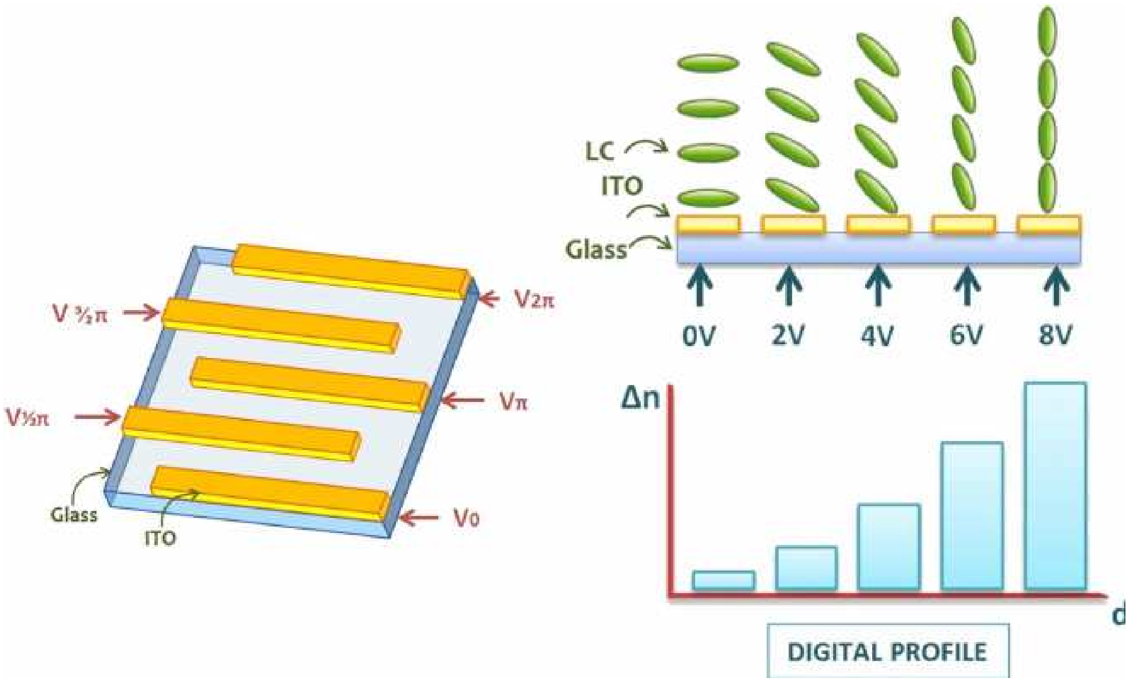
OVERVIEW

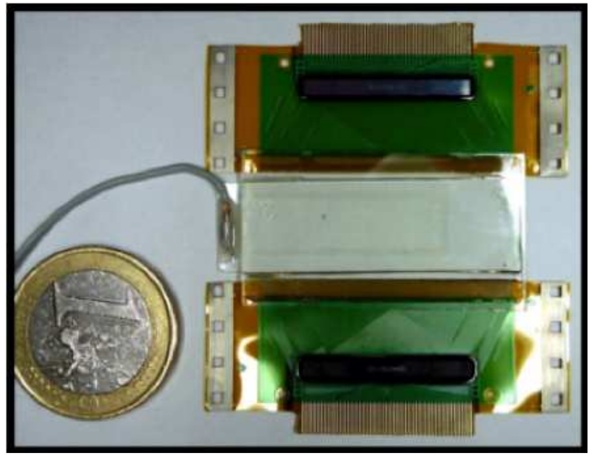
Photonic applications (6h)

- Liquid crystal beam steering
- Liquid crystal tunable lenses
- Liquid crystal smart windows
- Spatial light modulator
- Liquid crystal flat optics
- Wave guide modulation
- Liquid crystal lasing


BEAM STEERING
SWITCHABLE LENS
SWITCHABLE DIFFUSER

LC BEAM STEERING



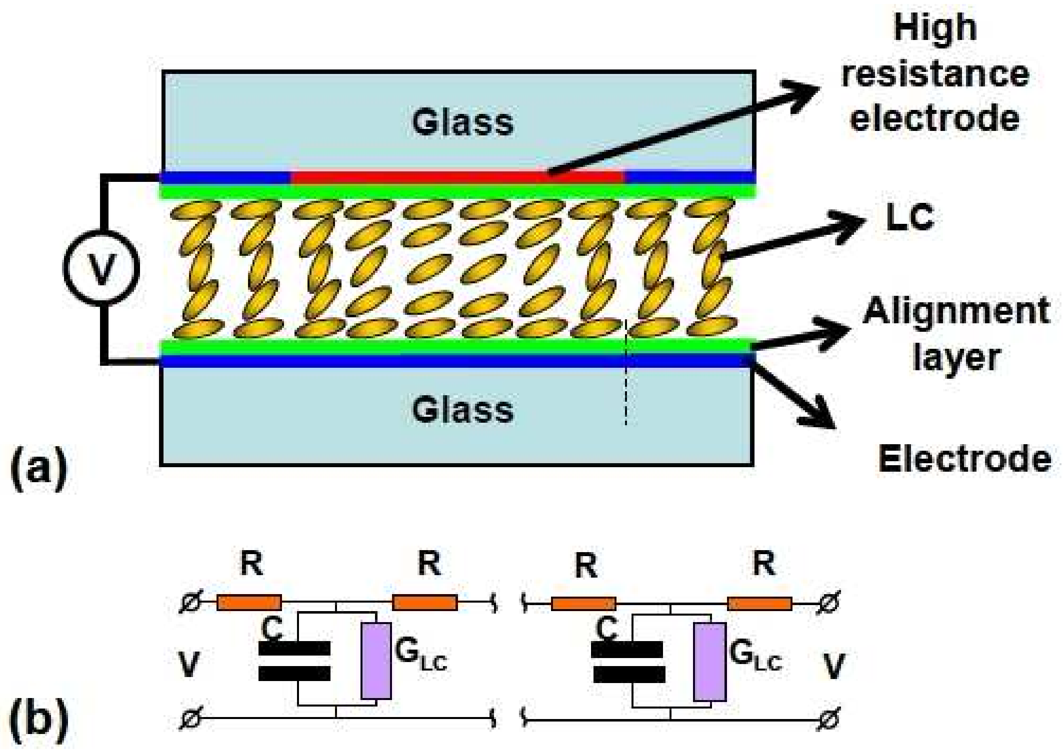


Eva Oton, IEEE photonics journal

Liquid Crystals and Photonics

GHENT UNIVERSITY

LC LENS



flat LC

flat electrodes

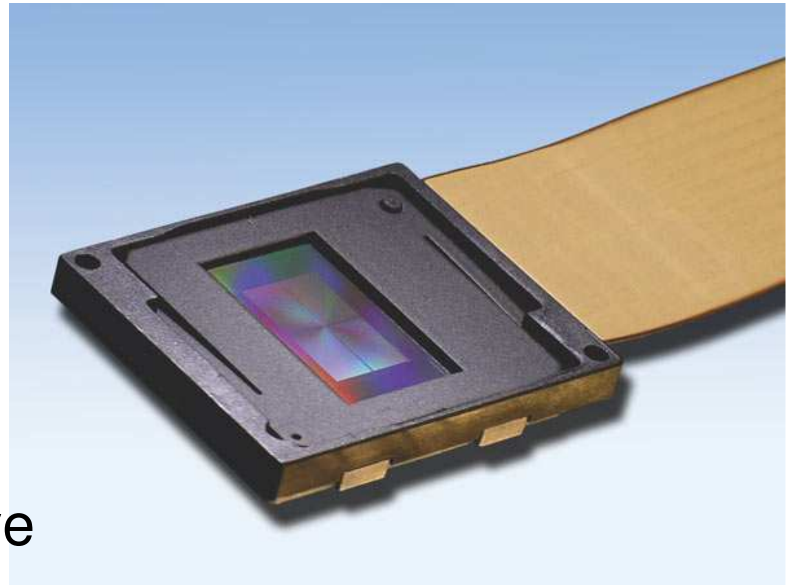
variable voltage

Lin Yi-Hsin

SPATIAL LIGHT MODULATOR

PLUTO-2 Spatial Light Modulator – Microdisplay Features

Display Type:	**Reflective LCOS (Phase Only)**
Resolution:	1920 x 1080
Pixel Pitch:	**8.0 µm**
Fill Factor:	93 % (dependent on version)
Active Area	15.36 x 8.64 mm (0.7″ Diagonal)
Addressing	8 Bit (256 Grey Levels)
Signal Formats	DVI – HDTV Resolution
Input Frame Rate	60 Hz



holoeye

Liquid Crystals and Photonics

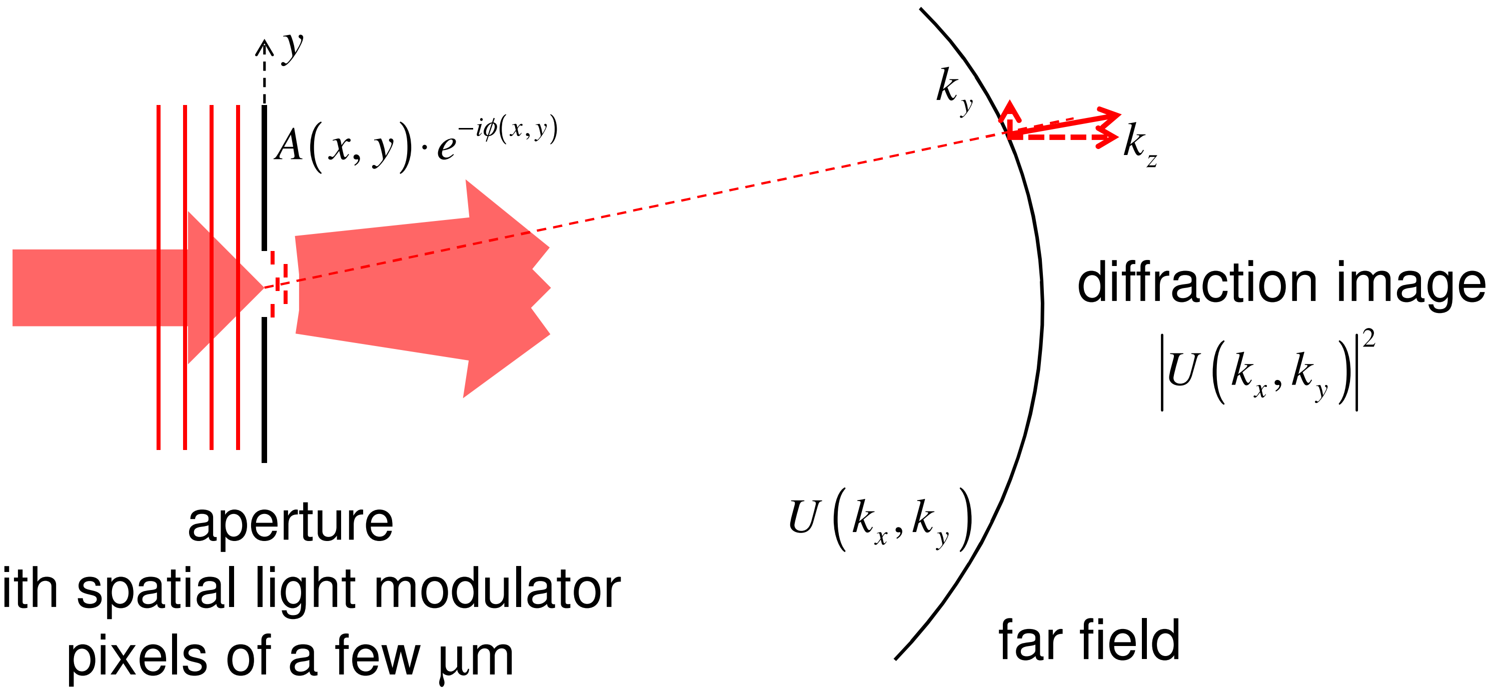
WAT

GHENT UNIVERSITY

HOLOGRAPHIC PROJECTION: SLM

Fraunhofer diffraction: a Fourier transform in the far field

$$U\left(k_x, k_y\right) = \int_{aperture} A(x,y)\cdot e^{i\phi(x,y)}\cdot e^{i\left(k_x x + k_y y\right)} dxdy$$



