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

WAT

nb-photonics
Center for Nano- and Biophotonics
Ghent University

Liquid Crystals and Photonics

OVERVIEW

Liquid crystal properties (10h)

Properties of nematic liquid crystals
Nematic order parameter
Polarization and dielectric constant
Elastic energy
Surface alignment
Electrical energy
Freederickz threshold
VAN mode
IPS mode
TN mode
Polarization microscopy

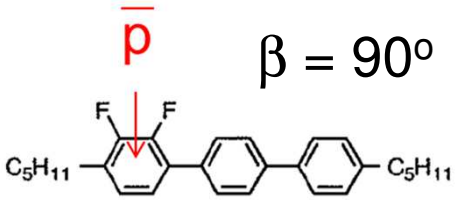
Liquid Crystals and Photonics

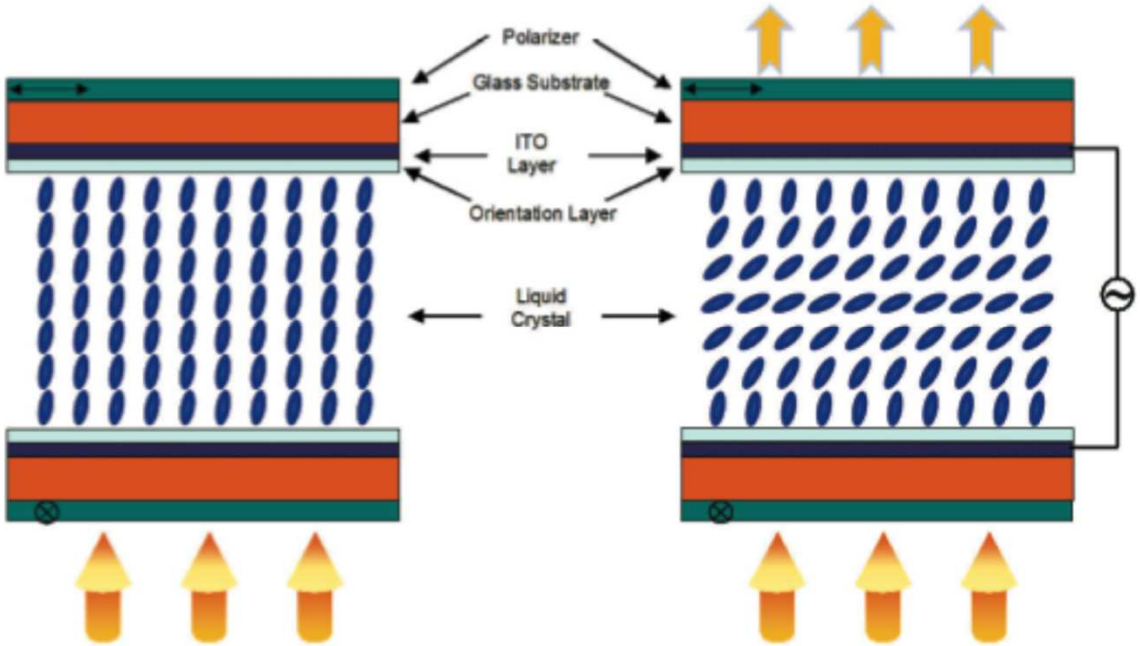
WAT

GHENT UNIVERSITY

VERTICALLY ALIGNED NEMATIC (VAN)

Initially vertically aligned, and $\Delta\varepsilon < 0$
with particular alignment material





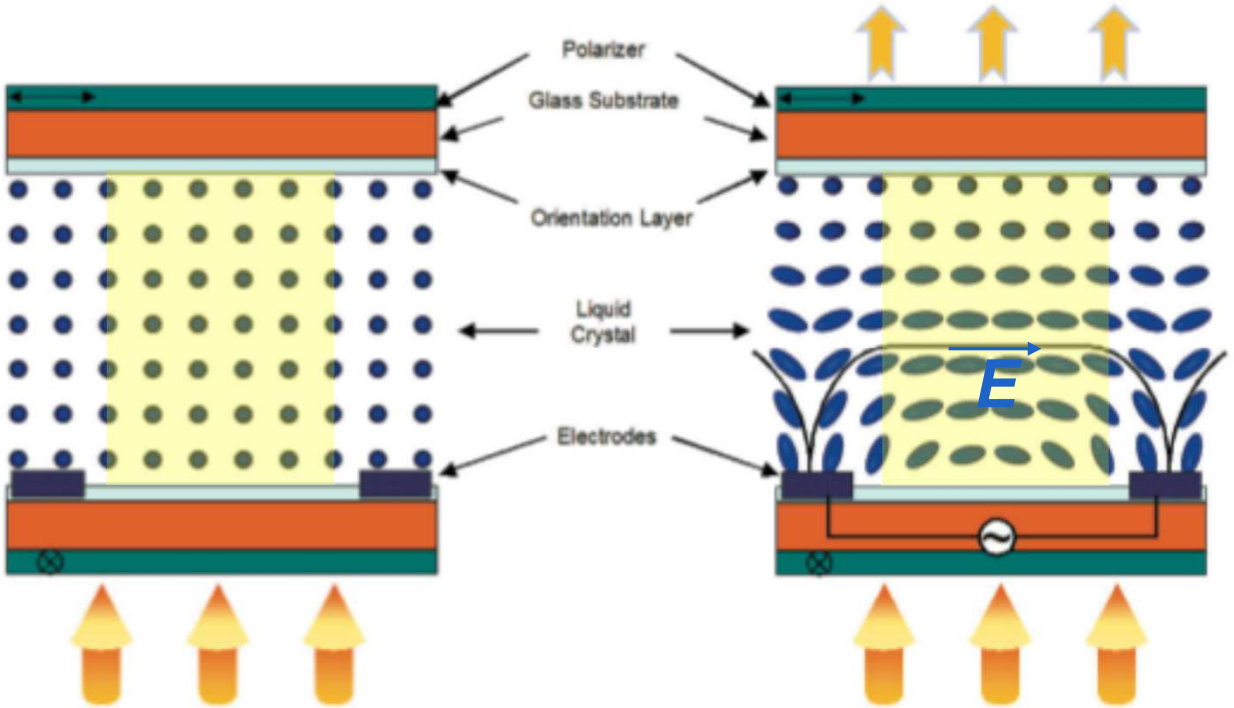
Liquid Crystals and Photonics

GHENT UNIVERSITY

IN PLANE SWITCHING (IPS) MODE

initially: director homogeneous

with voltage: director reorients in plane



Liquid Crystals and Photonics

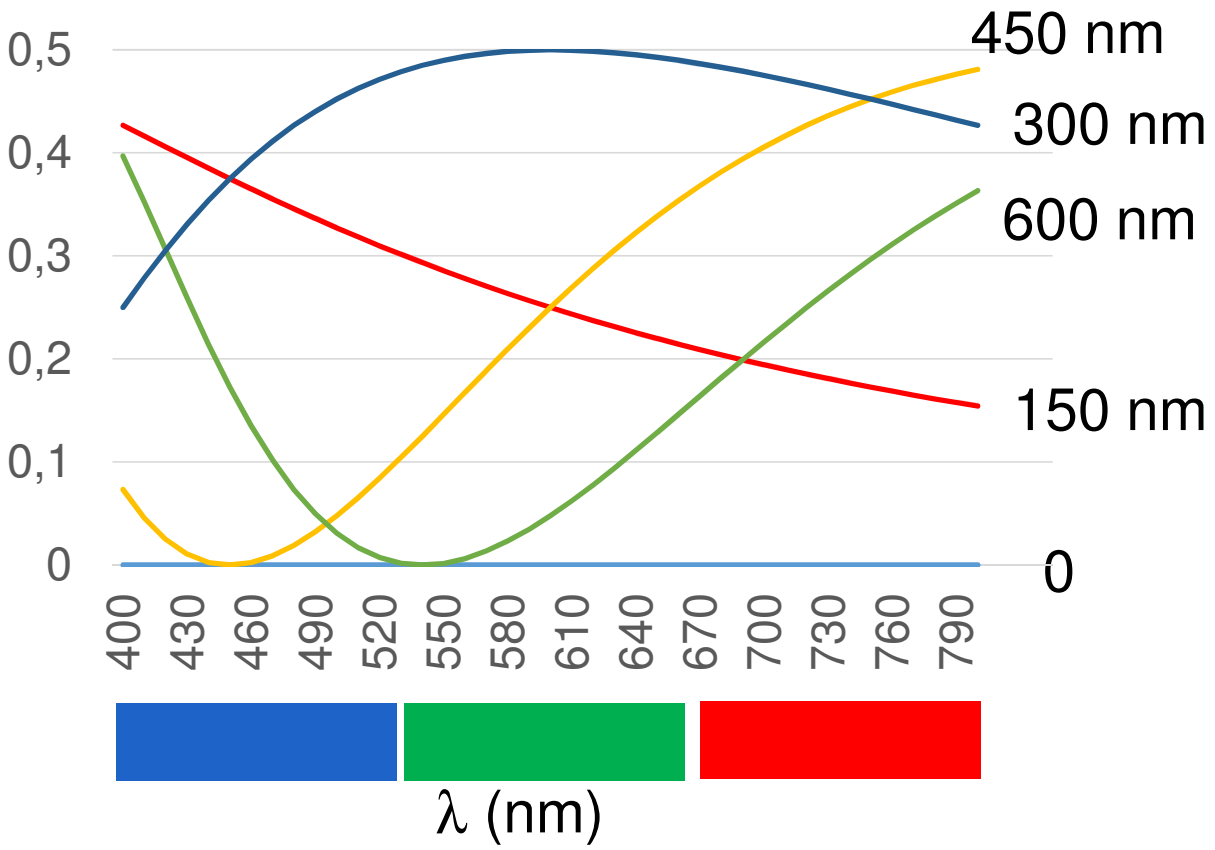
GHENT UNIVERSITY

TRANSMISSION FOR LIQUID CRYSTALS

$$T = \frac{1}{2}\sin^2 2\phi \sin^2\left(\frac{\pi \Delta n_{avg} d}{\lambda}\right)$$