HOLOGRAPHIC PROJECTION: SLM

nematic LC SLM with PBS: **amplitude modulation**

incident on LC: *s*-pol

0 < retardation < π/2

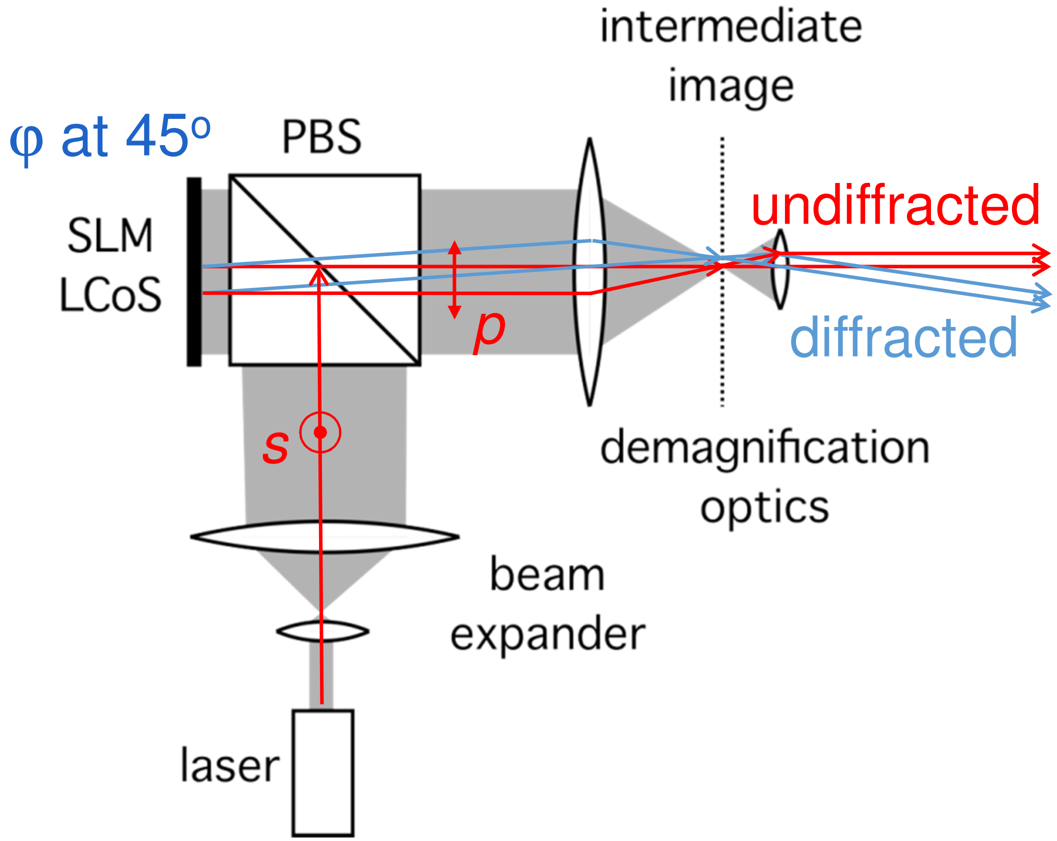
result: *s* or *p*

only *p* transmitted

amplitude modulation

Fourier lens

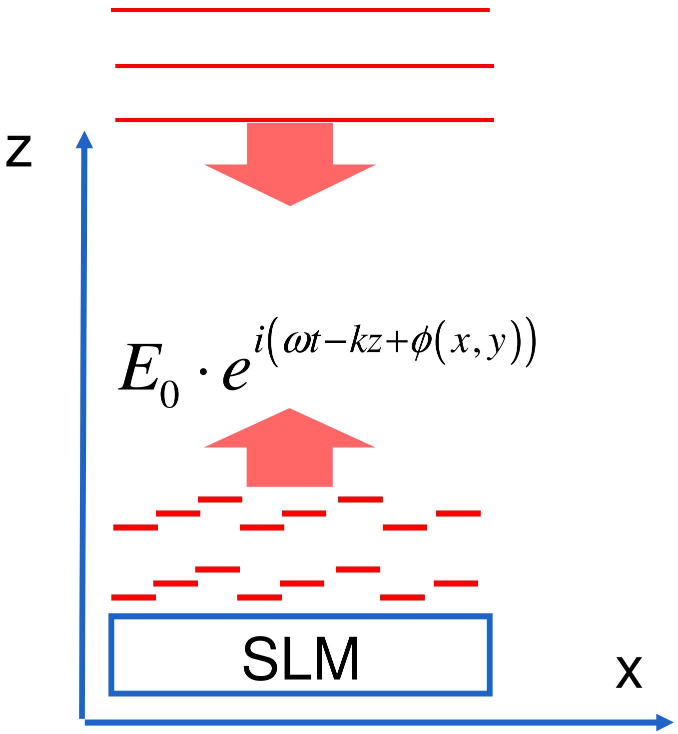
for intermediate image



SPATIAL LIGHT MODULATOR

$$E_0 \cdot e^{i(\omega t + kz)}$$

$$E_0 \cdot e^{i(\omega t - kz + \phi(x,y))}$$

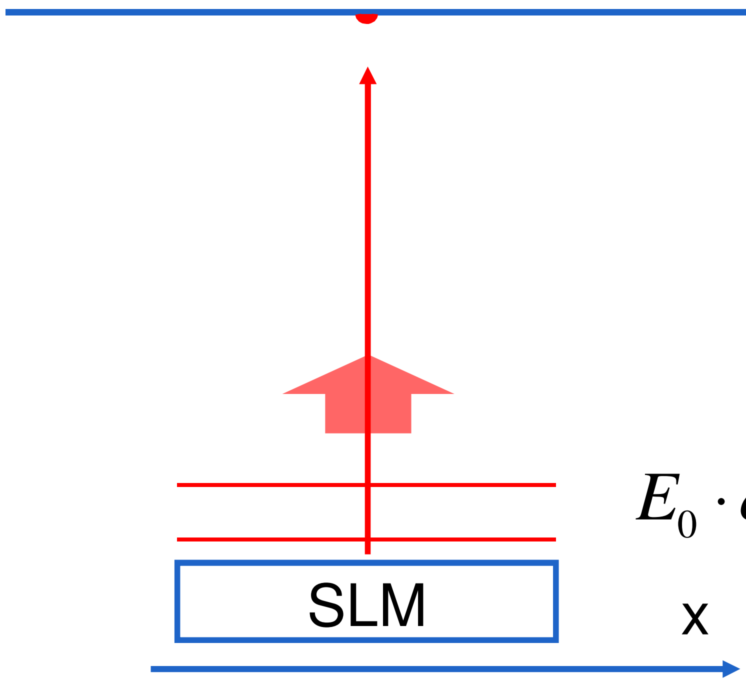


phase of light $\phi(x, y)$

far field pattern

$$U(k_x, k_y) = \int_{aperture} e^{i\phi(x,y)} \cdot e^{i(k_x x + k_y y)} dxdy$$

$$E_0 \cdot e^{i(\omega t - kz + \phi(x,y))}$$



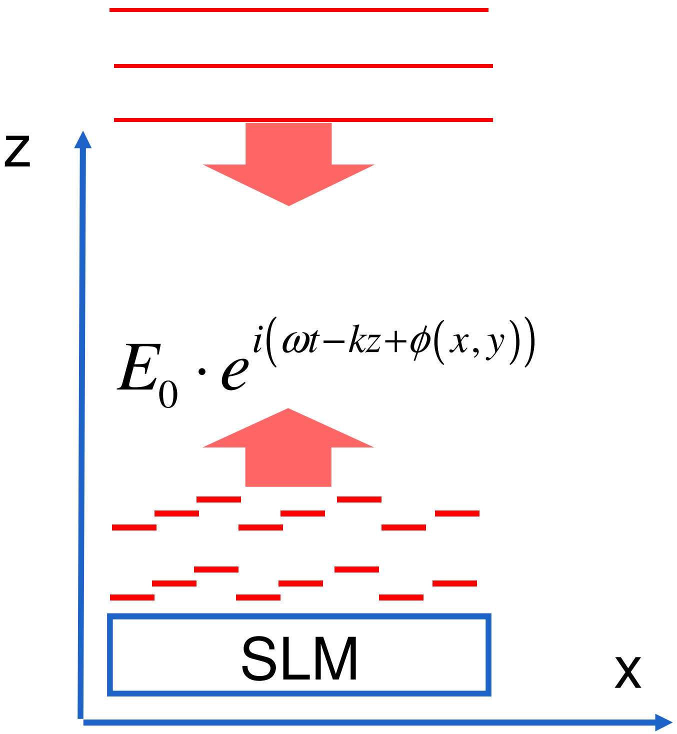
$\phi(x, y) = 0$

Liquid Crystals and Photonics

GHENT UNIVERSITY

SPATIAL LIGHT MODULATOR

$$E_0 \cdot e^{i(\omega t + kz)}$$

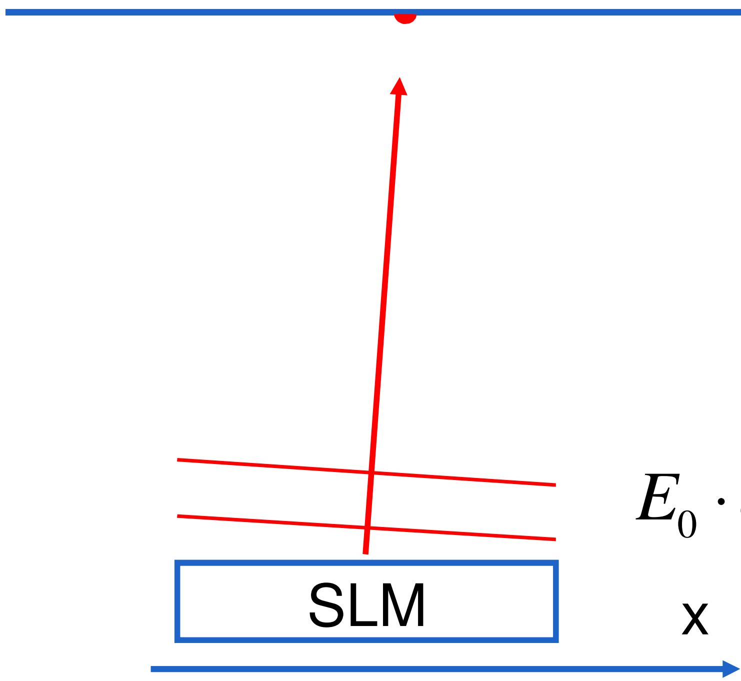


$$E_0 \cdot e^{i(\omega t - kz + \phi(x,y))}$$

phase of light $\phi(x, y)$

far field pattern

$$U(k_x, k_y) = \int_{aperture} e^{i\phi(x,y)} \cdot e^{i(k_x x + k_y y)} dxdy$$



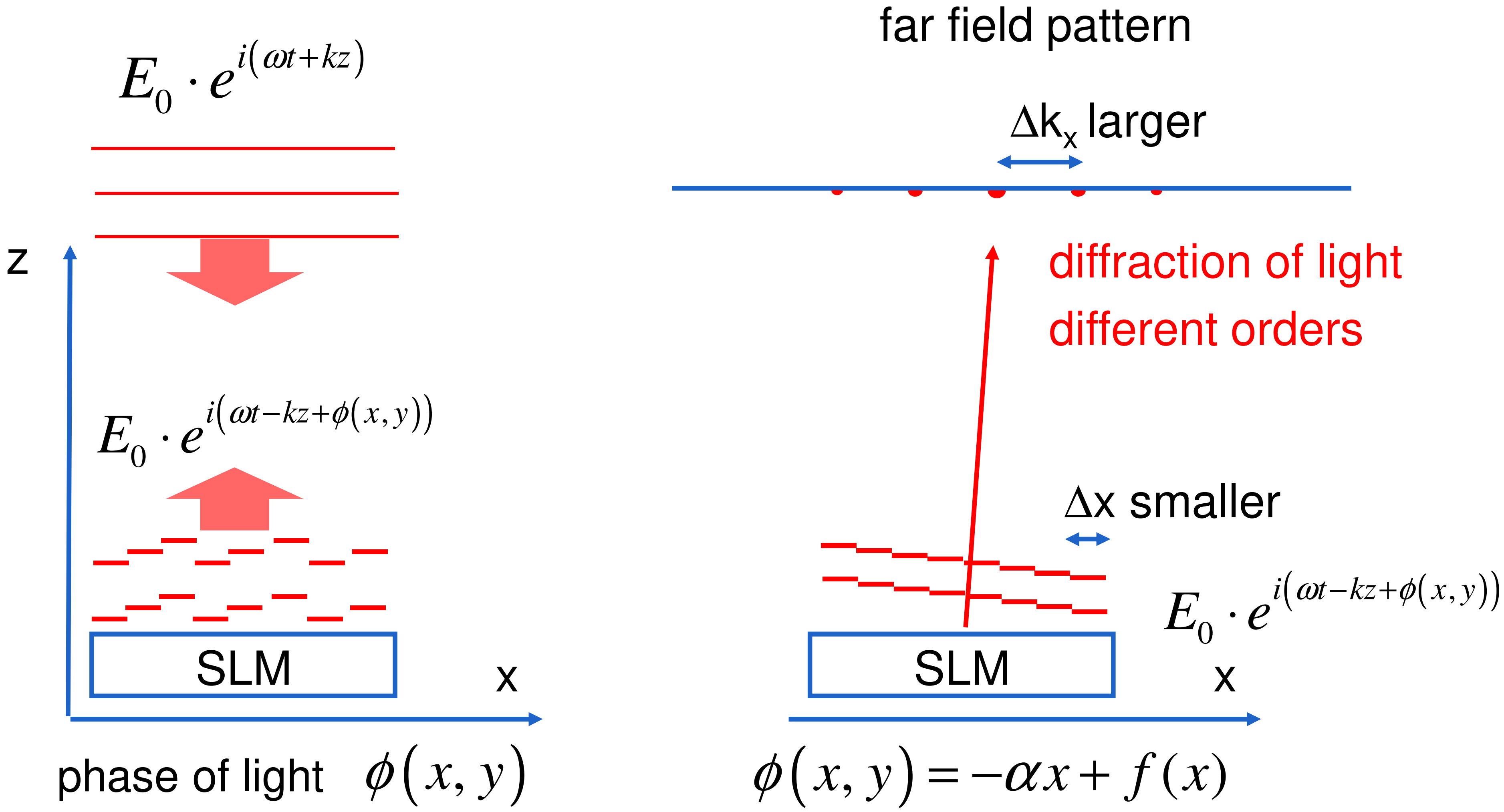
$$E_0 \cdot e^{i(\omega t - kz + \phi(x,y))}$$

$$\phi(x, y) = -\alpha x$$

Liquid Crystals and Photonics

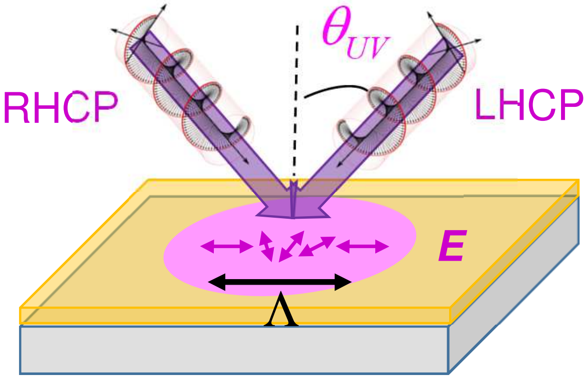
GHENT UNIVERSITY

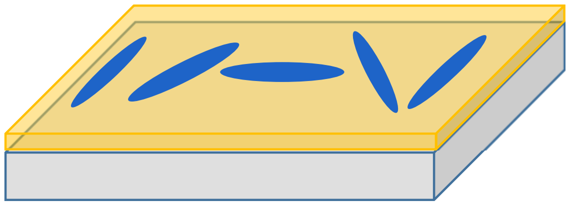
SPATIAL LIGHT MODULATOR

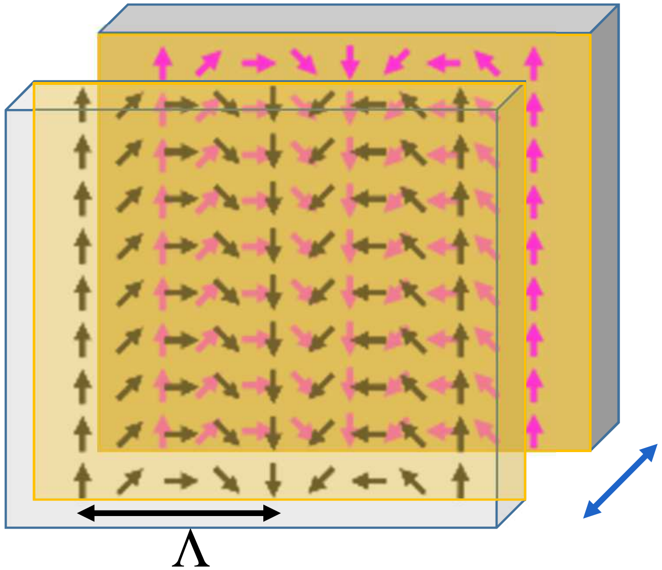


PHASE GRATING

periodic UV illumination







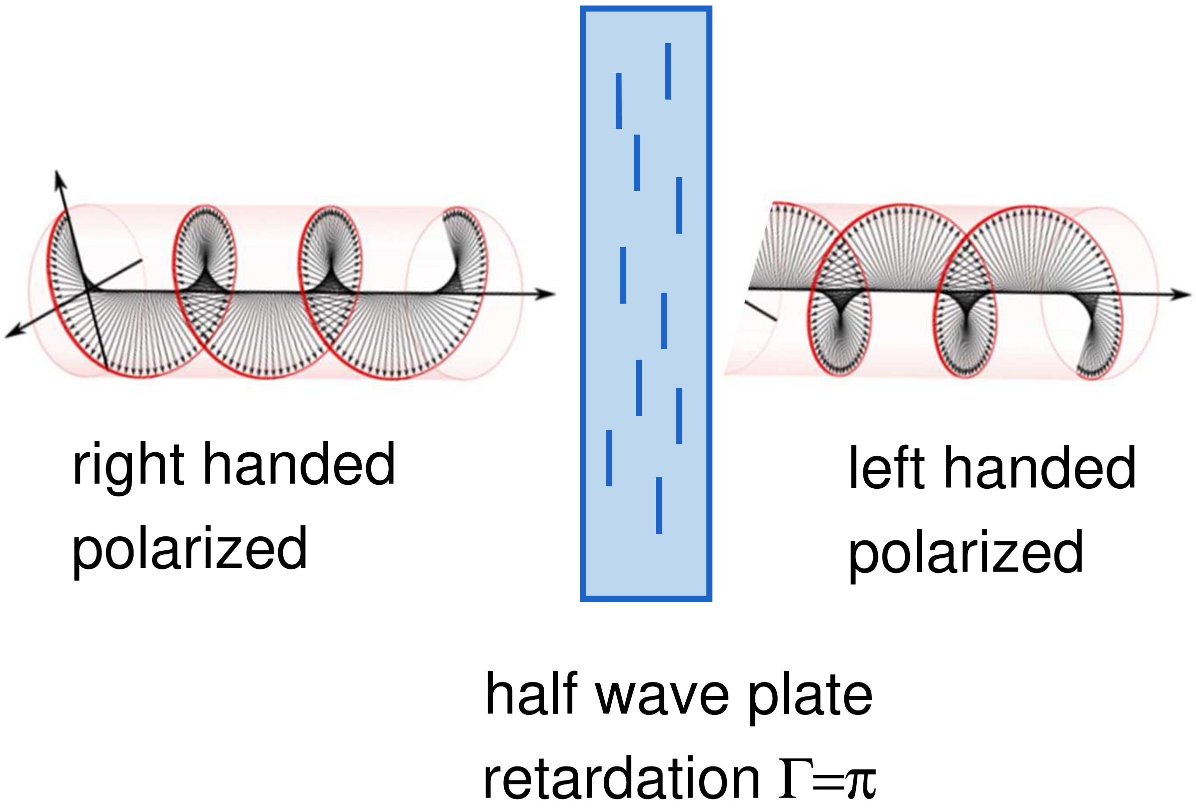
half wave plate

retardation $\Gamma=\pi$

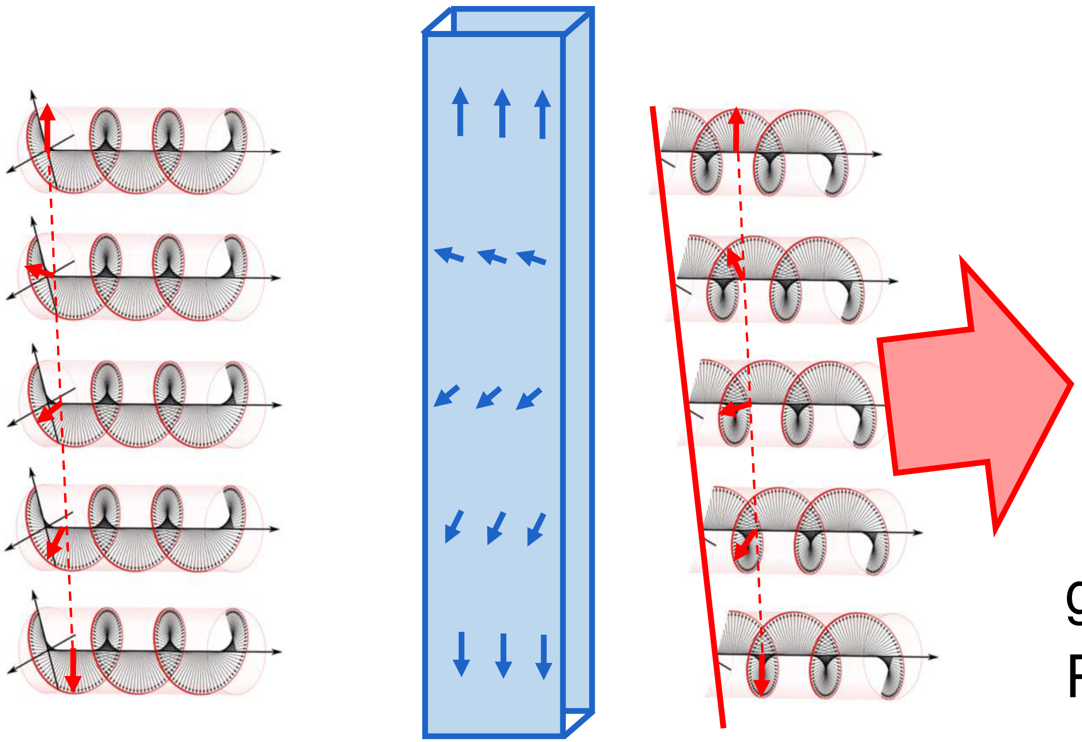
Liquid Crystals and Photonics

GHENT UNIVERSITY

RETARDATION PLATE Π



PHASE GRATING



continuous
phase delay
1 diffraction order

geometric phase
Pancharatnam-Berry

right handed polarized

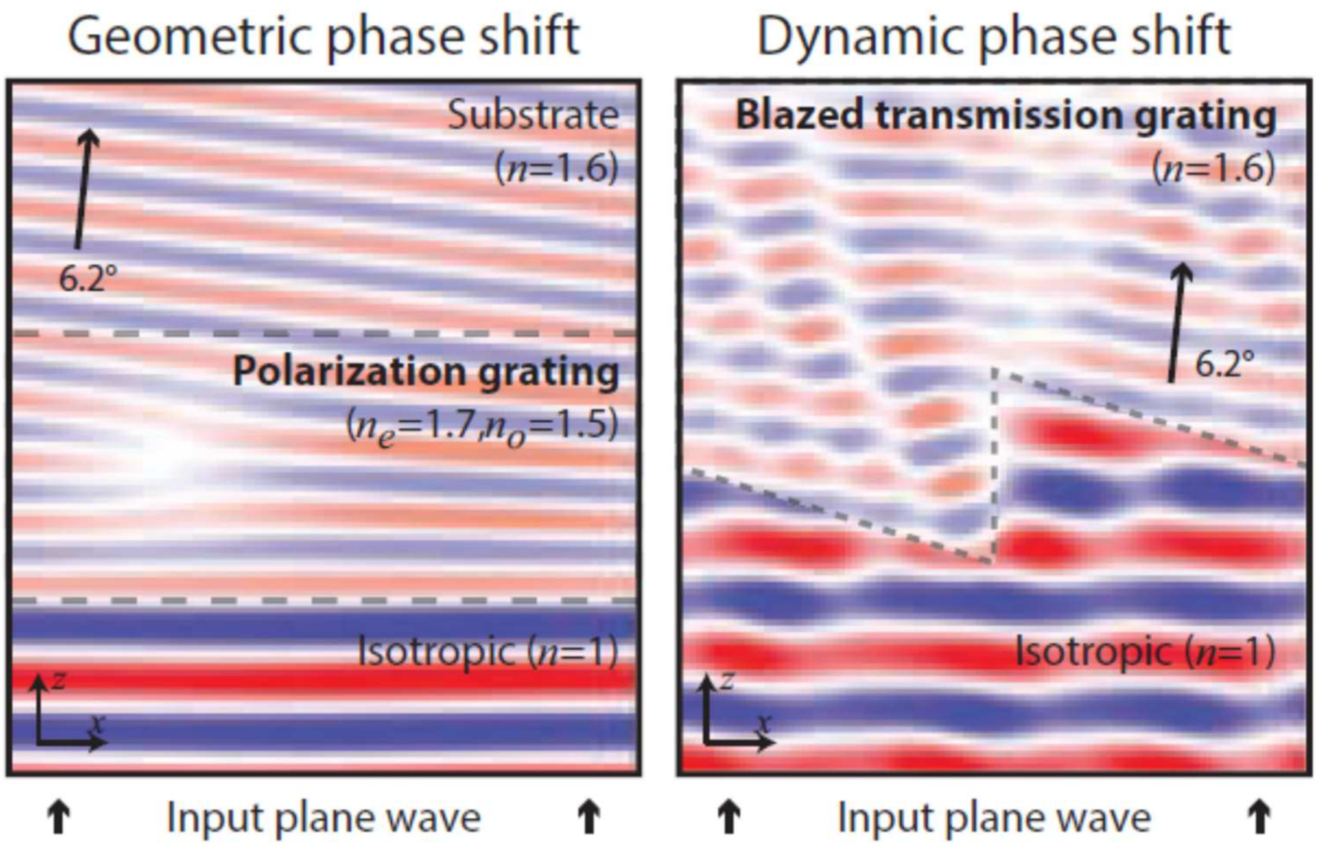
half wave retardation $\Gamma=\pi$

left handed polarized

Liquid Crystals and Photonics

GHENT UNIVERSITY

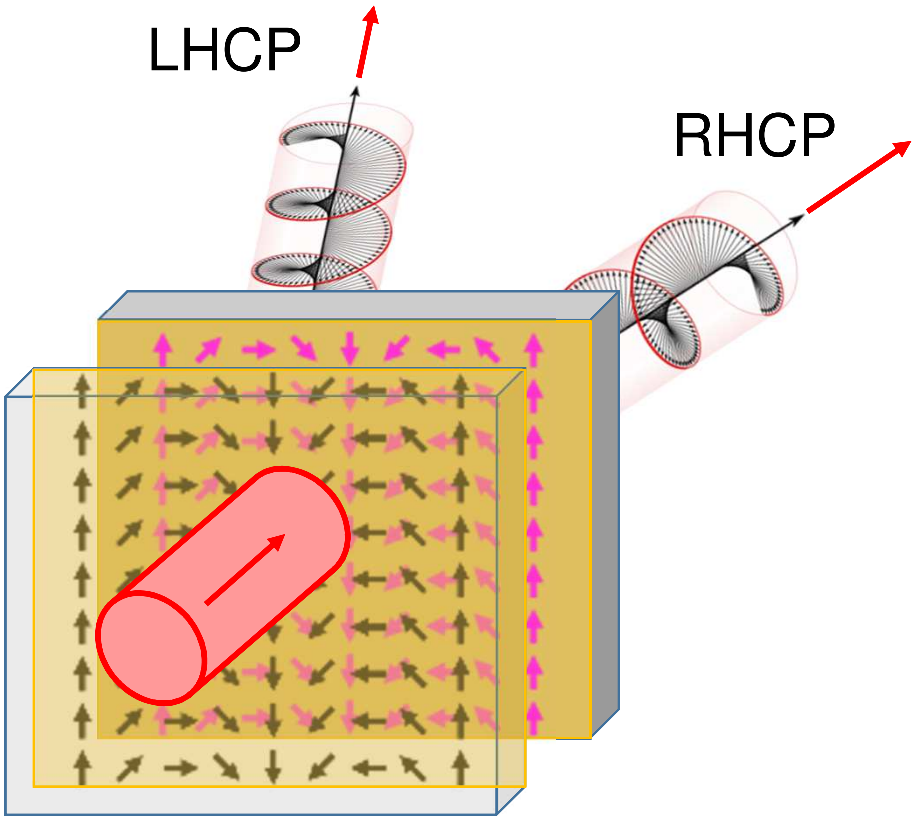
PHASE GRATING

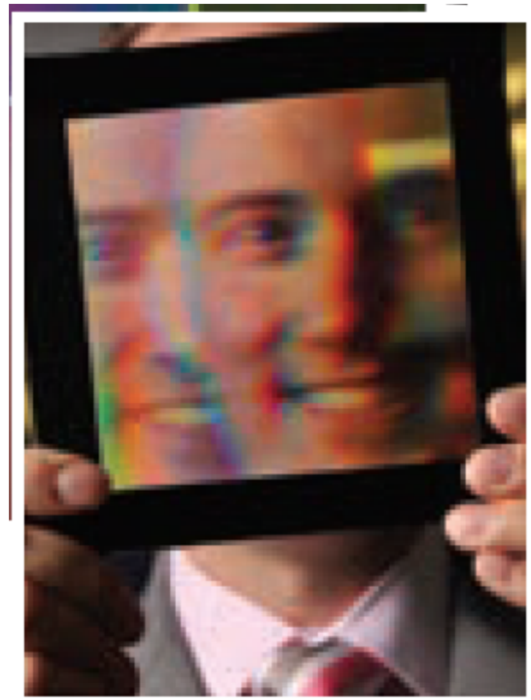


Escuti et al.