ϕ=45°

$\Delta n_{avg} d$

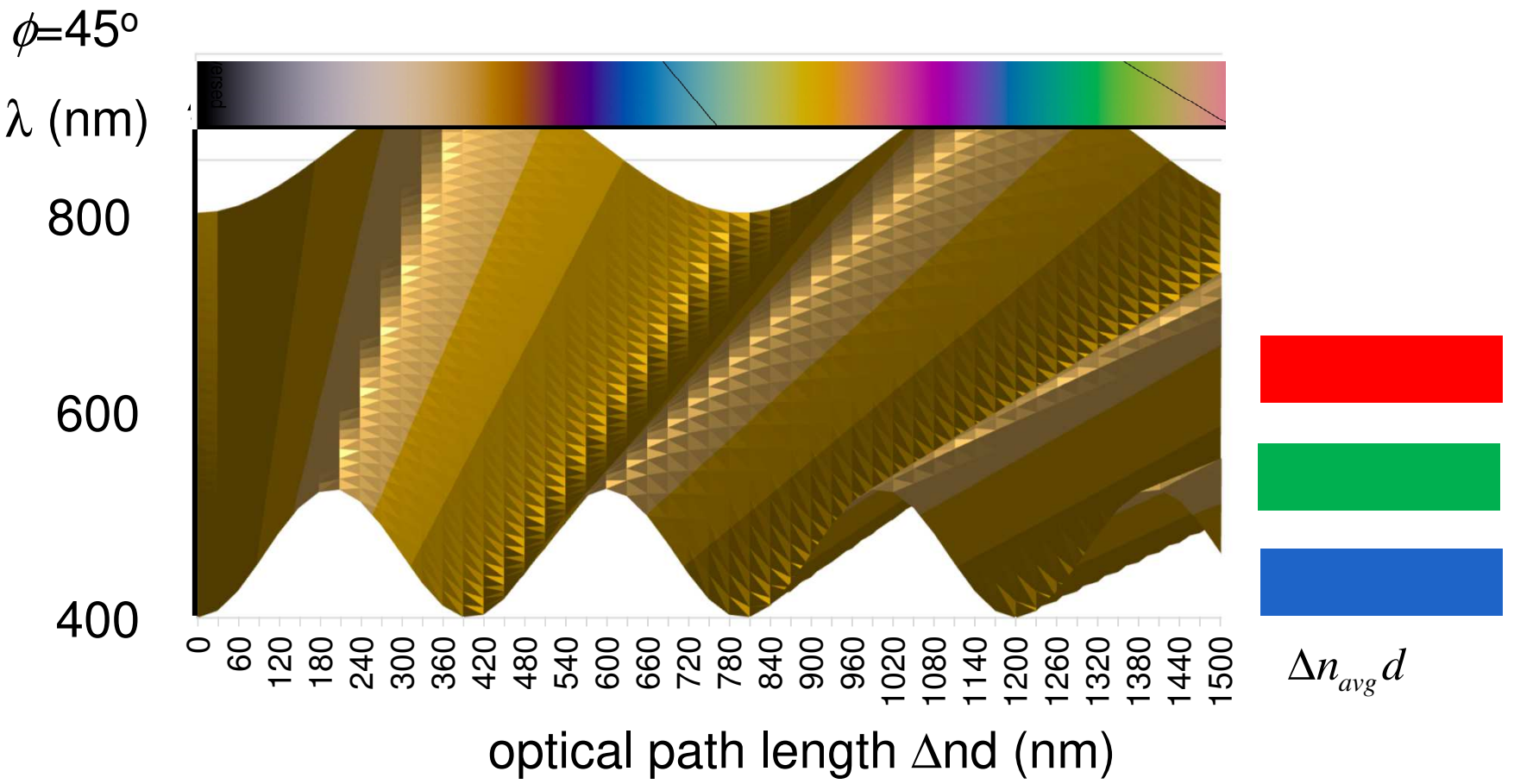


Liquid Crystals and Photonics

GHENT UNIVERSITY

TRANSMISSION FOR LIQUID CRYSTALS

$$T = \frac{1}{2}\sin^2 2\phi \sin^2\left(\frac{\pi \Delta n_{avg} d}{\lambda}\right)$$

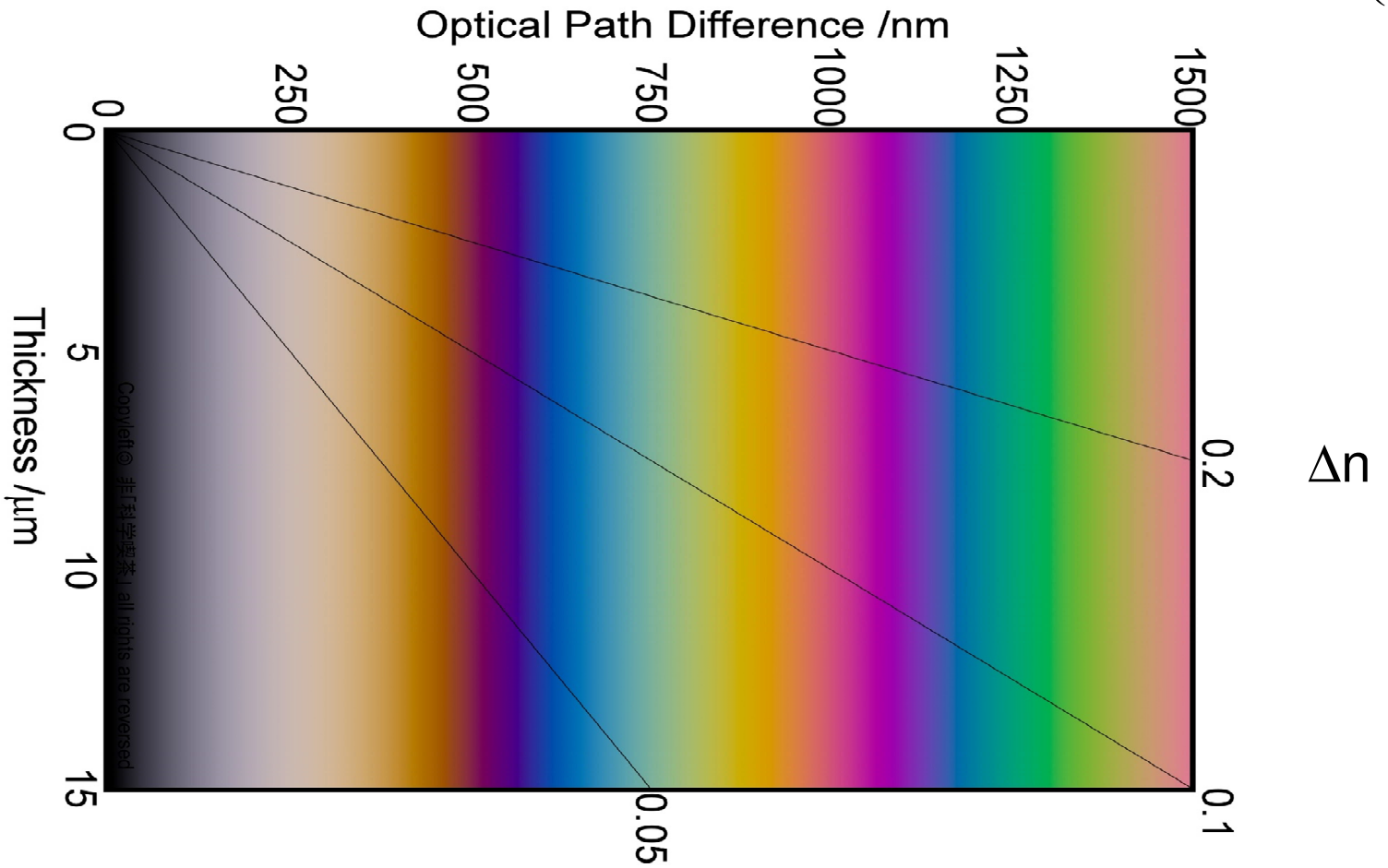


Liquid Crystals and Photonics

GHENT UNIVERSITY

TRANSMISSION FOR LIQUID CRYSTALS

$$T = \frac{1}{2}\sin^2 2\phi \sin^2\left(\frac{\pi \Delta n_{avg} d}{\lambda}\right)$$



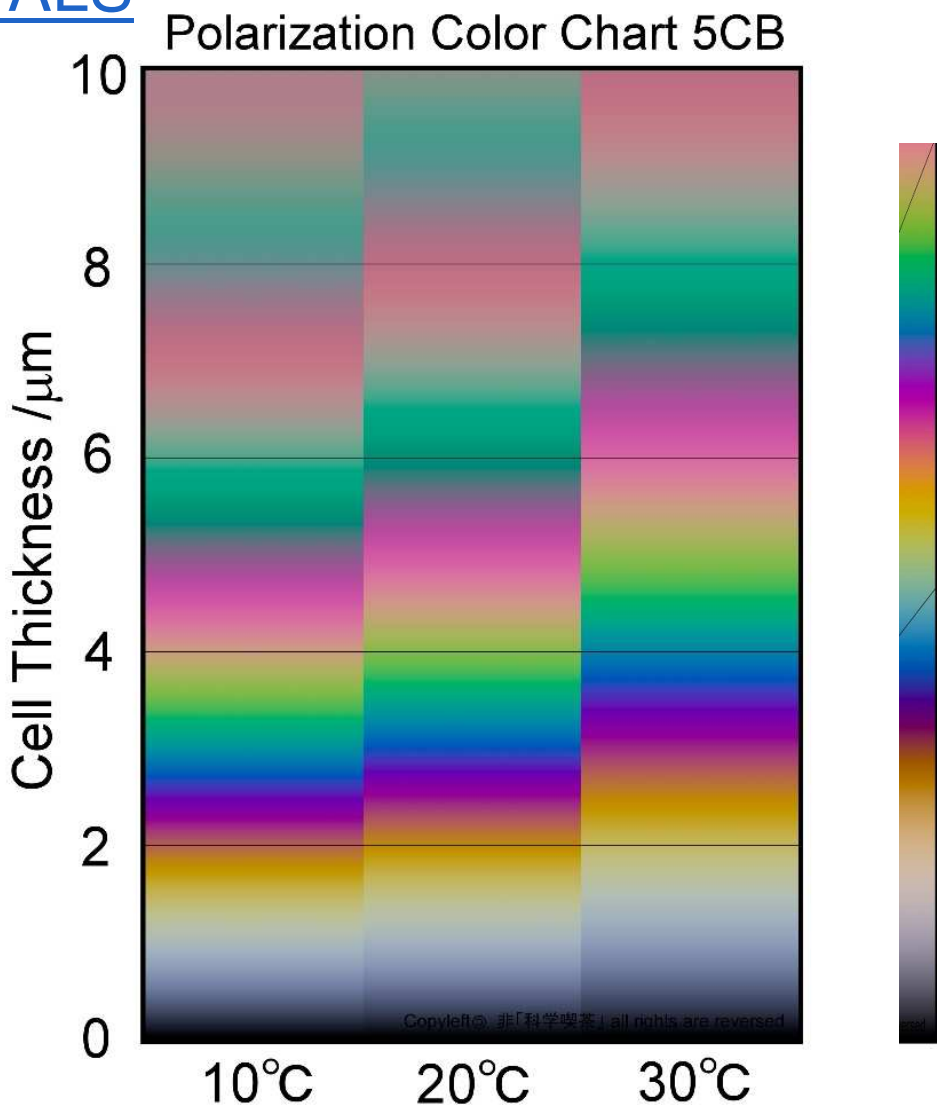
TRANSMISSION FOR LIQUID CRYSTALS

$$T = \frac{1}{2}\sin^2 2\phi \sin^2\left(\frac{\pi\Delta n(\lambda,T)d}{\lambda}\right)$$