PHASE GRATING

RH and LH polarized light are separated



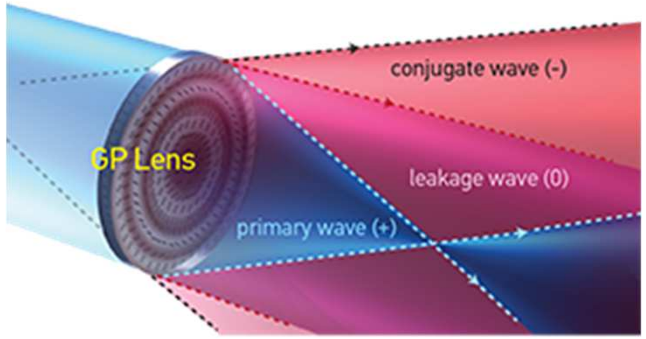


unpolarized incident light

1D OPTICAL AXIS GRATING

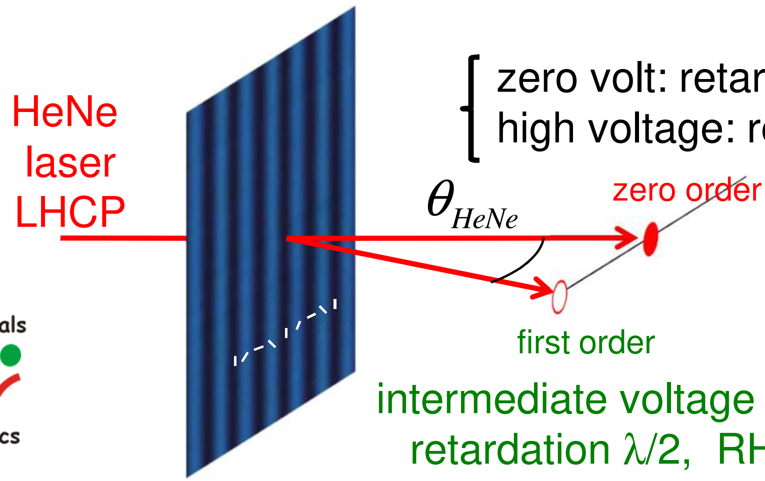
Photo-alignment SD1 (Hong Kong University of Technology)

Photo-alignment PAAD22 (Beam Co)



Pancharatnam filter

geometric phase grating (π)

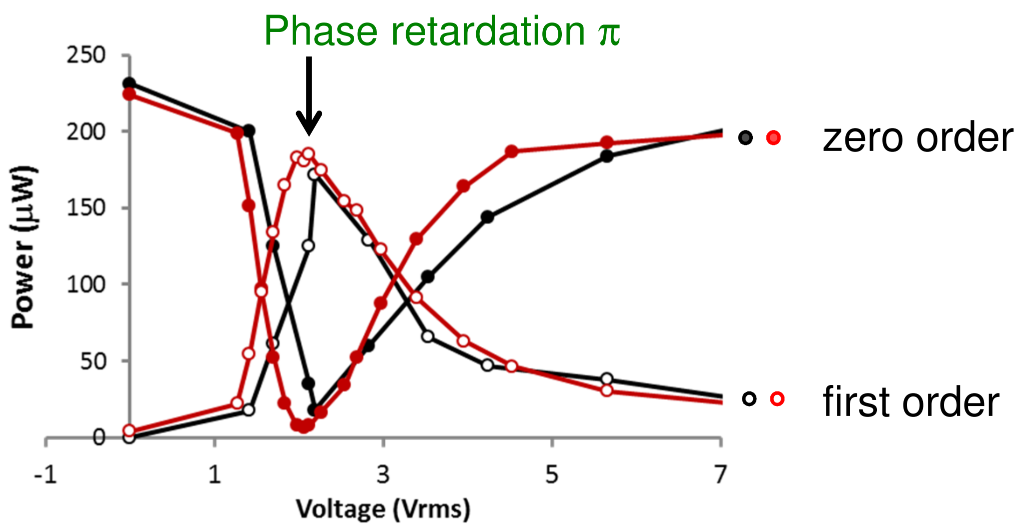


zero volt: retardation ~ λ

high voltage: retardation 0

intermediate voltage (2V):

retardation $\lambda/2$, RHCP



Liquid Crystals and Photonics

$$\sin\theta_{HeNe} = \frac{\lambda_{HeNe}}{\Lambda}$$

Λ =6.5 μm

d =3 μm

Δnd = 600 nm

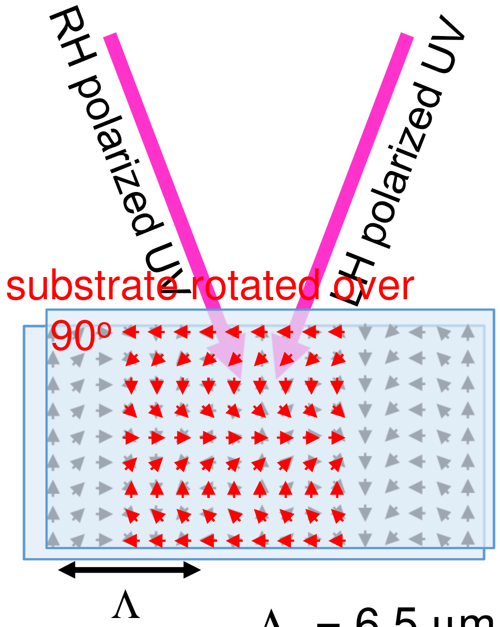
λ_{HeNe}= 632 nm

GHENT UNIVERSITY

2D PERIODIC GRATING

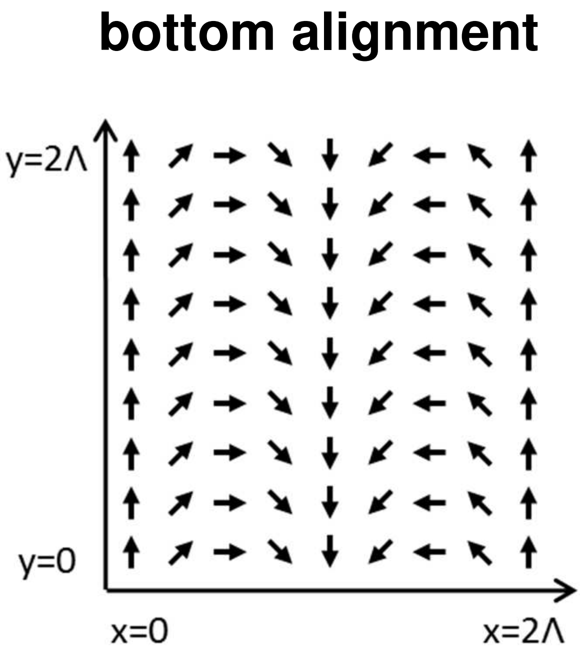
alignment rotated over 90°

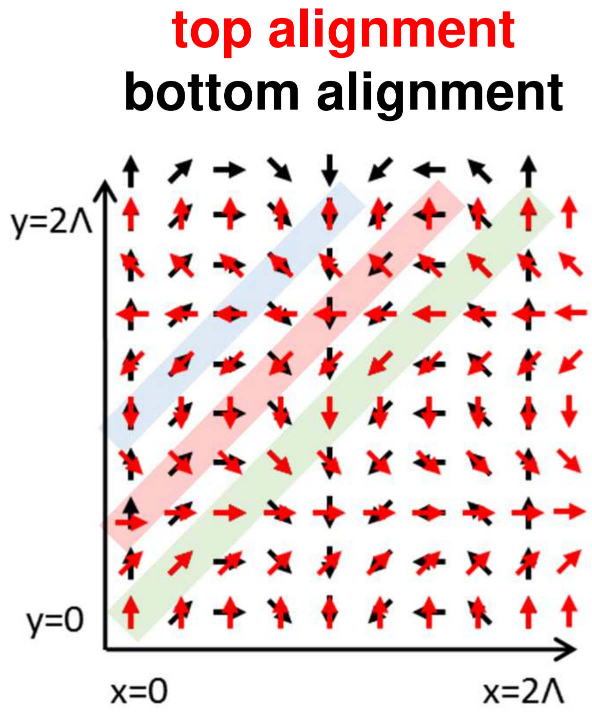
top compared to bottom substrate



Λ = 6.5 μm

d = 3 μm

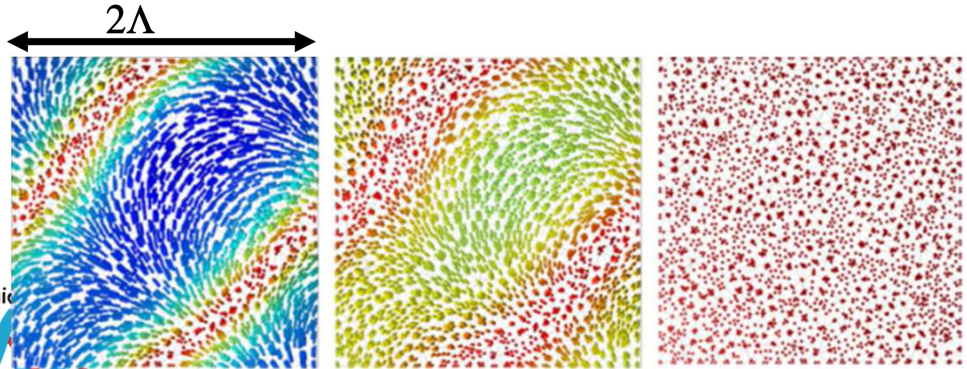




2D PERIODIC GRATING

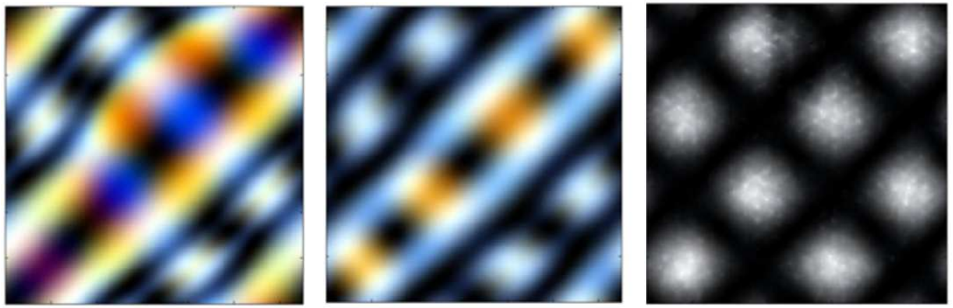
Results of the numerical calculations (strong anchoring)

simulated mid-plane director



0 V_{RMS} 1,5 V_{RMS} 4 V_{RMS}

simulated transmission (Jones calc)