the refractive index

has some dispersion

Δn decreases with temperature



Liquid Crystals and Photonics

WAT

GHENT UNIVERSITY

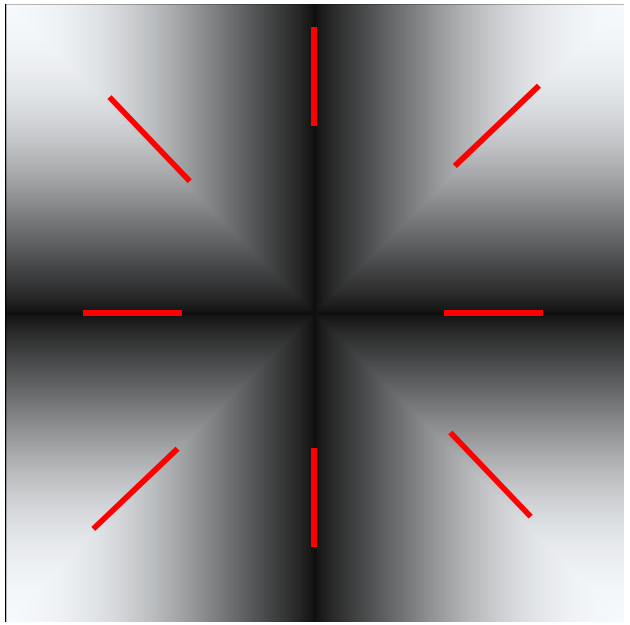
TRANSMISSION FOR LIQUID CRYSTALS

crossed polarizers at 0° and 90°

$$T = \frac{1}{2}\sin^2 2\phi \sin^2\left(\frac{\pi\Delta n d}{\lambda}\right)$$

angle dependency?
(small thickness,
no colors visible)

director orientation



Liquid Crystals and Photonics

WAT

GHENT UNIVERSITY

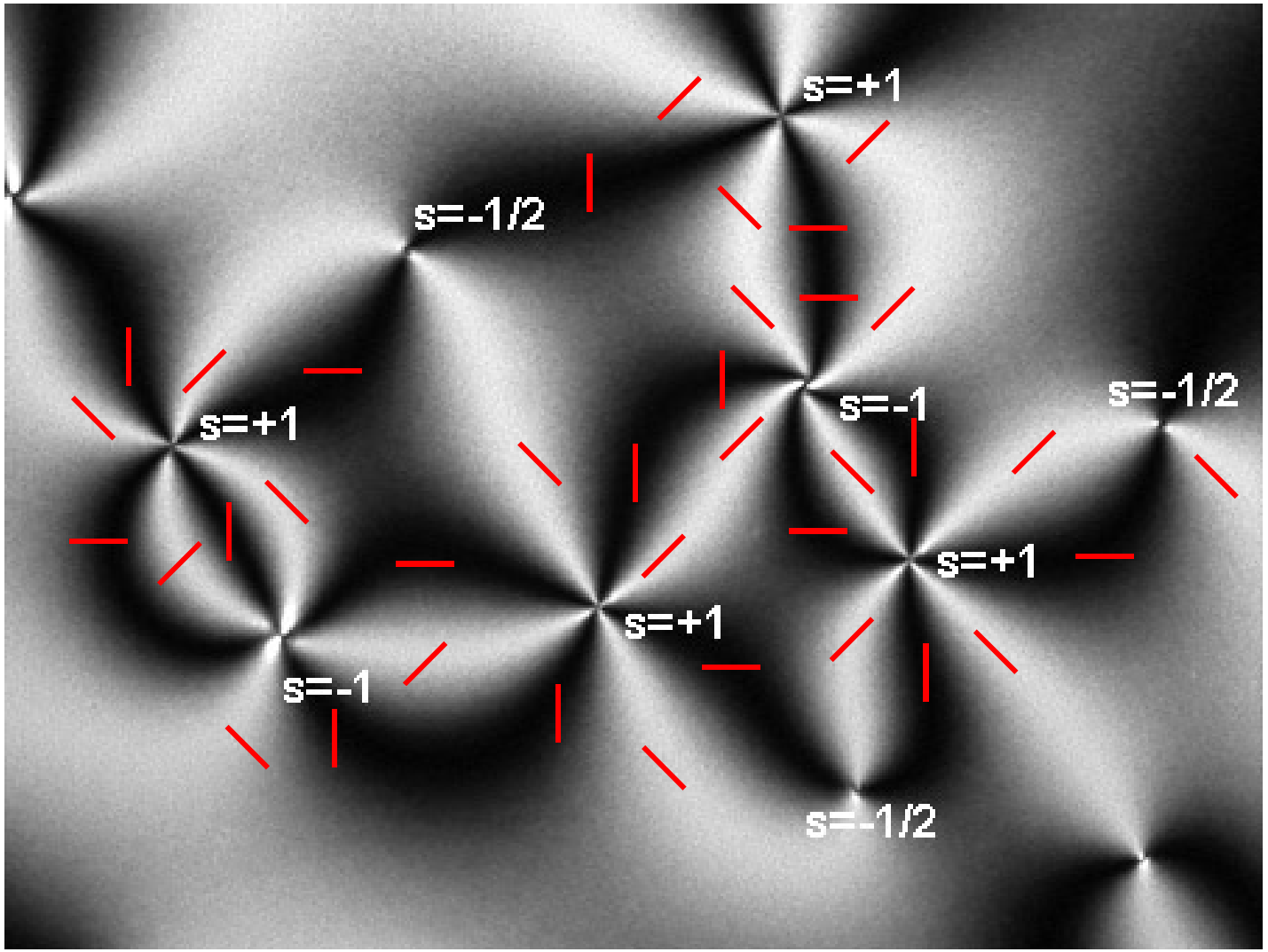
TRANSMISSION FOR LIQUID CRYSTALS

Liquid Crystals and Photonics

WAT

GHENT UNIVERSITY

TRANSMISSION FOR LIQUID CRYSTALS



Liquid Crystals and Photonics

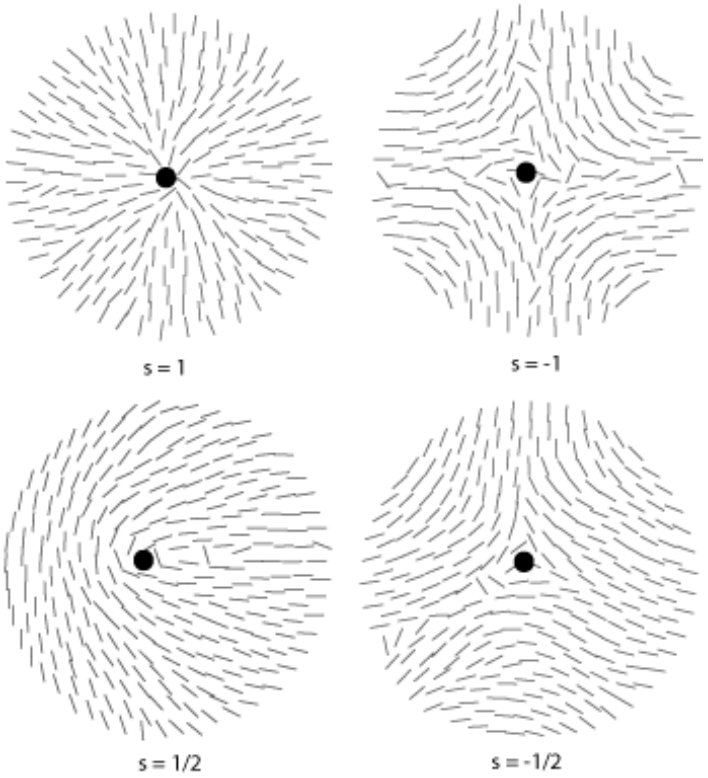
WAT

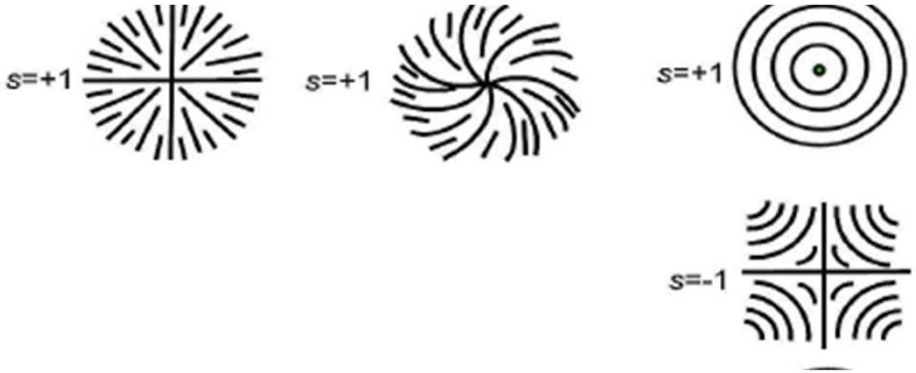
GHENT UNIVERSITY

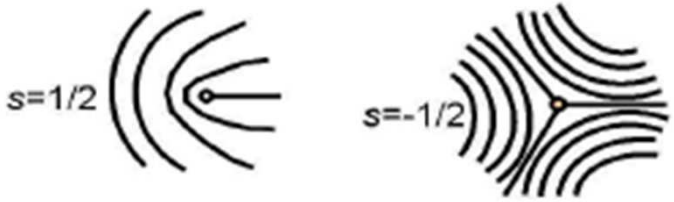
TRANSMISSION FOR LIQUID CRYSTALS

defects in planar liquid crystals

director parallel to substrates







Liquid Crystals and Photonics

WAT

GHENT UNIVERSITY

PHOTO-ALIGNMENT

UV illumination

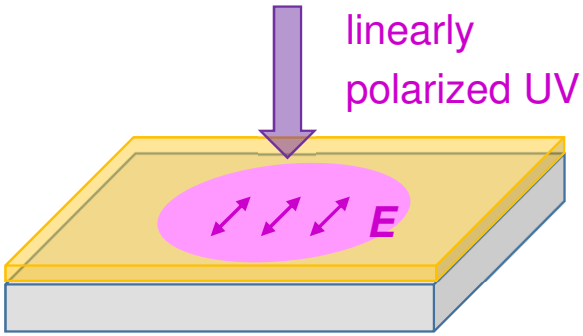
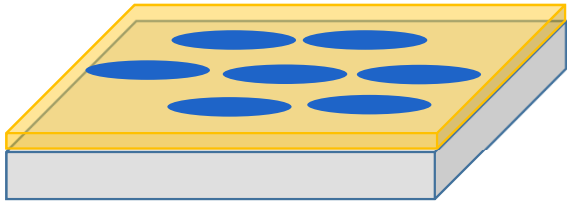
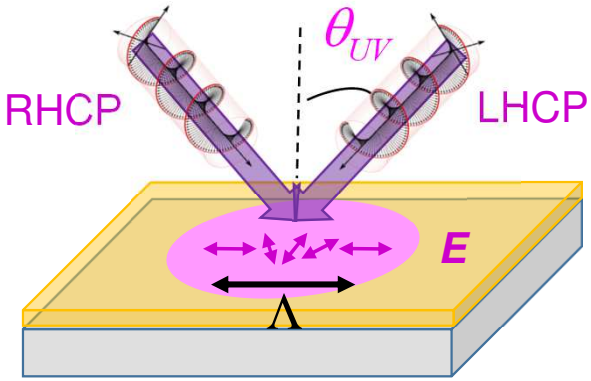


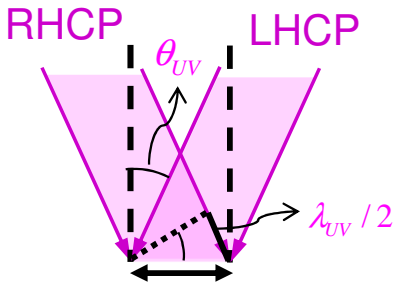
Photo-alignment azo dye
PAAD 22 or SD1

LC director ⊥ E-field of UV pol



periodic UV illumination





$$\Lambda = \frac{\lambda_{UV}}{2\sin\theta_{UV}}$$

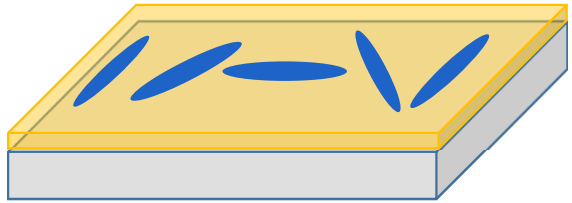


PHOTO-ALIGNMENT

UV periodic alignment

director ⊥ UV pol

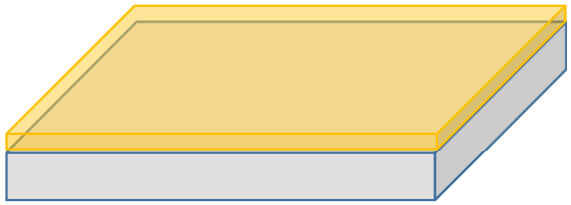
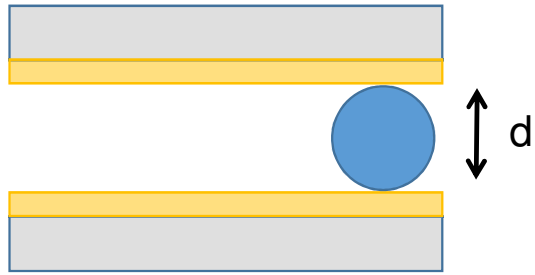


Photo-alignment azo dye
PAAD 22 or SD1



Glued cell with spacers

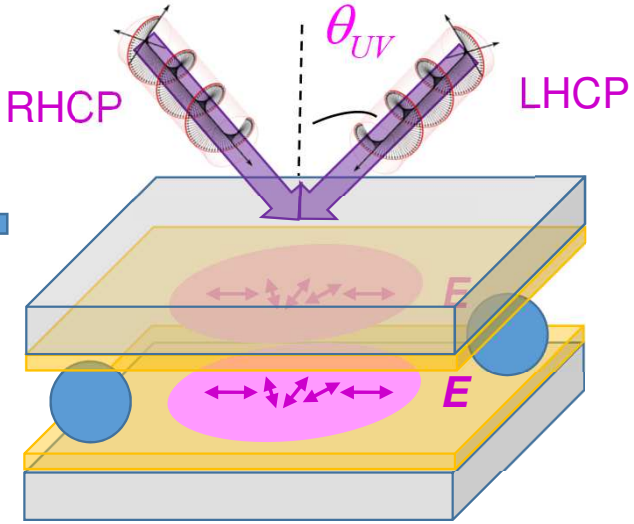
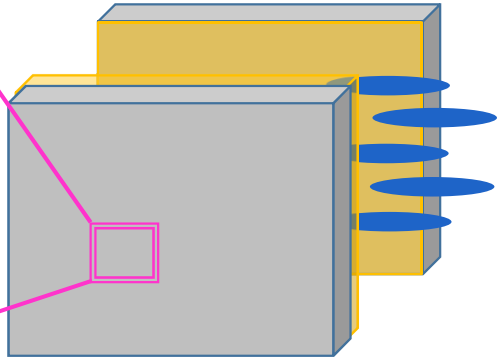
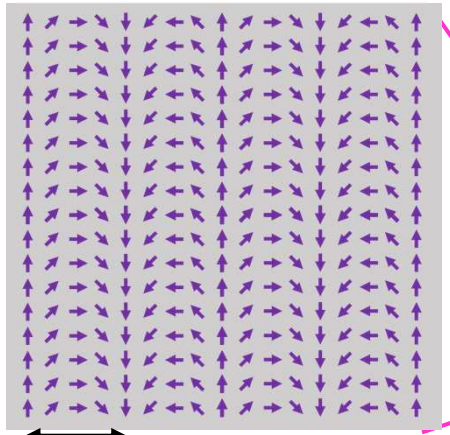