1 V_{RMS} 1,5 V_{RMS} 4 V_{RMS}

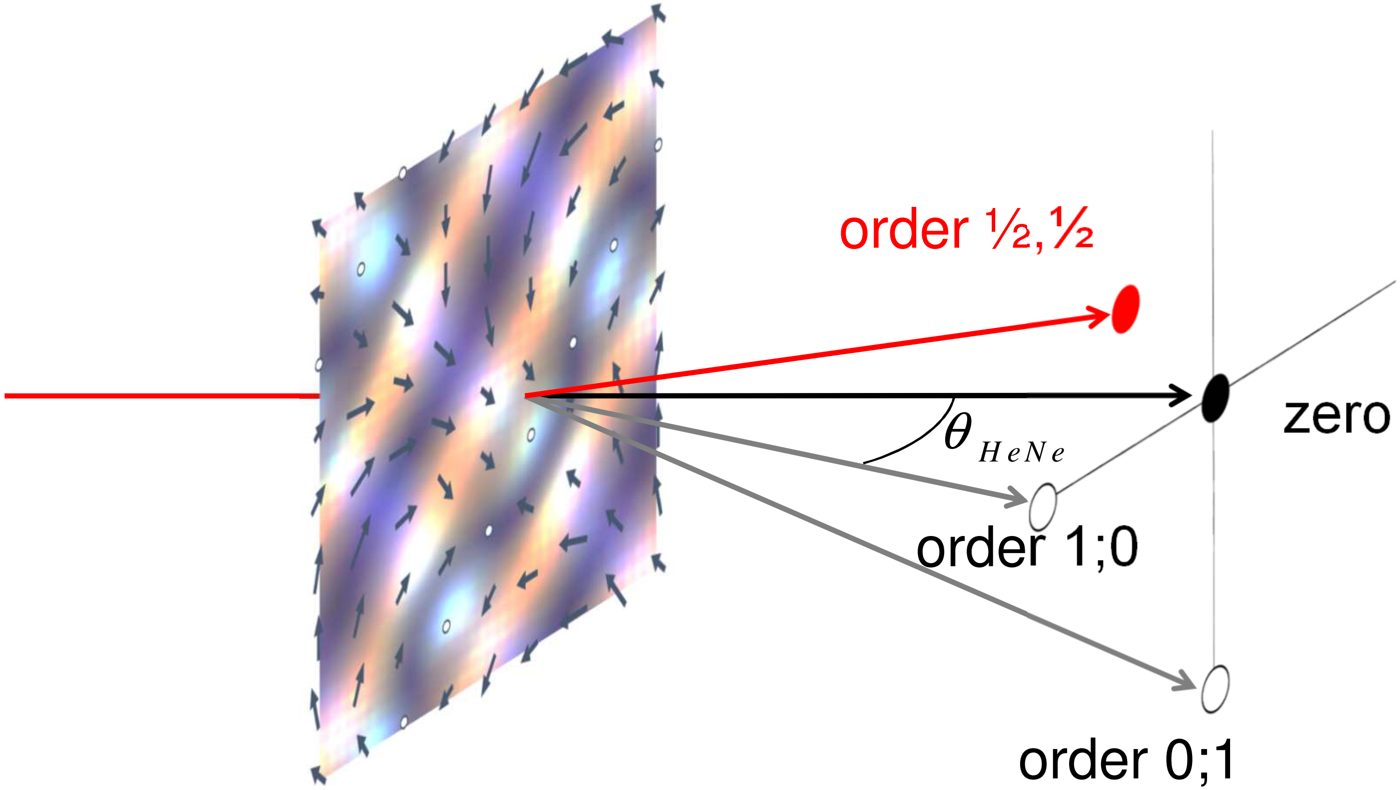
measured transmission

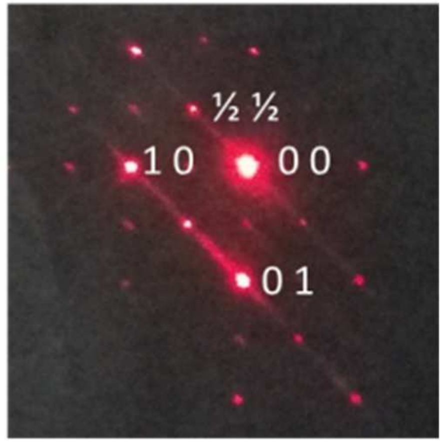
polarization microscopy with crossed polarizers

1.5 V_p 2 V_p 3 V_p

GHENT UNIVERSITY

DIFFRACTION WITH 2D GRATING





$$\sin \theta_{HeNe} = \frac{\lambda_{HeNe}}{\Lambda}$$

Liquid Crystals and Photonics

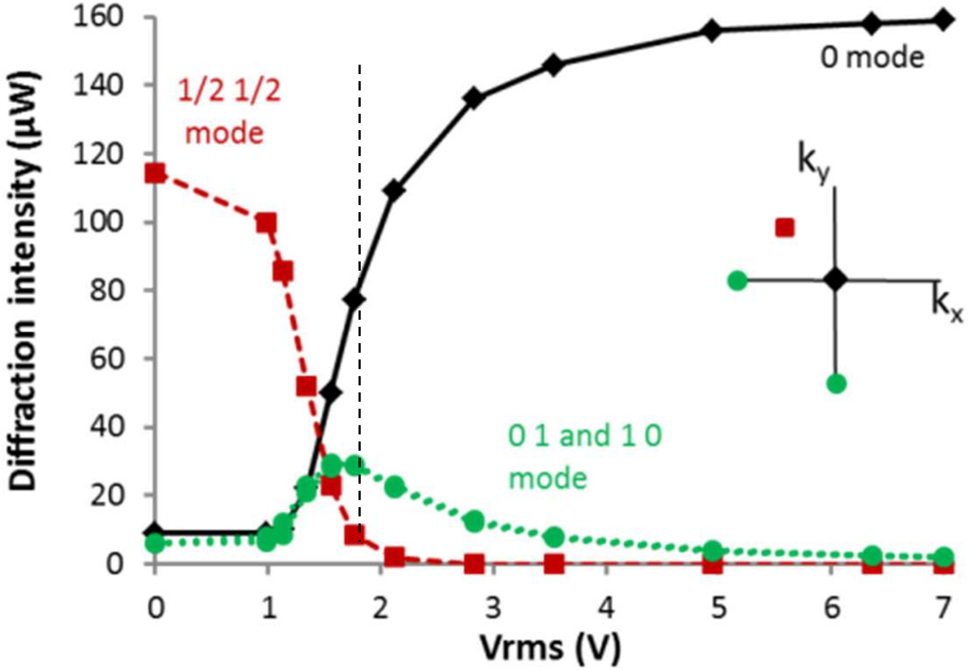
WAT

GHENT UNIVERSITY

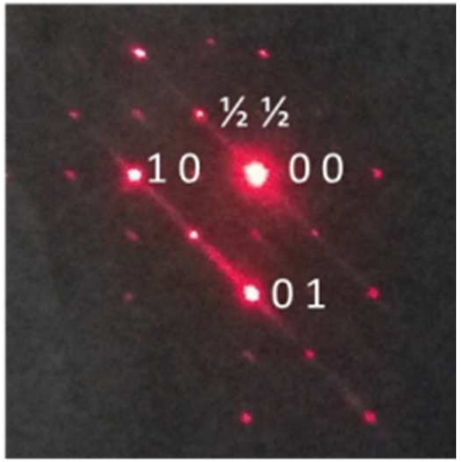
2D PERIODIC GRATING

highly efficient switchable 2D diffraction grating

Voltage dependency



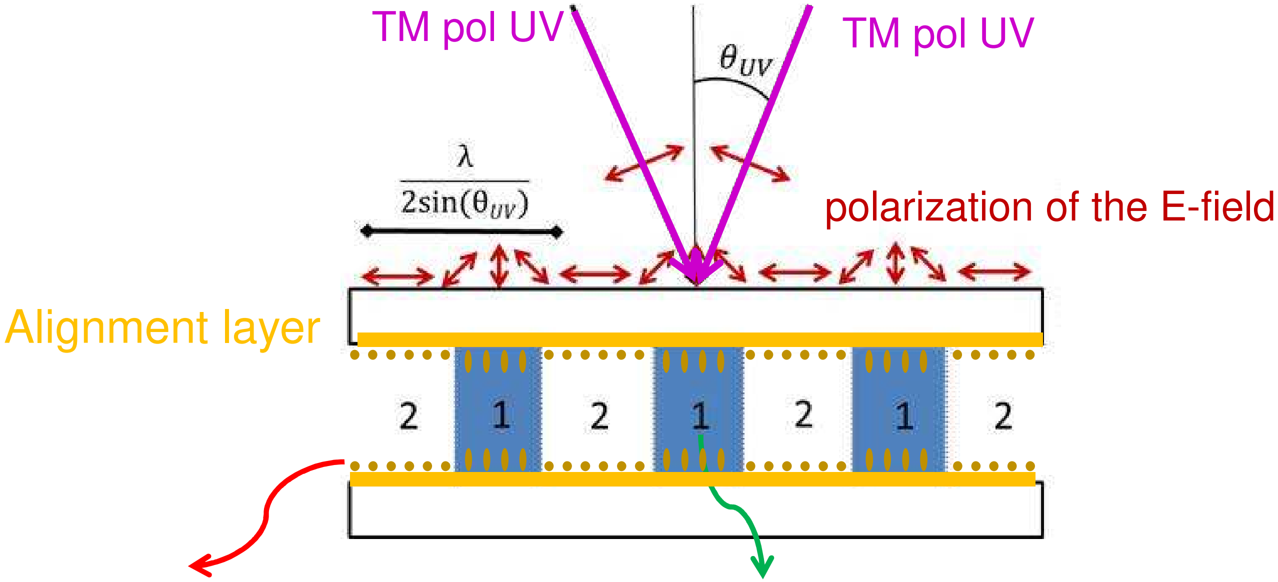
2D diffraction grating



Nys, Soft matter 11, 7802 (2015)

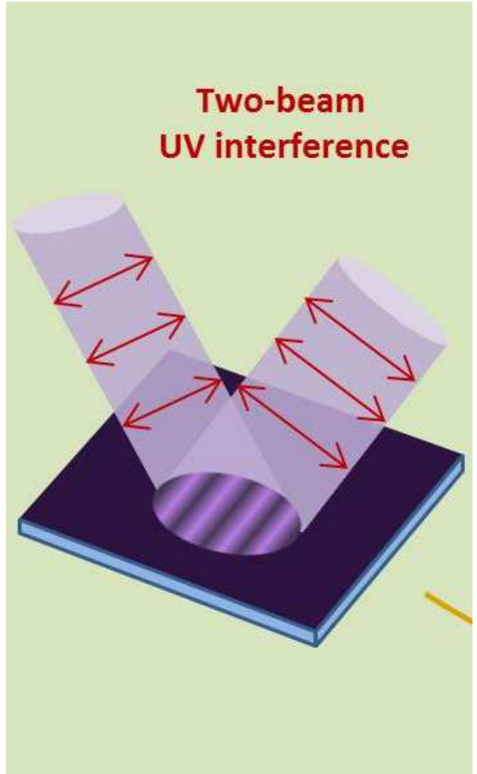
PERIODIC HOMEOTROPIC/PLANAR ALIGNMENT

mixture of 90 wt% PAAD22 (photo-alignment)
and 10 wt% SE4811 (homeotropic alignment)



Alignment becomes **planar** in region 2 (strong illumination)

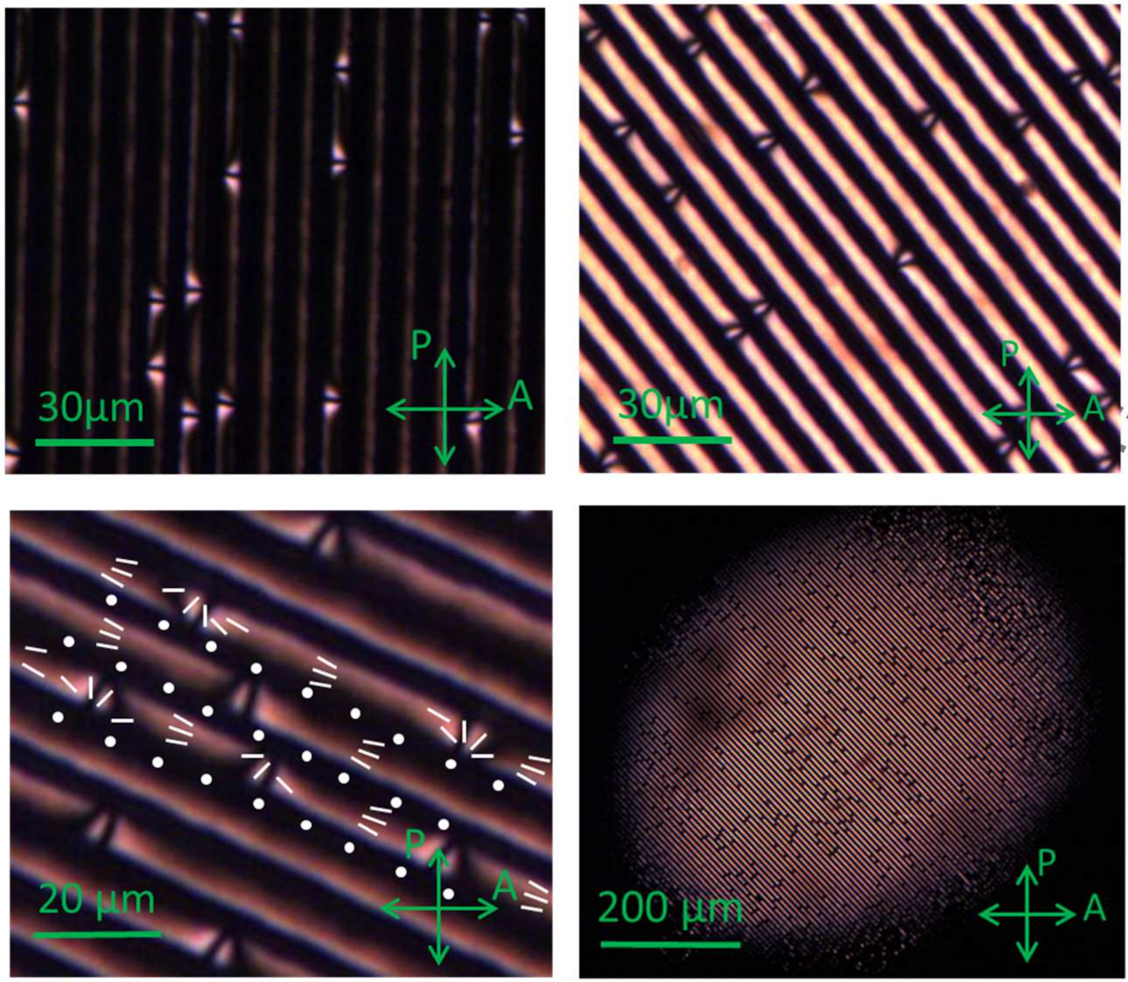
Alignment remains **homeotropic** in region 1 weak illumination