Photo-alignment

Filling with E7 LC





$$\Lambda = \frac{\lambda_{UV}}{2\sin\theta_{UV}}$$

Liquid Crystals and Photonics

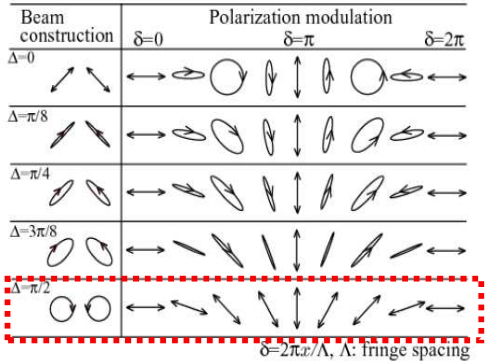
GHENT UNIVERSITY

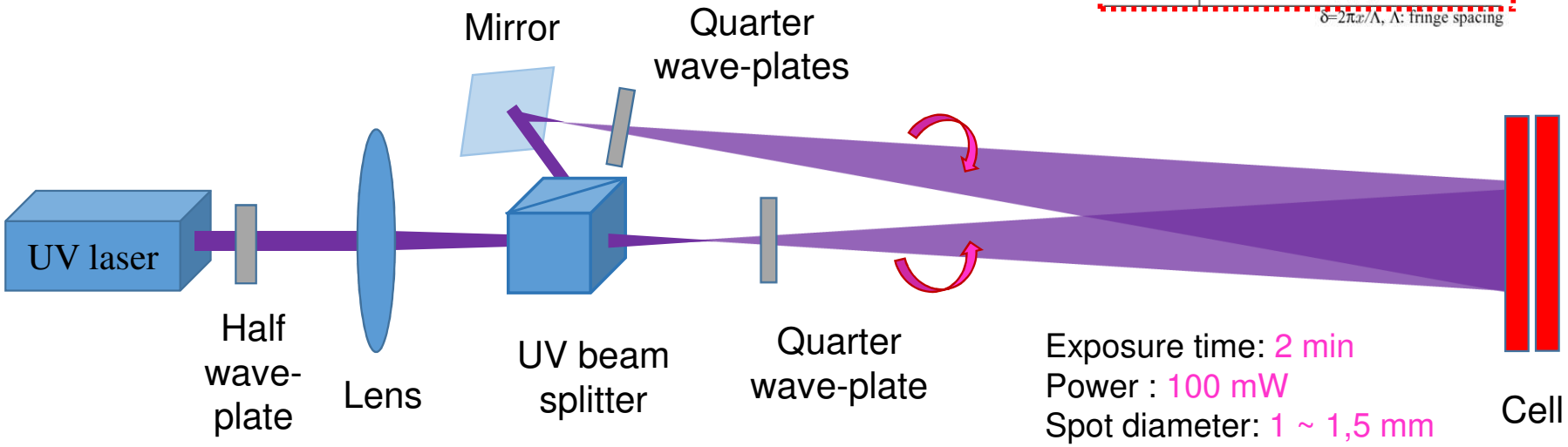
PHOTO-ALIGNMENT

UV illumination of azo based material

periodic E-field

periodic director alignment

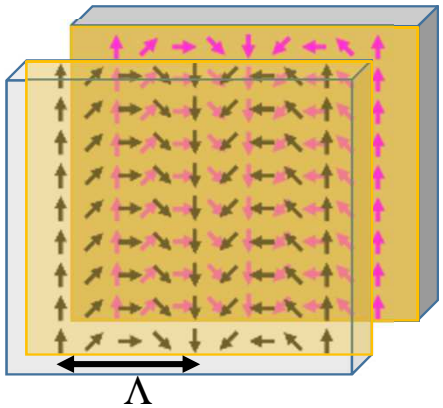


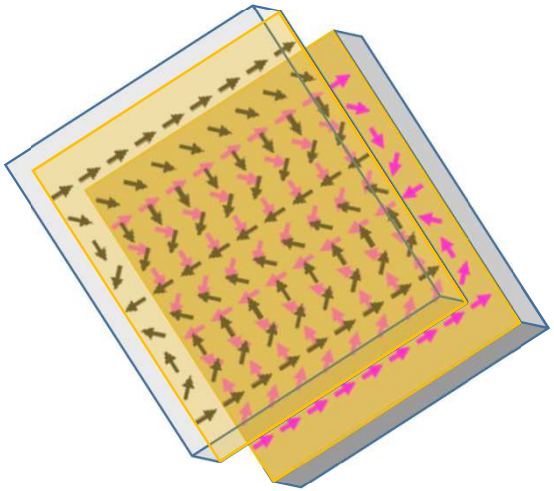


*Escuti, SID Symposium Digest., 2006, **37**, 1443*

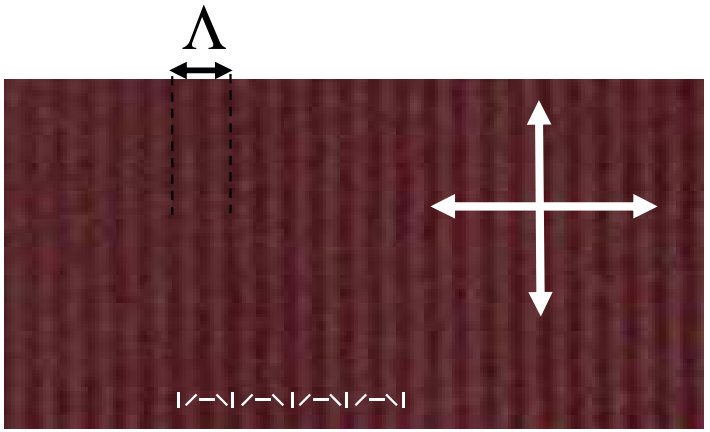
PHOTO-ALIGNMENT

grating alignment



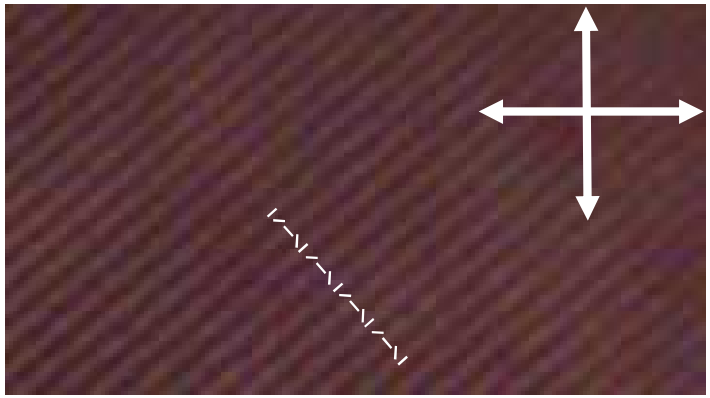


0°



polarization microscopy

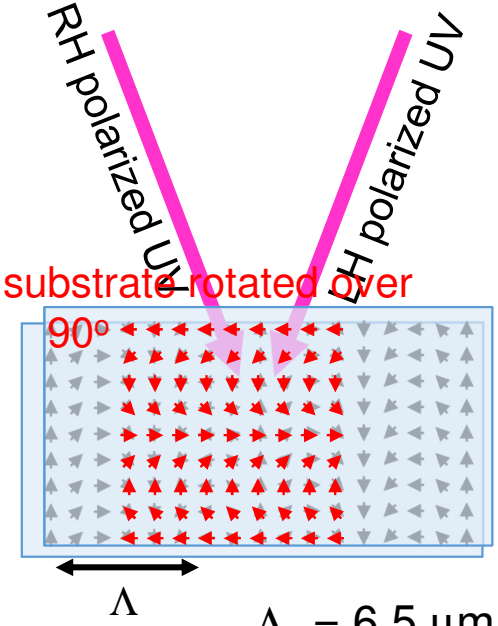
45°



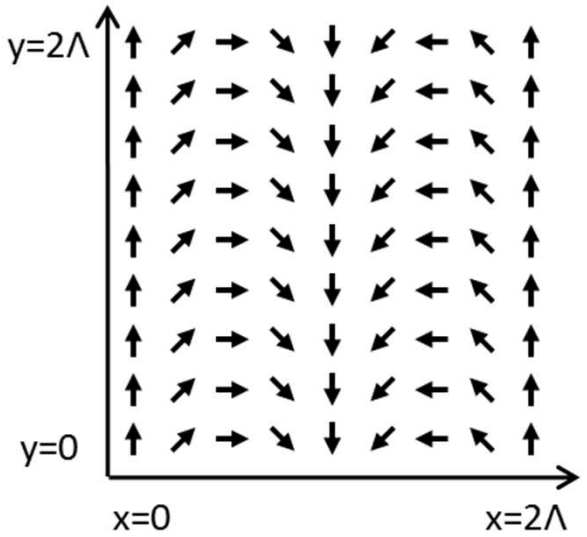
2D PERIODIC GRATING

alignment rotated over 90°

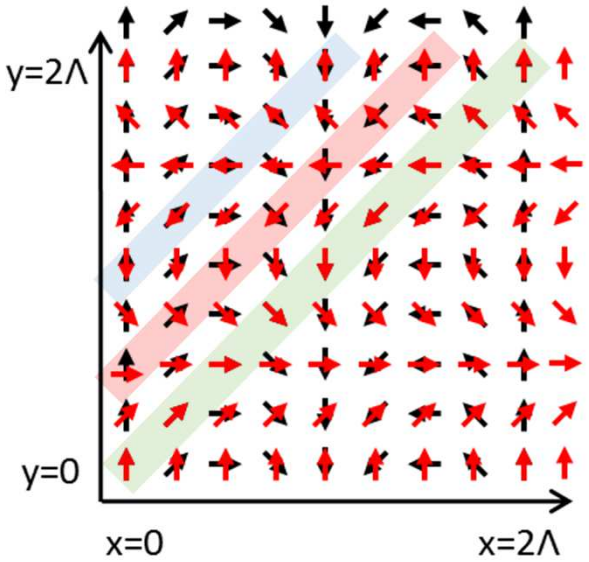
top compared to bottom substrate



bottom alignment

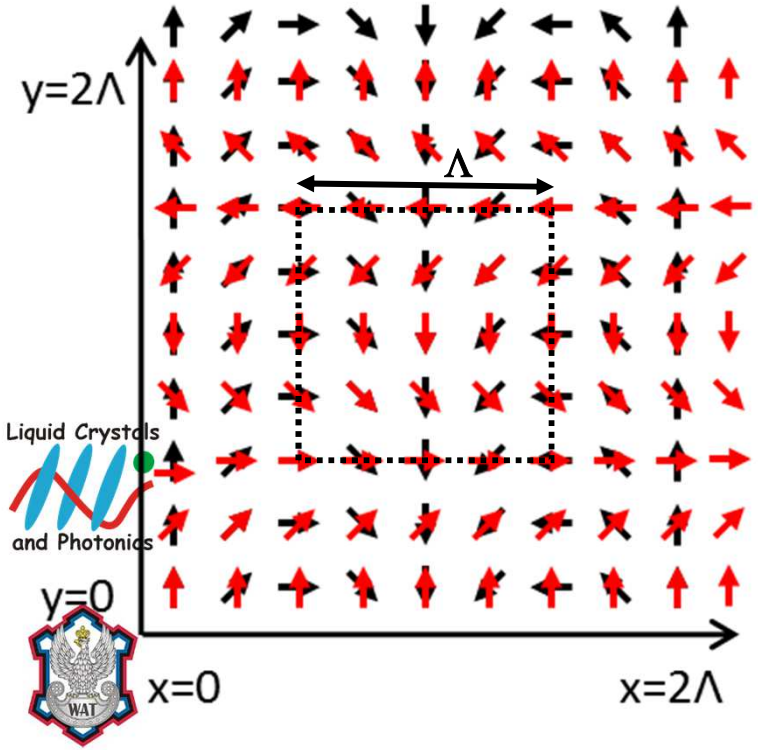


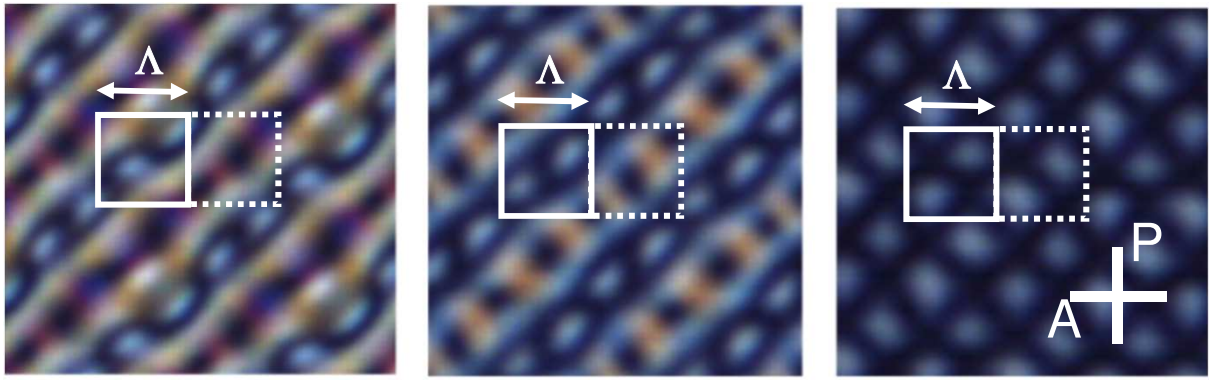
top alignment
bottom alignment



2D PERIODIC GRATING

alignment rotated over 90°





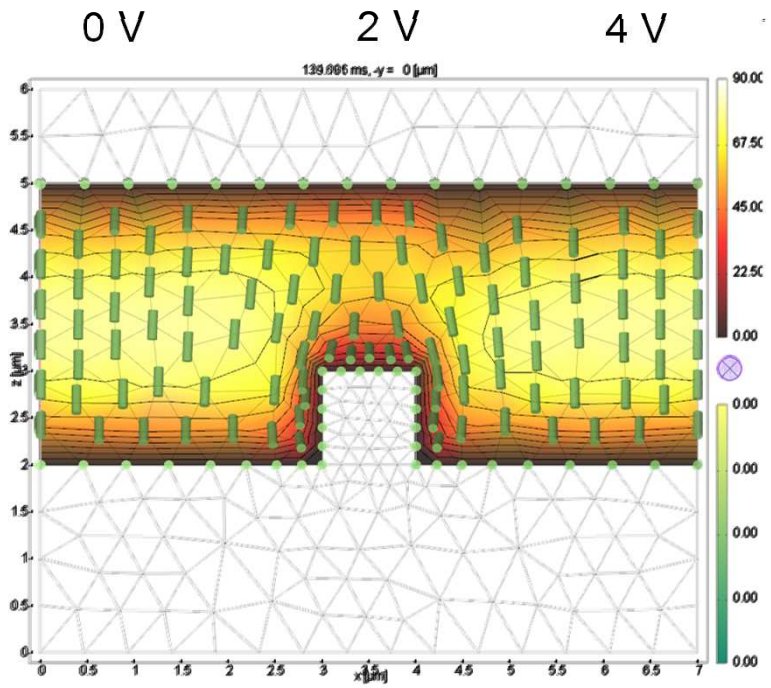
periodicity of the pattern is not Λ but 2Λ!
this is due to symmetry breaking