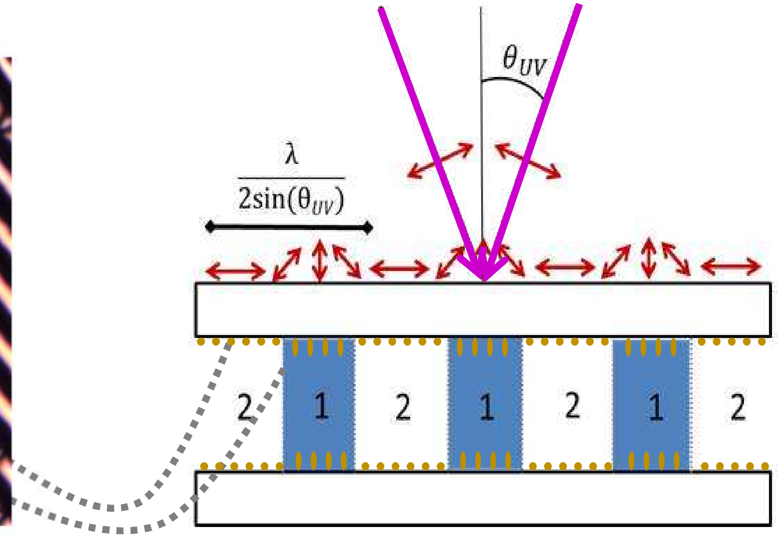


Liquid Crystals and Photonics

GHENT UNIVERSITY

PERIODIC HOMEOTROPIC/PLANAR ALIGNMENT





Nematic LC
follows the boundary conditions
(planar or homeotropic)
transition region with twist

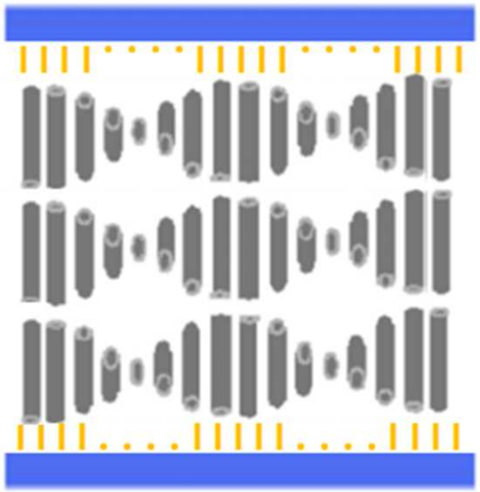
V=0

Liquid Crystals and Photonics

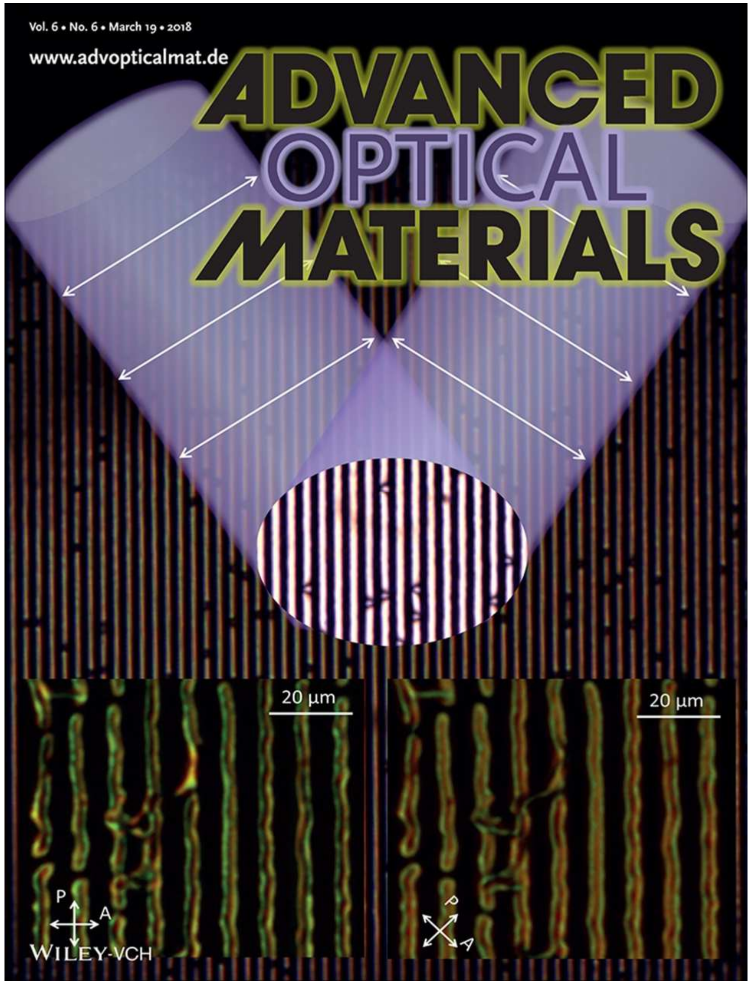
GHENT UNIVERSITY

PERIODIC HOMEOTROPIC/PLANAR ALIGNMENT

Add chiral liquid crystal on this structure



?



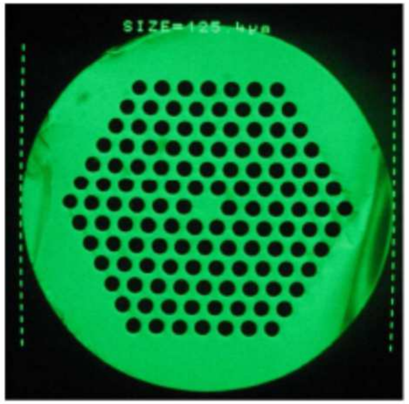
Nys, *Adv. Optical Mater.* **2018**, 1701163

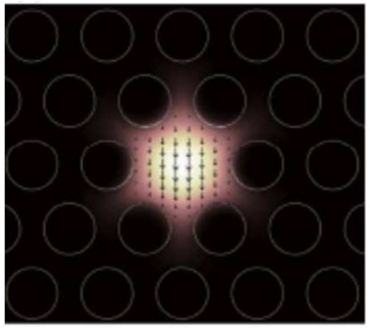
Liquid Crystals and Photonics

GHENT UNIVERSITY

WAVEGUIDES WITH LC

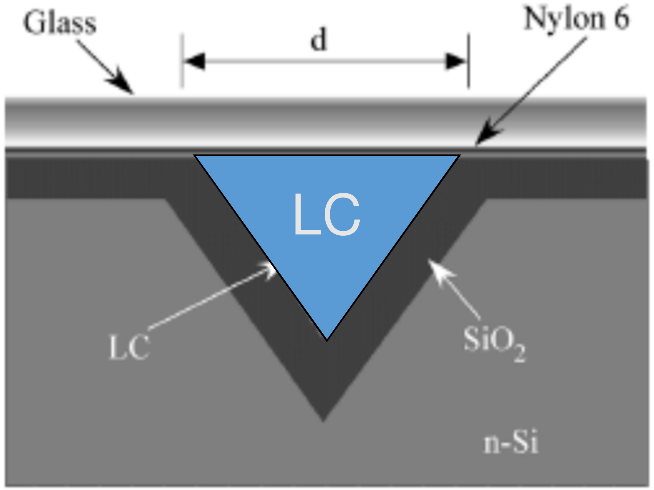
Holey fibers filled with LC

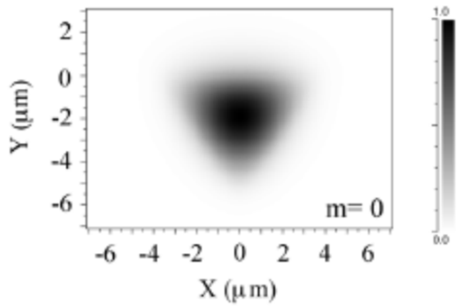




S. Ertman et al.,Optics Express 2009

Groove in silicon wafer with SiO_2 and LC



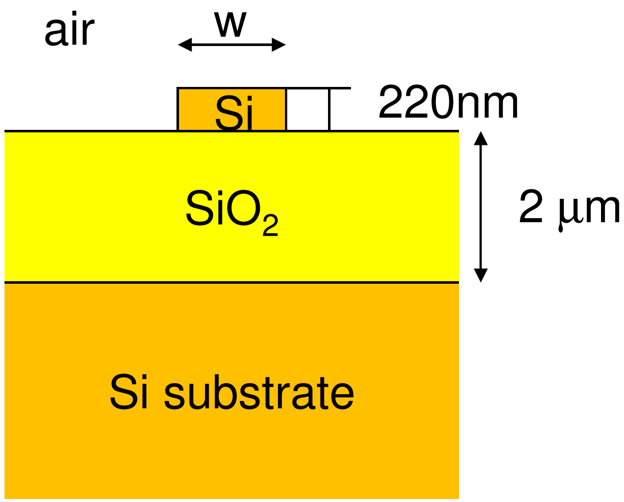


A. d'Alessandro, IEEE JQE 2006

Liquid Crystals and Photonics

GHENT UNIVERSITY

SILICON WAVEGUIDES

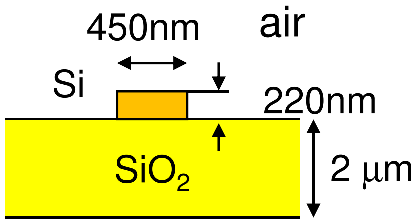


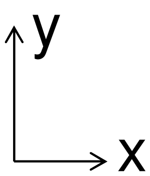
Silicon on Insulator waveguides

- Transparent for 1550 nm (telecom)
- High index contrast (n_{Si}=3.5, n_{SiO2}=1.45)
- CMOS compatible
- small size (193nm DUV lithography)
- limited accuracy, tuning/trimming

SOI samples by IMEC – INTEC Photonics Research Group

SILICON WAVEGUIDES



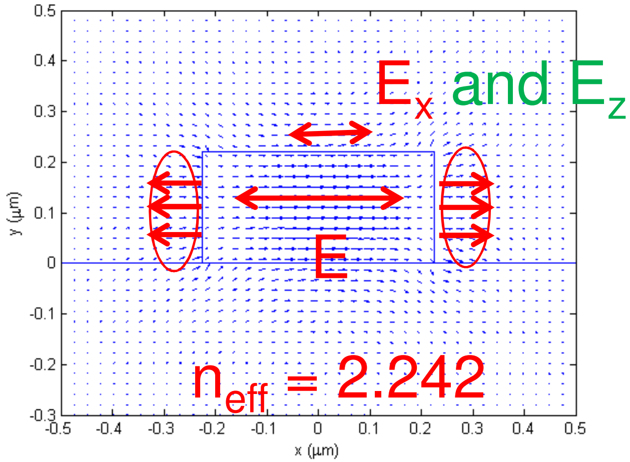


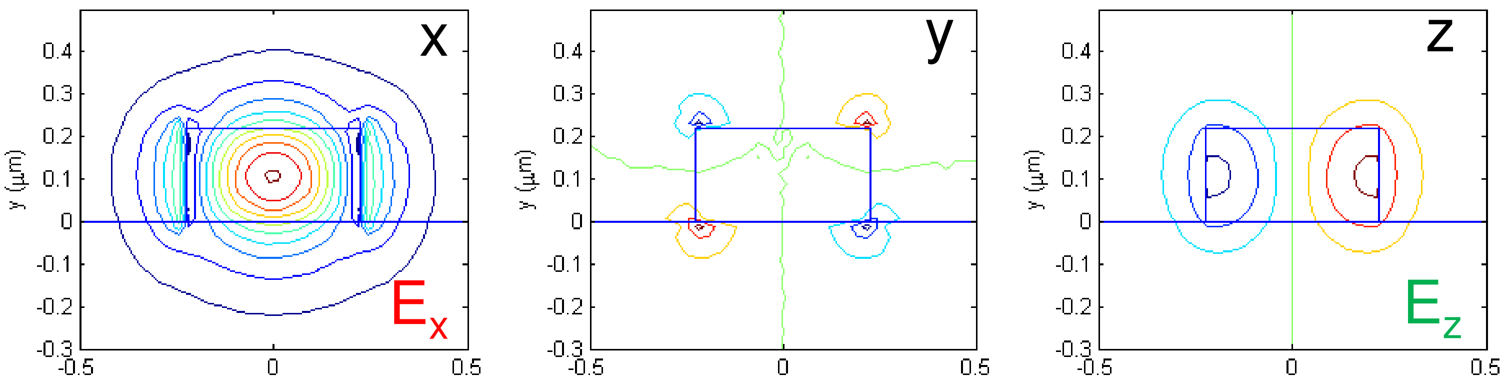
$\lambda = 1550$ nm

$n_{Si} = 3.5$

$n_{SiO2} = 1.45$

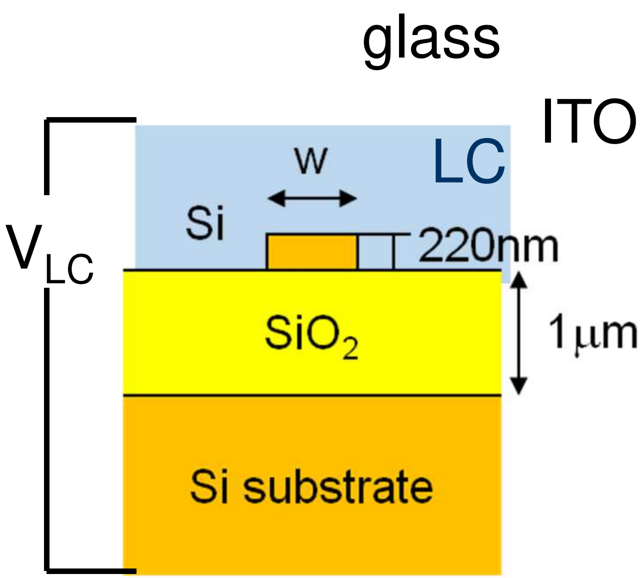
TE polarized mode

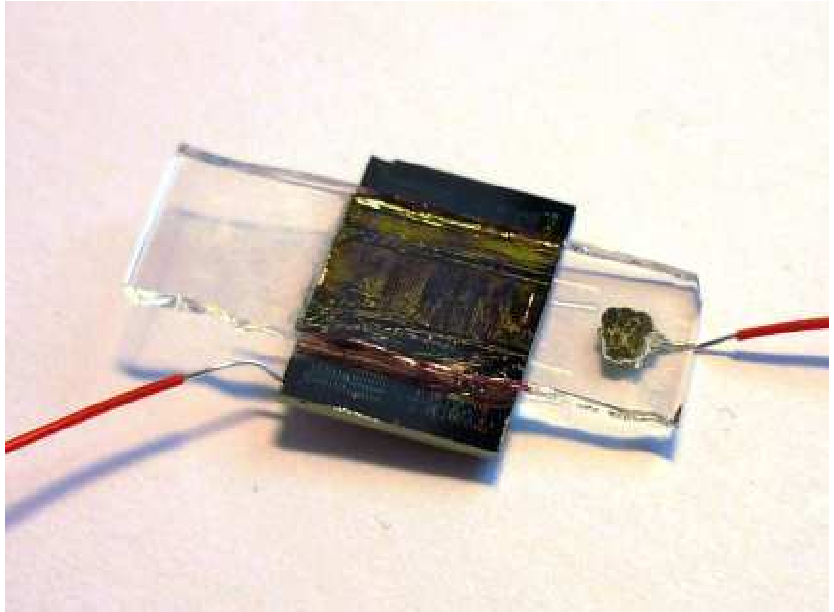




SOI WAVEGUIDE WITH LC

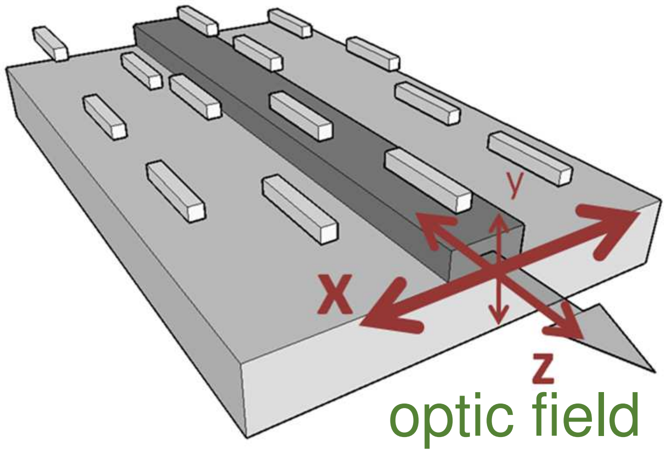
SOI: high index Si core, low index cladding: SiO_2 and LC





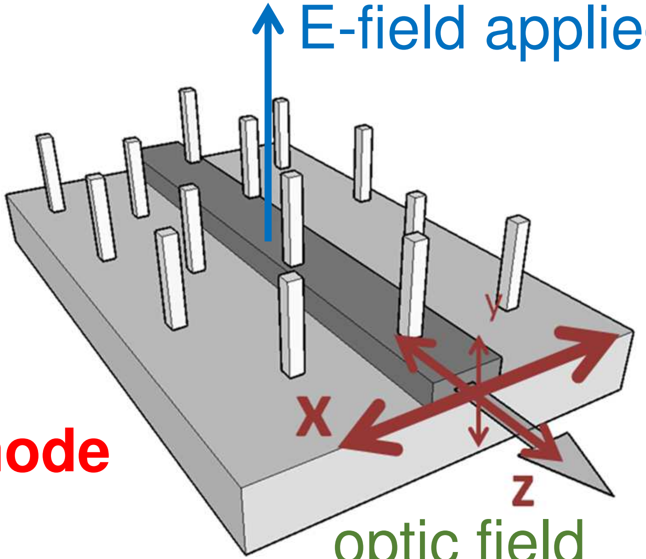
SOI WAVEGUIDE WITH LC

No applied field



TE mode

E-field applied



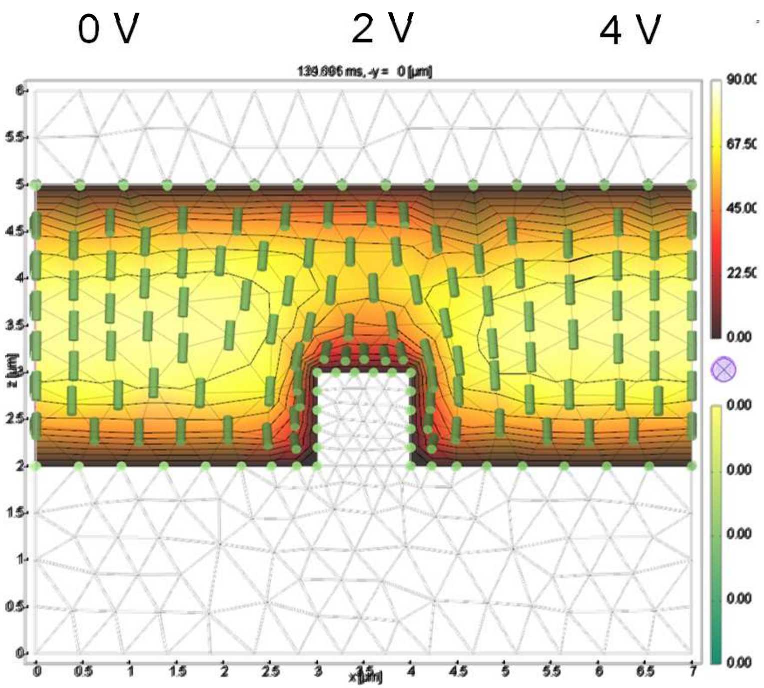
for E_x : n_o
for E_z : n_e

→ **smaller n_{eff}!!**

for E_x : n_o
for E_z : n_o

SOI WAVEGUIDE WITH LC

Simulation of director: software by University College London
Simulation of waveguide modes: software by UGent



Finite Elements simulation

Full optical anisotropy (including all ε components)

effective refractive index n_{eff} depends on V

J. Beeckman et al, J. Lightwave Technology, 2009

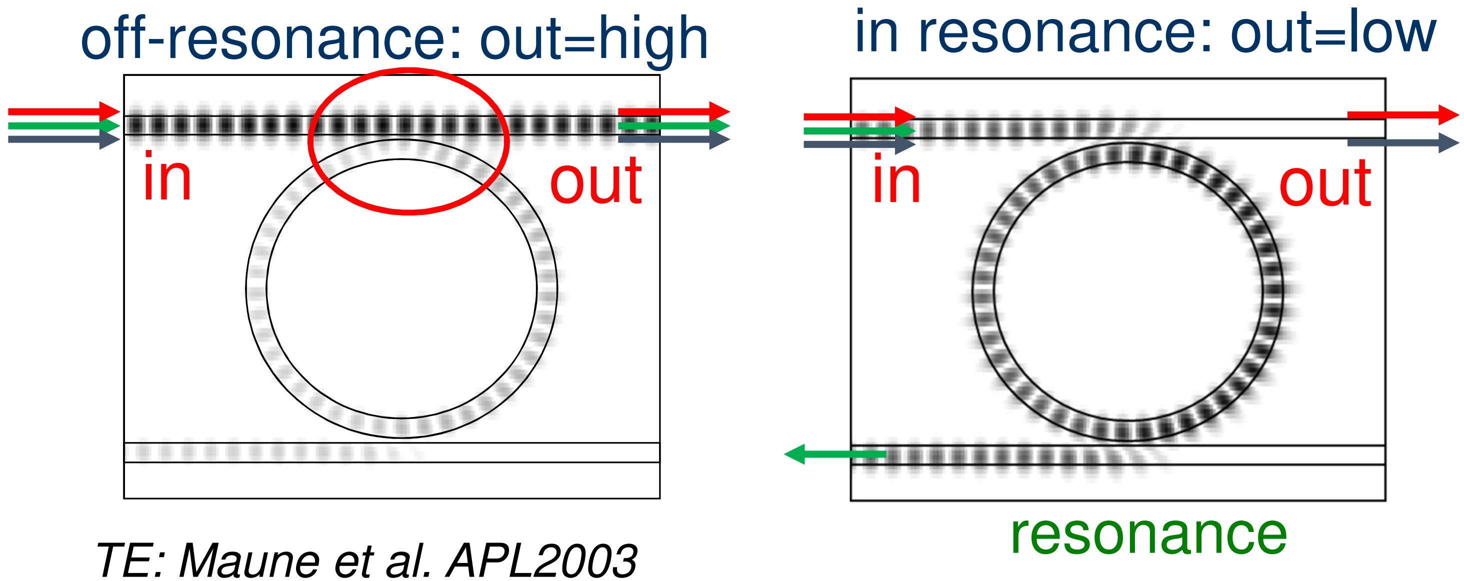
Liquid Crystals and Photonics

GHENT UNIVERSITY

SOI WAVEGUIDE WITH LC

ring resonator increases interaction with LC

- coupling between straight line and ring
- resonance in ring for: $2\pi R n_{eff} = m\lambda_{res}$ → $\frac{\Delta n_{eff}}{n_{eff}} = \frac{\Delta \lambda_{res}}{\lambda_{res}}$
- tune λ_{res} by tuning n_{eff} by tuning V_{LC}

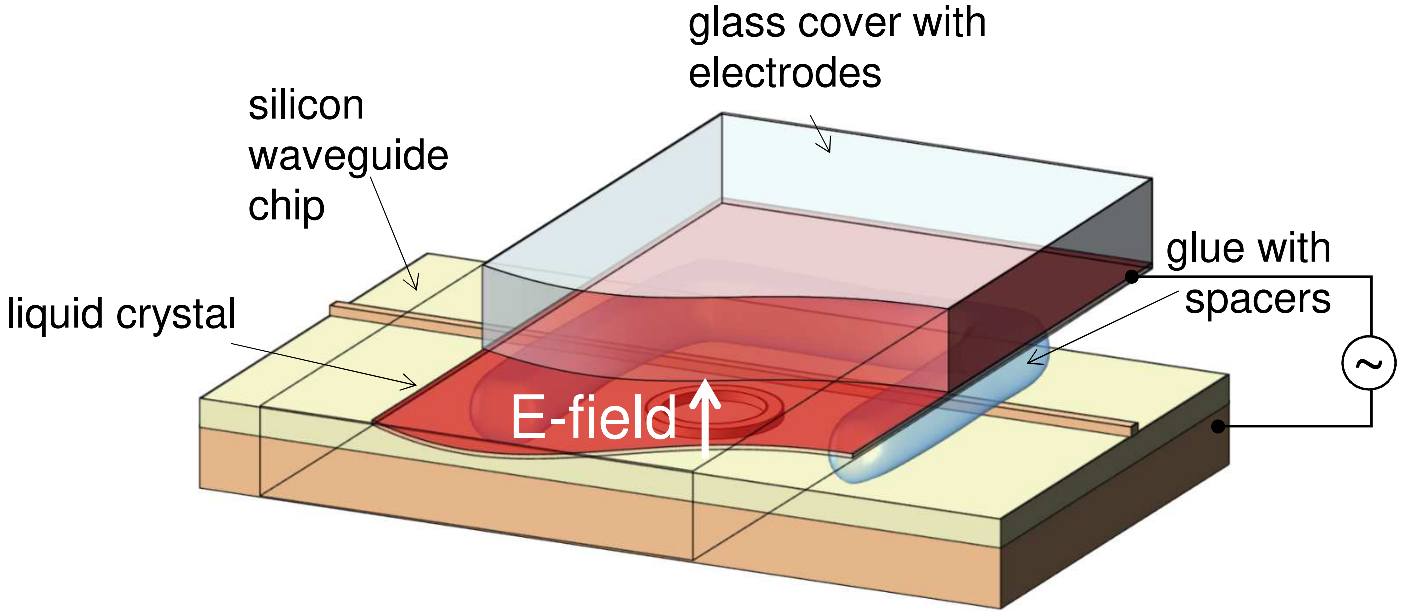


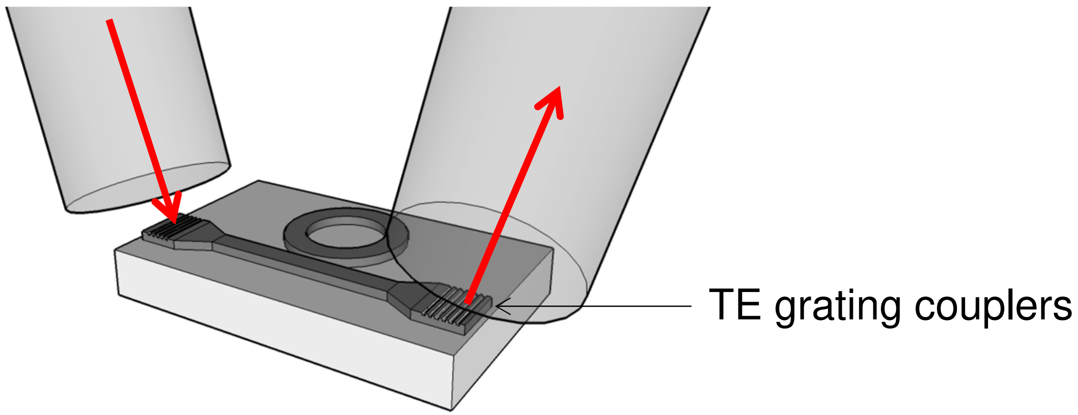
TE: Maune et al. APL2003
TM: Chigrinov et al. US patent 2007