Λ = 6.5 µm
d = 3 µm

GHENT UNIVERSITY

LIQUID CRYSTAL DIRECTOR SIMULATION

Simulation of liquid crystal director



Finite Elements simulation

Full electrical anisotropy

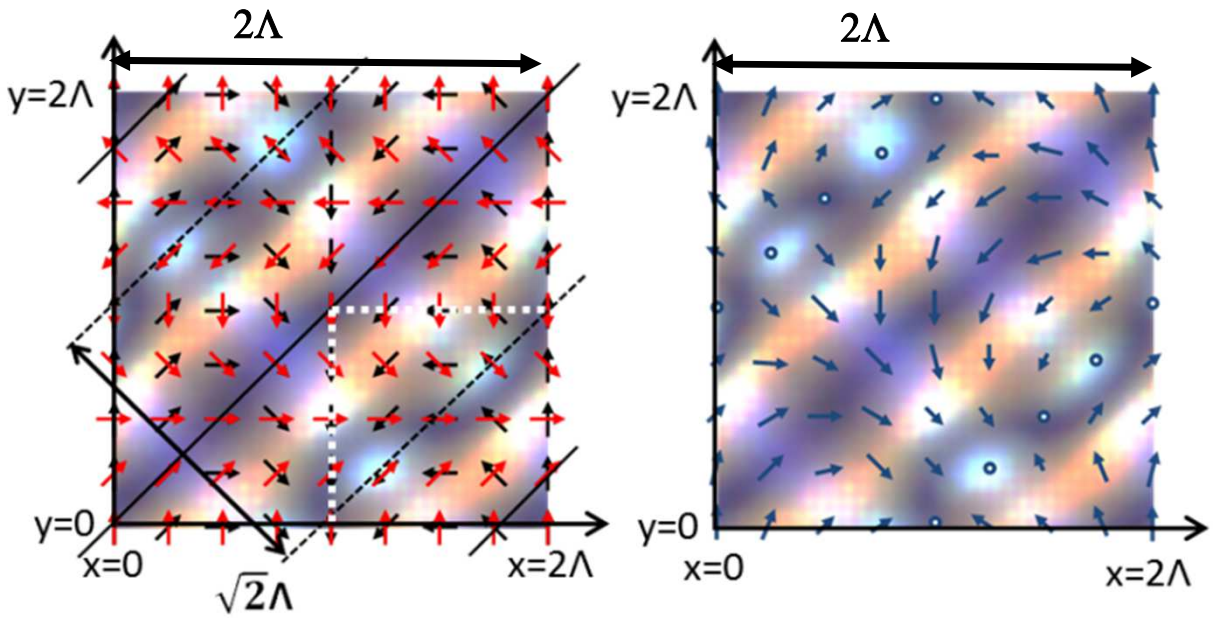
Liquid Crystals and Photonics

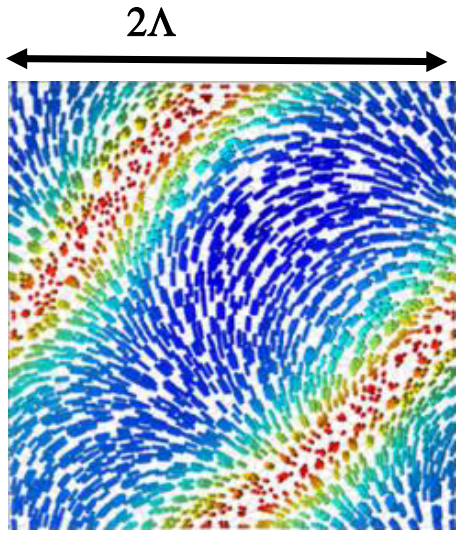
GHENT UNIVERSITY

LIQUID CRYSTAL DIRECTOR SIMULATION

simulation result in volume 2Λ,2Λ, *d*

spontaneous symmetry breaking, regions with homeotropically aligned regions





mid-plane director

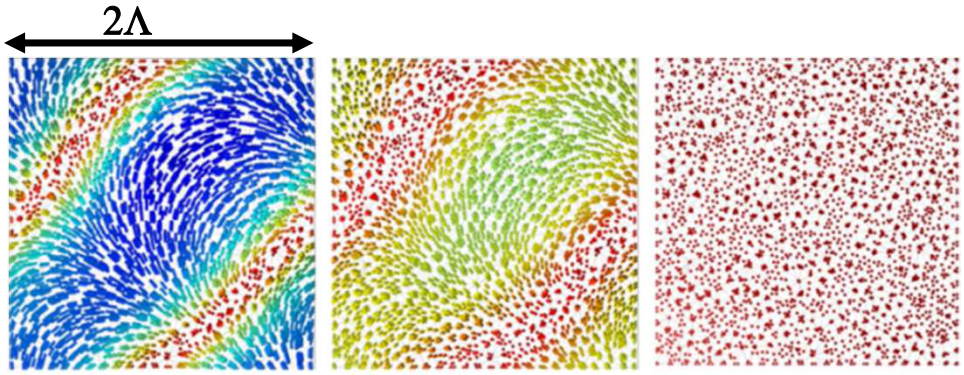
Liquid Crystals and Photonics

GHENT UNIVERSITY

LIQUID CRYSTAL DIRECTOR SIMULATION

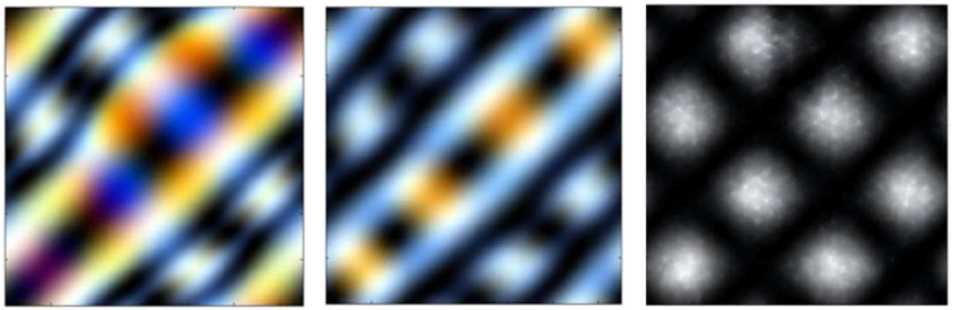
Results of the numerical calculations (strong anchoring)