Liquid Crystals and Photonics

GHENT UNIVERSITY

SOI WAVEGUIDE WITH LC

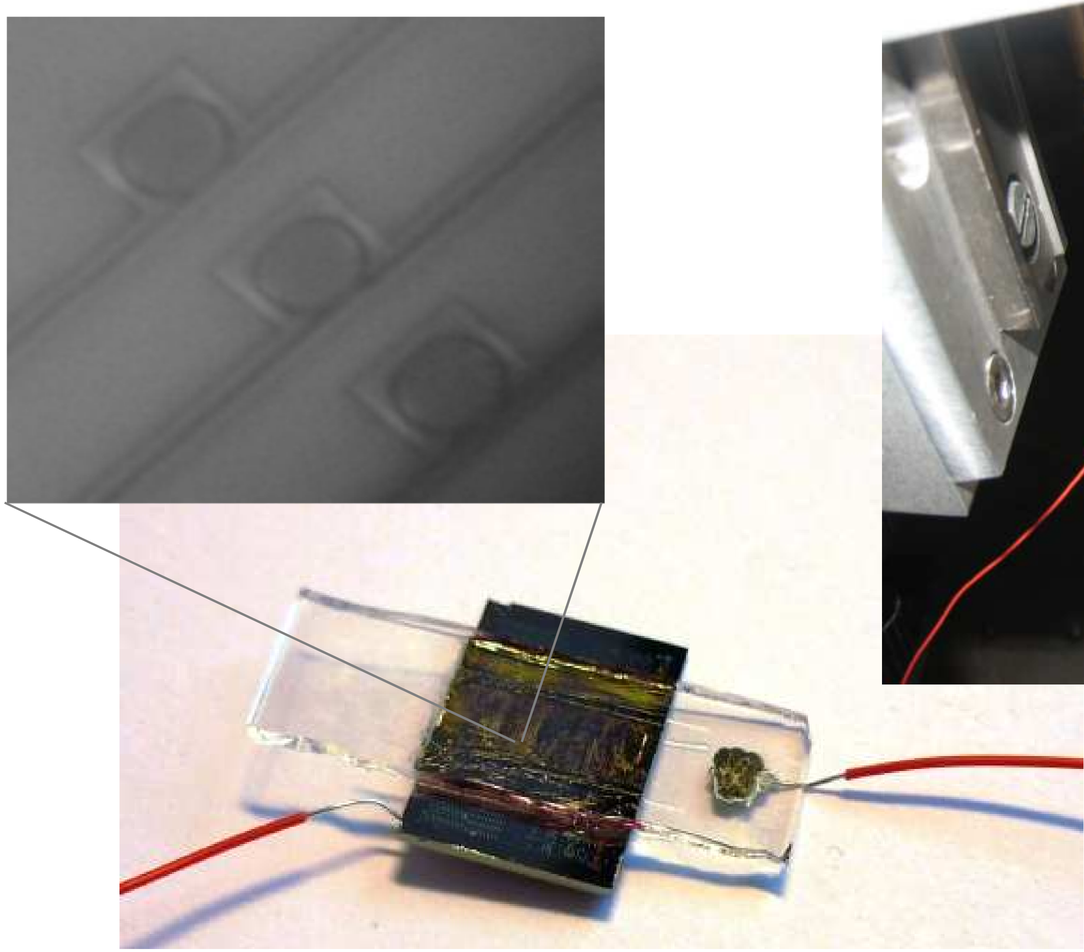


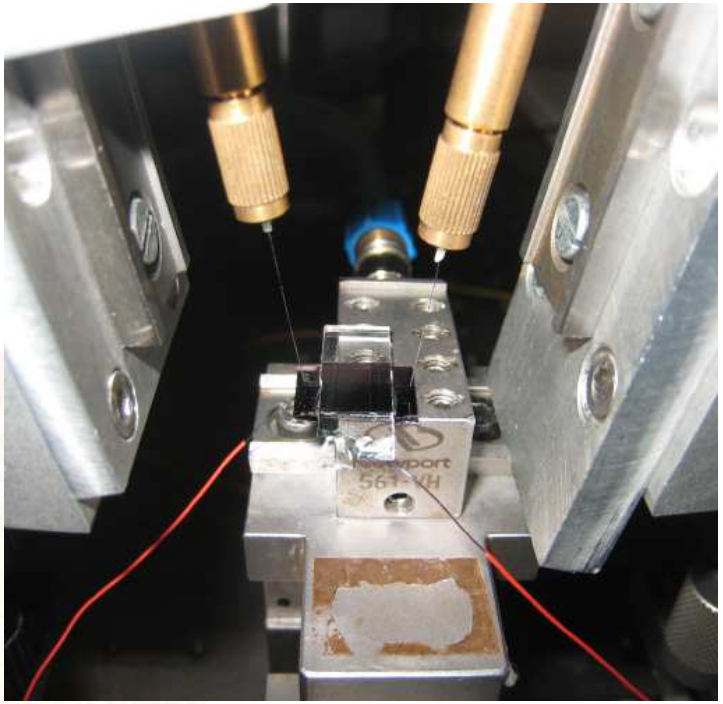


Liquid Crystals and Photonics

GHENT UNIVERSITY

SOI WAVEGUIDE WITH LC



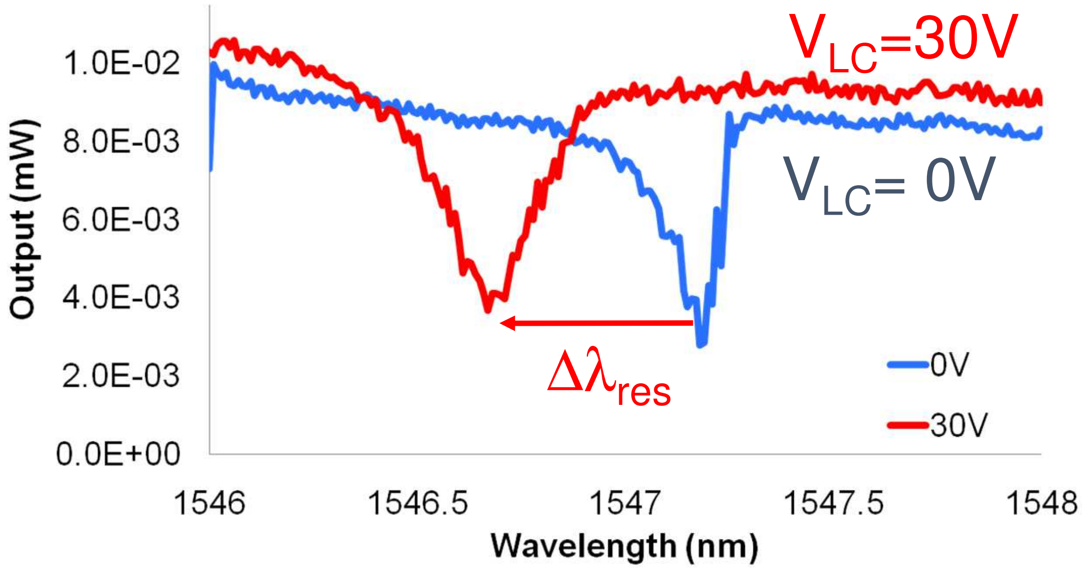


Liquid Crystals and Photonics

GHENT UNIVERSITY

RING RESONATOR TUNING

SOI waveguide, TE mode, covered with 5CB
resonance wavelength tuning



V_{LC} on
n_{eff} decreases
λ_{res} decreases 0.6nm

$$\frac{\Delta n_{eff}}{n_{eff}} = \frac{\Delta \lambda_{res}}{\lambda_{res}}$$

W. De Cort et al. Optics Letters 2009

RING RESONATOR TUNING

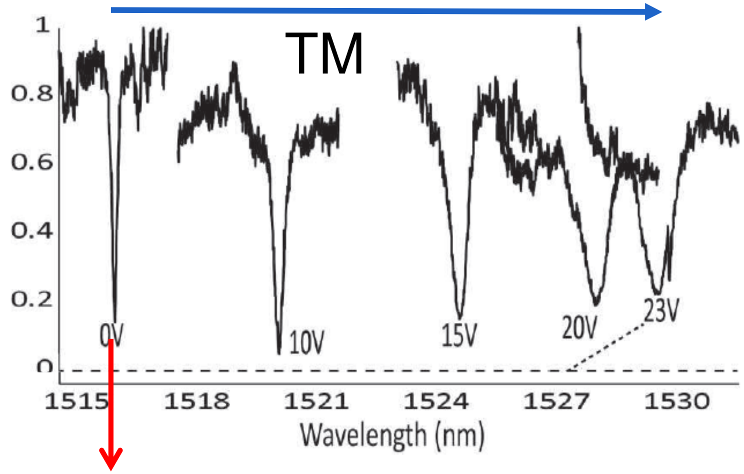
result for ring resonators with E7:

larger tuning range in the 1550nm band:

for TE waveguide: **4.5nm decrease** of λ_{res} with V

for TM waveguide: **31nm increase** of λ_{res} with V

shift with voltage



De Cort et al., Optics Letters 2011

$Q=11500=\lambda_{res}/FWHM$

TRIMMING SOI WAVEGUIDES

Trimming:
*"Setting the properties of a device **once**,*
to obtain well-defined characteristics"

why? Difficult to make SOI waveguides with high accuracy

How?
- Apply polymerizable liquid crystal
- Adjust the resonance by tuning the voltage
- Photopolymerize

Polymerizable LC
- RM23 (monoacrylate, Merck)
- RM257 (diacrylate, Merck)
- RM82 (diacrylate, Merck)
- 5CB (non-reactive LC)
- Irgacure 819 (photoinitiator, Ciba)
- TBHQ (inhibitor)

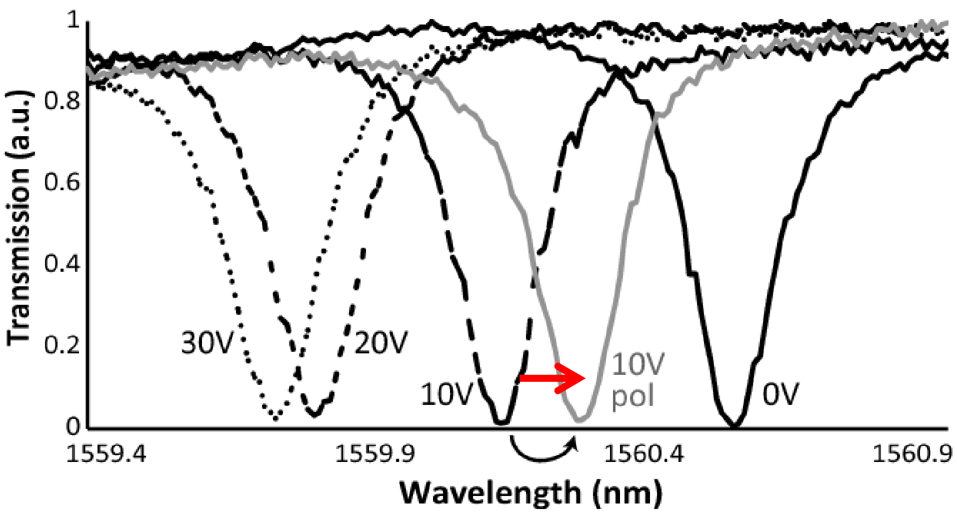
Liquid Crystals and Photonics

WAT

GHENT UNIVERSITY

TRIMMING SOI WAVEGUIDES

Ring resonator for TE mode with LC
Resonance wavelength: decreases with V
Choose voltage vor optimal wavelength
During polymerization: small increase of λ_{res}



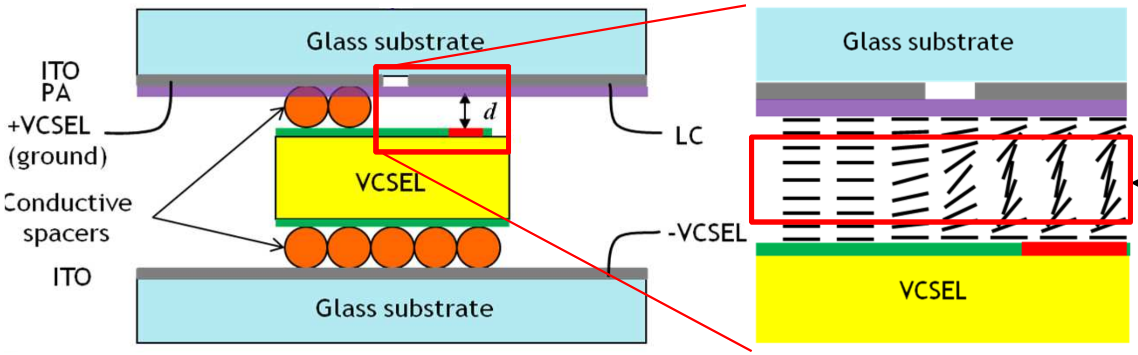
- RM23 (monoacrylate, Merck)
- RM257 (diacrylate, Merck)
- RM82 (diacrylate, Merck)
- 5CB (non-reactive LC)
- Irgacure 819 (photoinitiator, Ciba)
- TBHQ (inhibitor)

S. Lambert et al., Optics Letters 2012

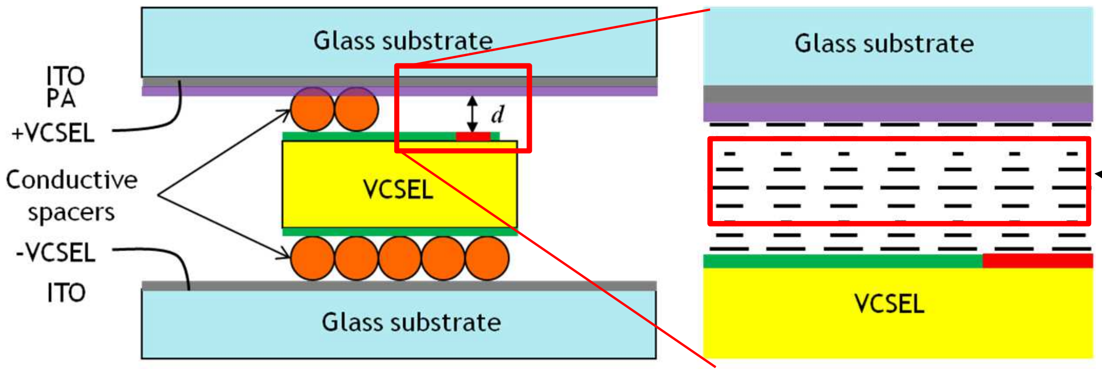
Liquid Crystals and Photonics

GHENT UNIVERSITY

VCSEL WITH LIQUID CRYSTAL



Nematic LC overlay



Chiral LC overlay

Liquid Crystals and Photonics

GHENT UNIVERSITY