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

1.5 V_p 2 V_p 3 V_p

polarization microscopy

with crossed polarizers

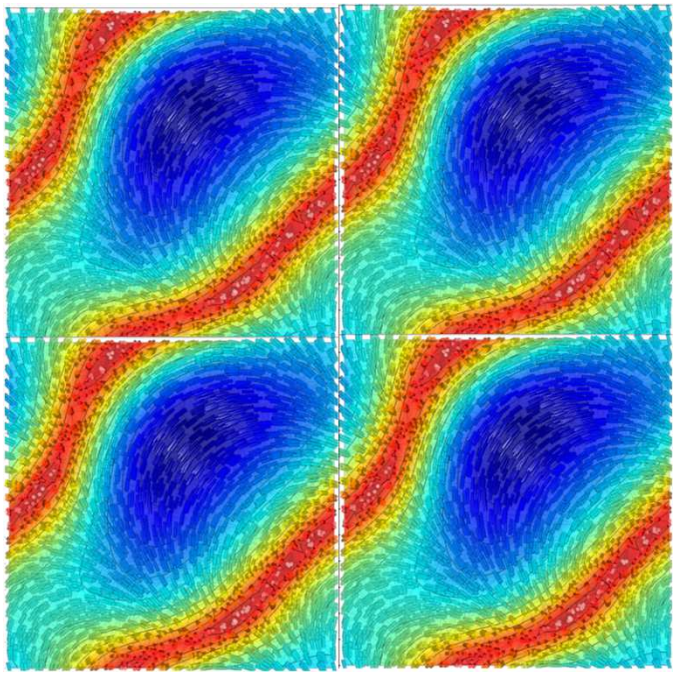
Liquid Crystals and Photonics

WAT

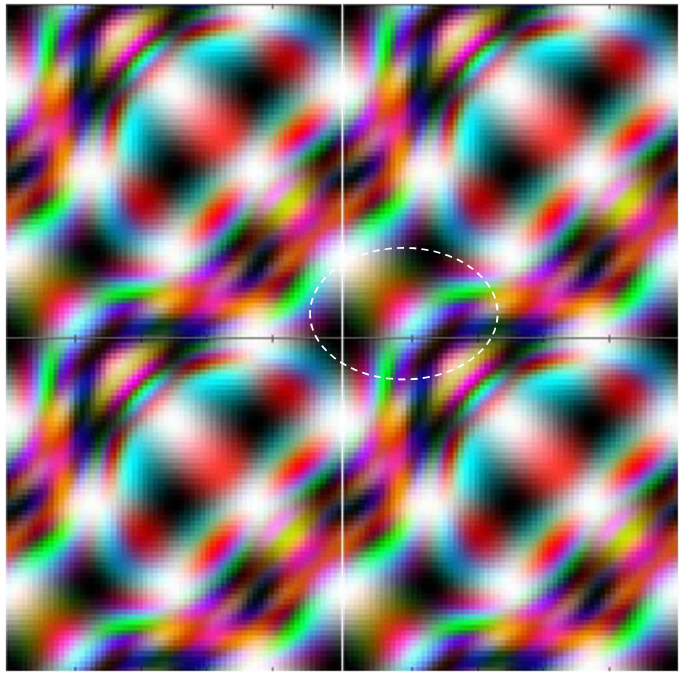
GHENT UNIVERSITY

LIQUID CRYSTAL DIRECTOR SIMULATION

mid-plane director

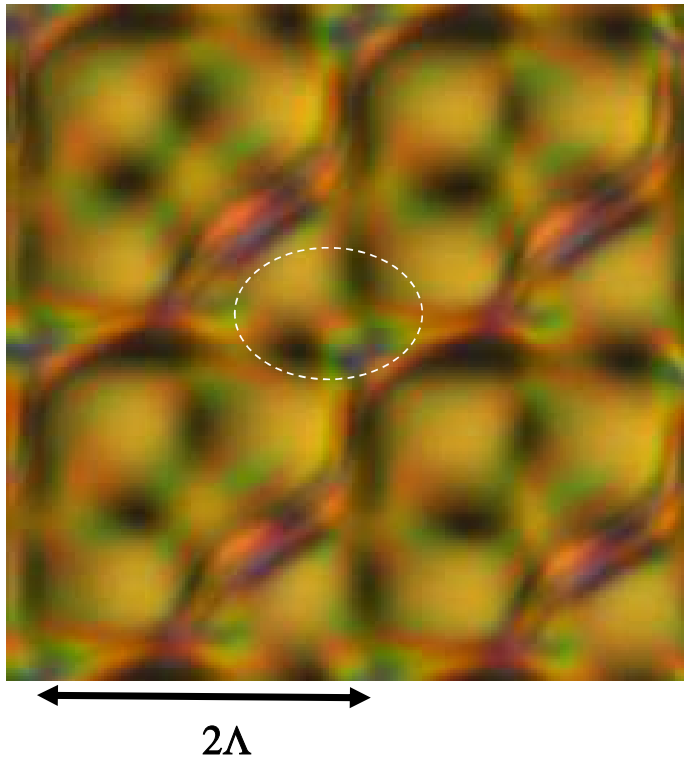


Jones Calculus



Λ = 12.5 µm
d = 10 µm
V = 0 Volt

Polarization microscopy



LIQUID CRYSTAL SWITCHING TIME

Rotation of the director yields a torque per unit volume due to viscosity:

viscous torque $\Gamma_v = -\gamma \frac{\partial \theta}{\partial t}$

rotational viscosity

change of the director with time

Total torque is zero (equilibrium): $\Gamma_{electric} + \Gamma_{elastic} + \Gamma_v = 0$

$$\Rightarrow \quad \frac{\partial \theta}{\partial t} = \frac{1}{\gamma}\left(\Gamma_{electric} + \Gamma_{elastic}\right)$$

elastic and electric torque yield a rotation

LIQUID CRYSTAL SWITCHING TIME

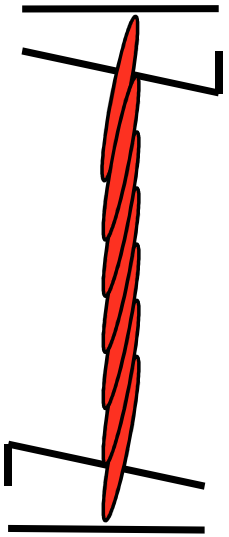
On switching: faster by high electric field

$$\frac{\partial\theta}{\partial t} = \frac{1}{\gamma}\left(\Gamma_{electric} + \Gamma_{elastic}\right)$$

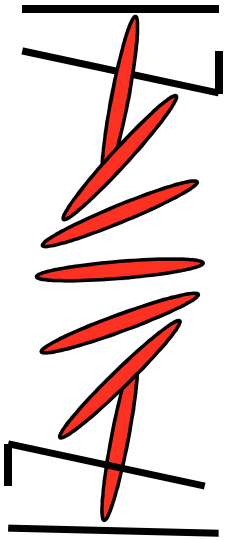
fast switching occurs when:

- strong electric torque
  (high electric field)
- or strong elastic torque
  (strong deformation)
- out of equilibrium
  (two torques different)

switch on



switch off



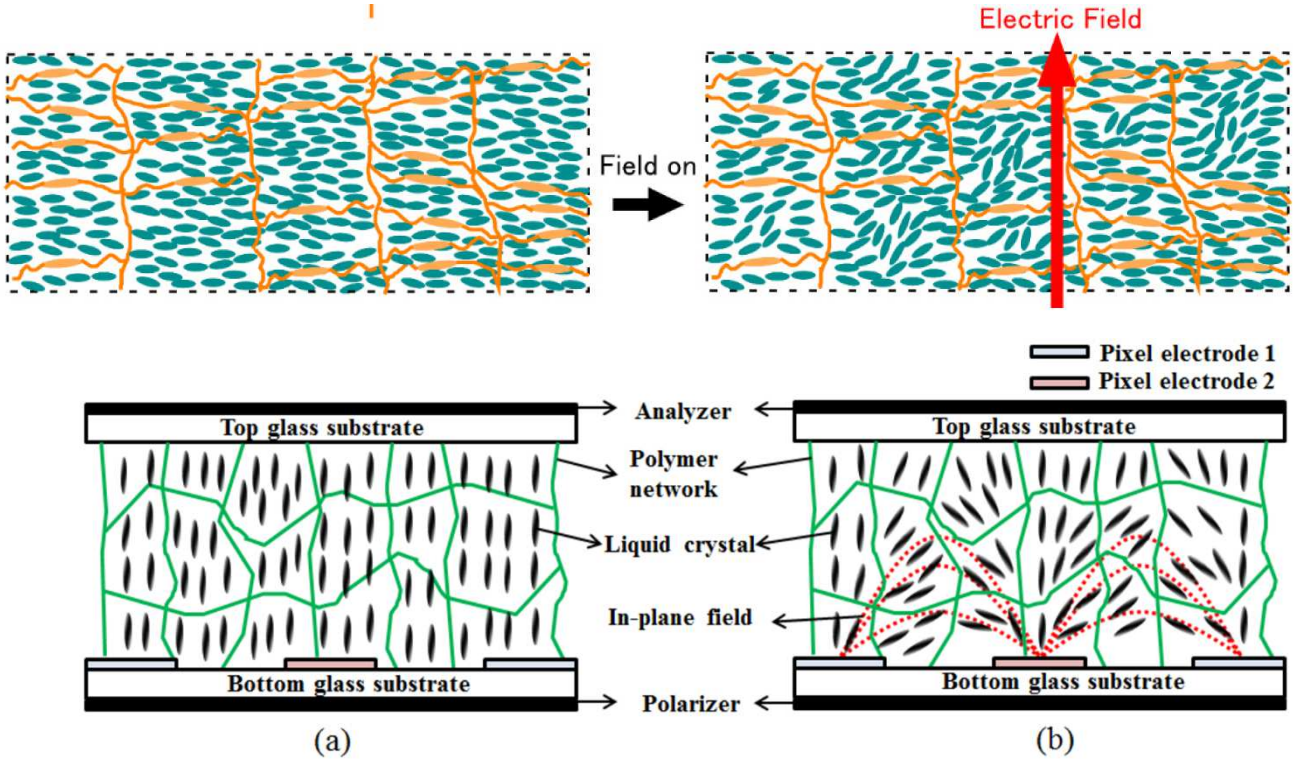
$$\Gamma_{electric} \sim E.\sin 2\theta$$

$$\Gamma_{elastic} \sim K\frac{\partial^2\theta}{\partial z^2}$$

LIQUID CRYSTAL SWITCHING TIME

polymer network reduces the distance,

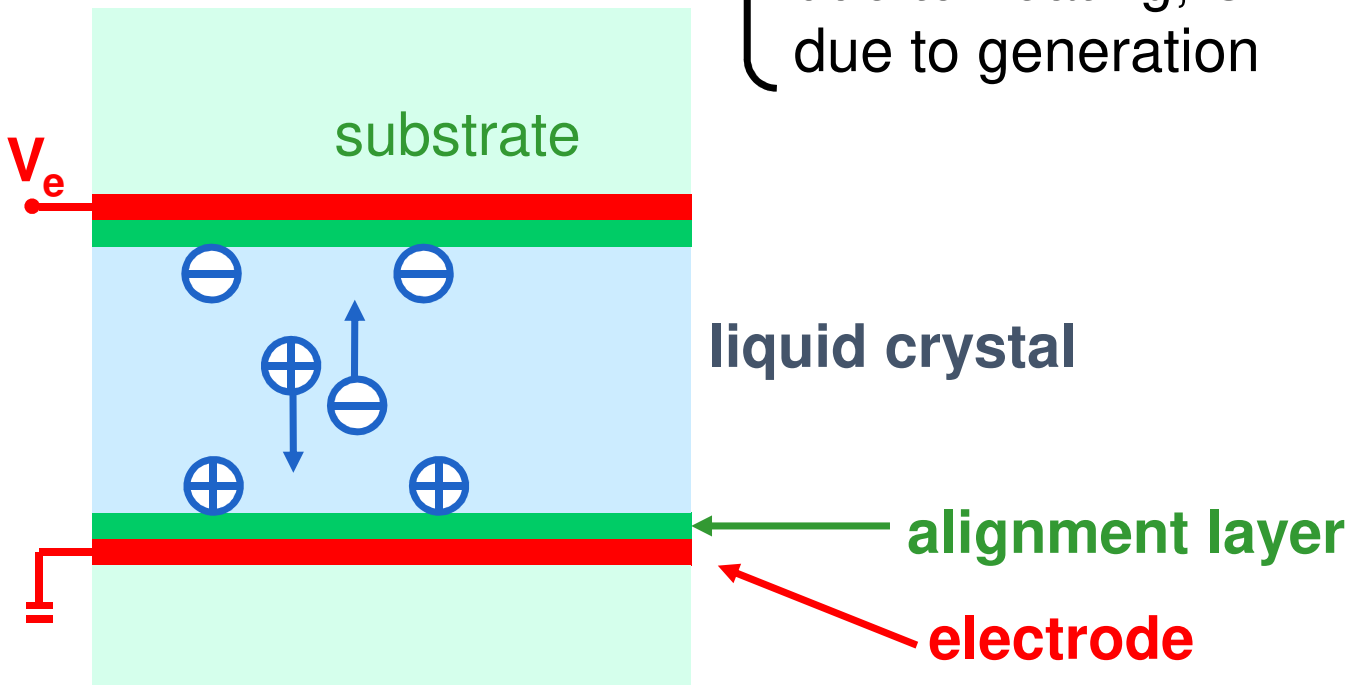
creating larger elastic torque, but also higher field needed



IONS IN LIQUID CRYSTALS

Liquid crystal with ions

- in LC material
- from alignment layers
- from glue
- due to heating, UV
- due to generation



Liquid Crystals and Photonics

WAT

GHENT UNIVERSITY

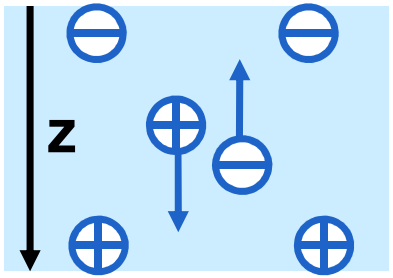
ION PROPERTIES

+ and – ions with:

concentration $n^{\pm}(z,t)$

mobility $\bar{\bar{\mu}}^{\pm}$

diffusion coefficient $\bar{\bar{D}}^{\pm} = \frac{kT}{e}\bar{\bar{\mu}}^{\pm}$



ion flux by drift and diffusion

$$\bar{F}^{\pm} = \pm n^{\pm}\bar{\bar{\mu}}^{\pm}\bar{E} - \bar{\bar{D}}^{\pm}\frac{\partial n^{\pm}}{\partial z}$$

change in ion concentration

$$\frac{\partial n^{\pm}}{\partial t} = -\frac{\partial F_z^{\pm}}{\partial z}$$

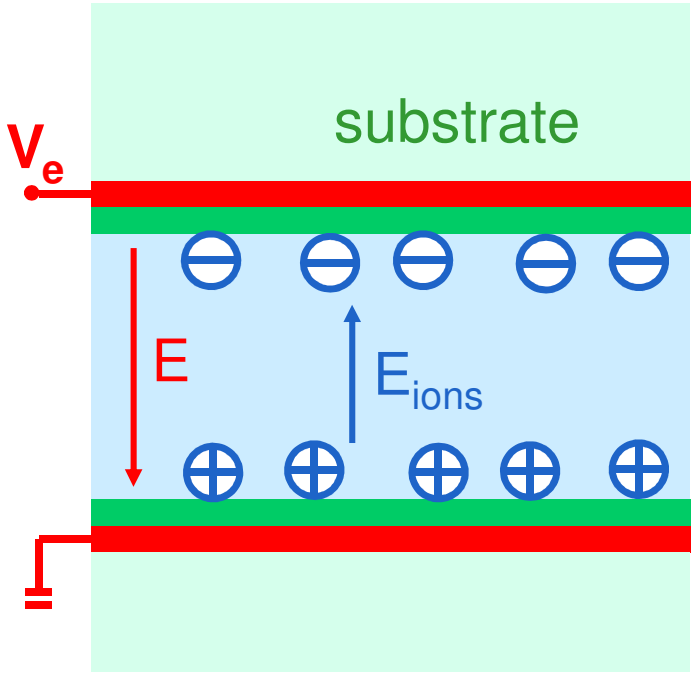
charge density

$$\rho = e\left(n^{+} - n^{-}\right)$$

Liquid Crystals and Photonics

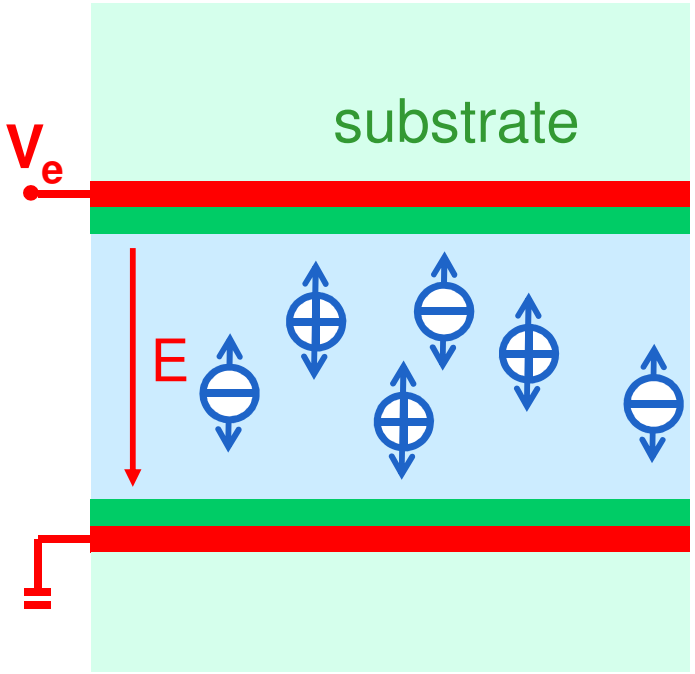
GHENT UNIVERSITY

IONS IN LIQUID CRYSTALS



after DC voltage:

$E_{tot}=E-E_{ions}$



with AC voltage:

ions remain homogeneous

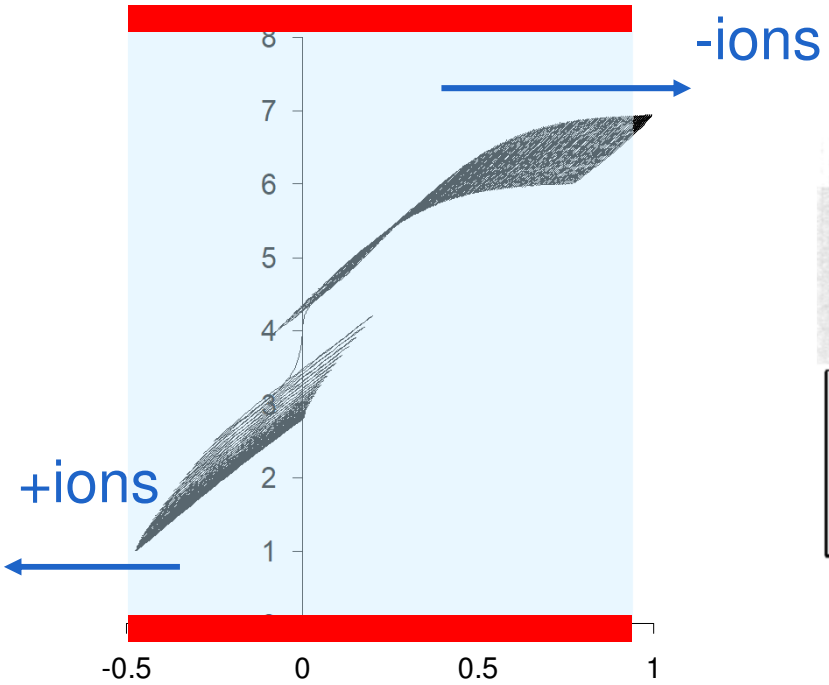
$E_{ions}\sim 0$

Liquid Crystals and Photonics

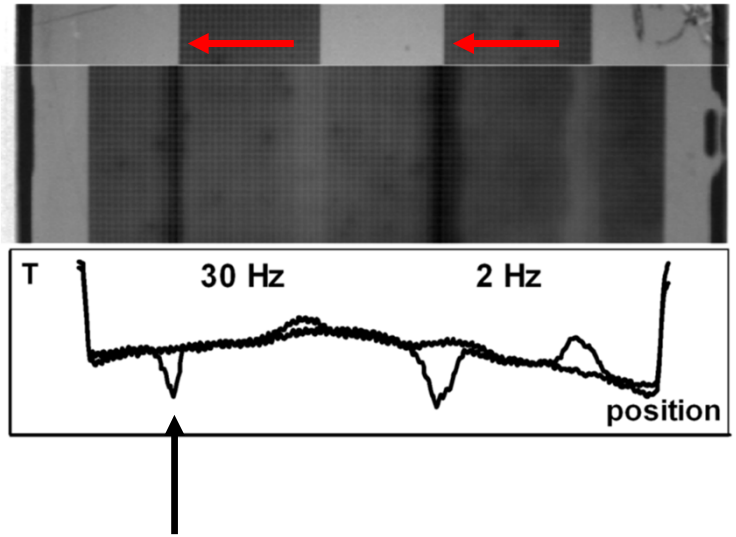
GHENT UNIVERSITY

IONS IN LIQUID CRYSTALS

anisotropic mobility $\overline{\overline{\mu}}^{\pm}$ ions move laterally!



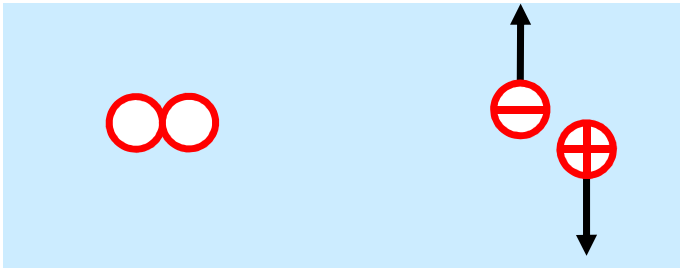
v=0.18 μm/s



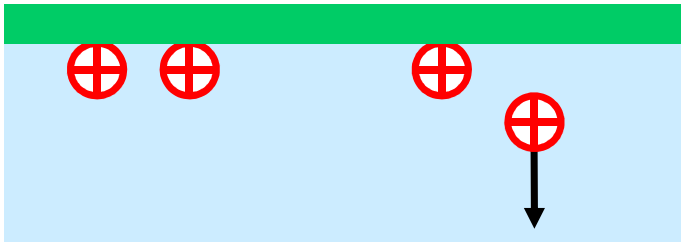
STN lcd: more ions,
lower transmission

IONS IN LIQUID CRYSTALS

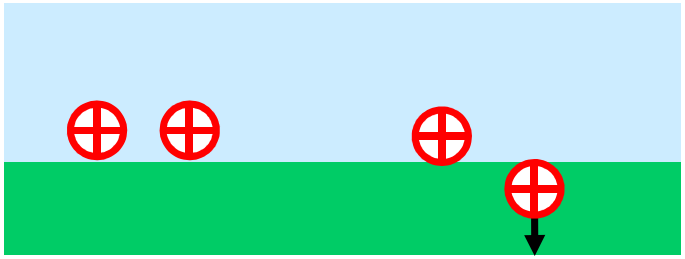
Ion generation



Ion trapping near alignment layer



Leakage through the alignment layer



Liquid Crystals and Photonics

WAT

GHENT UNIVERSITY