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

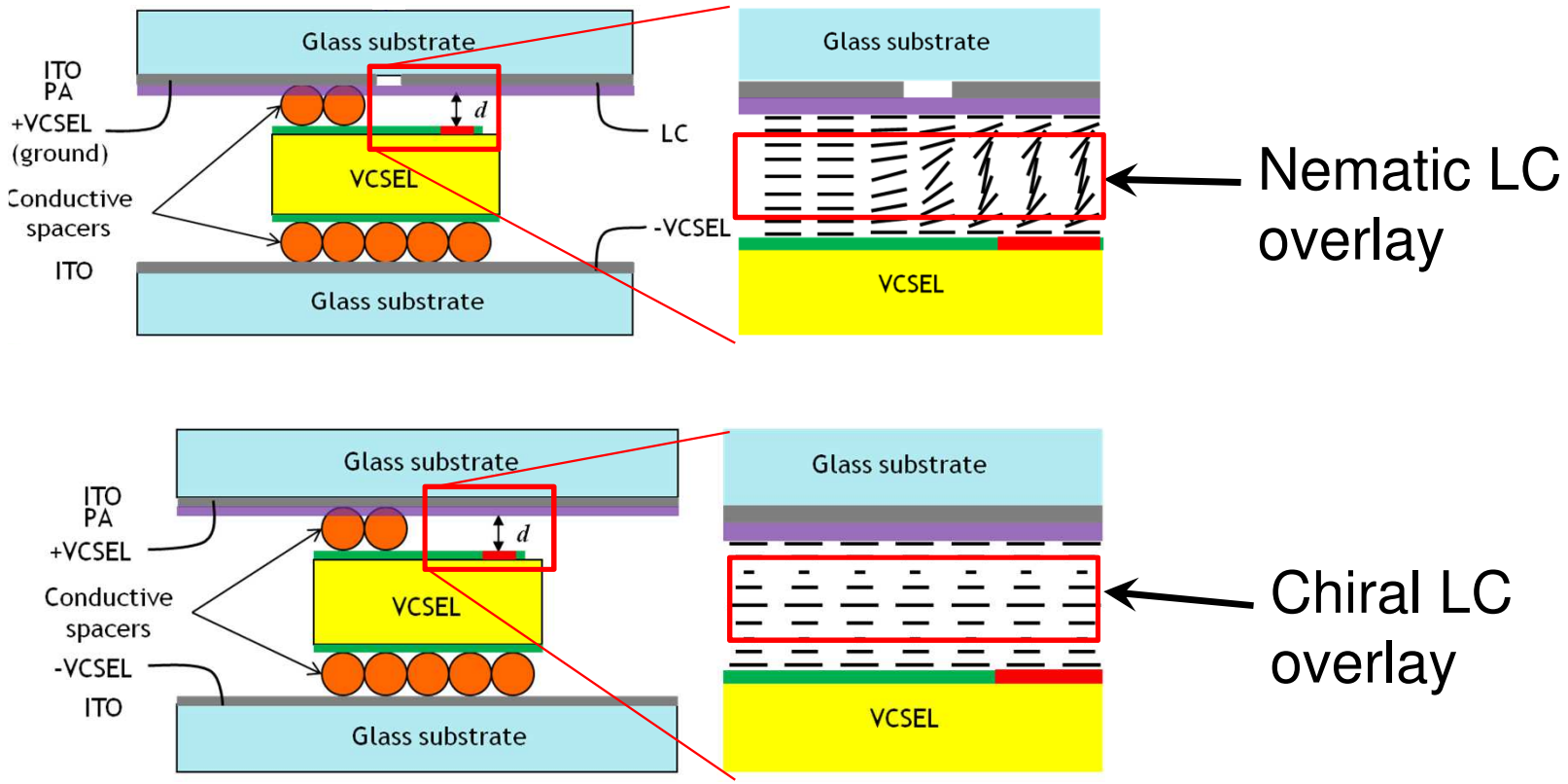
Liquid Crystals and Photonics

OVERVIEW

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
- Liquid crystal filters

VCSEL WITH LIQUID CRYSTAL



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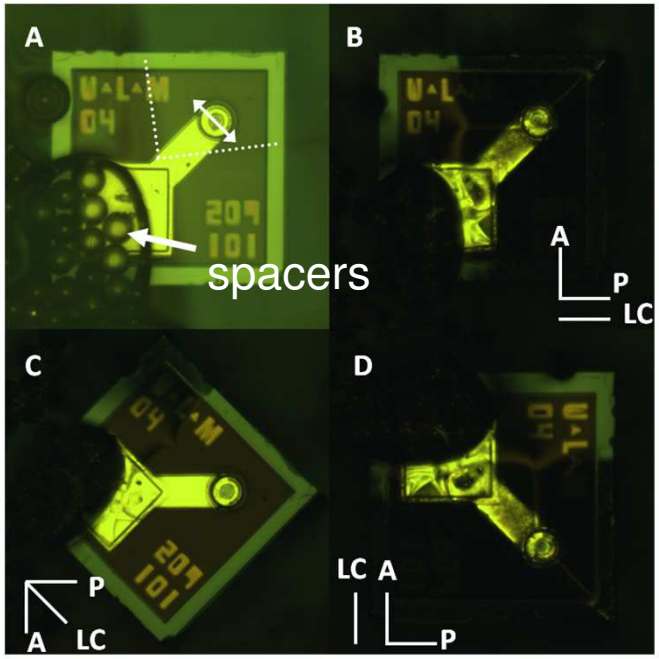
VCSEL WITH LC

reflection microscopy images

A: no LC
no polarizers



B, C, D:
with LC
and crossed polarizers

C: LC along 45°

B,D: LC // one polarizer

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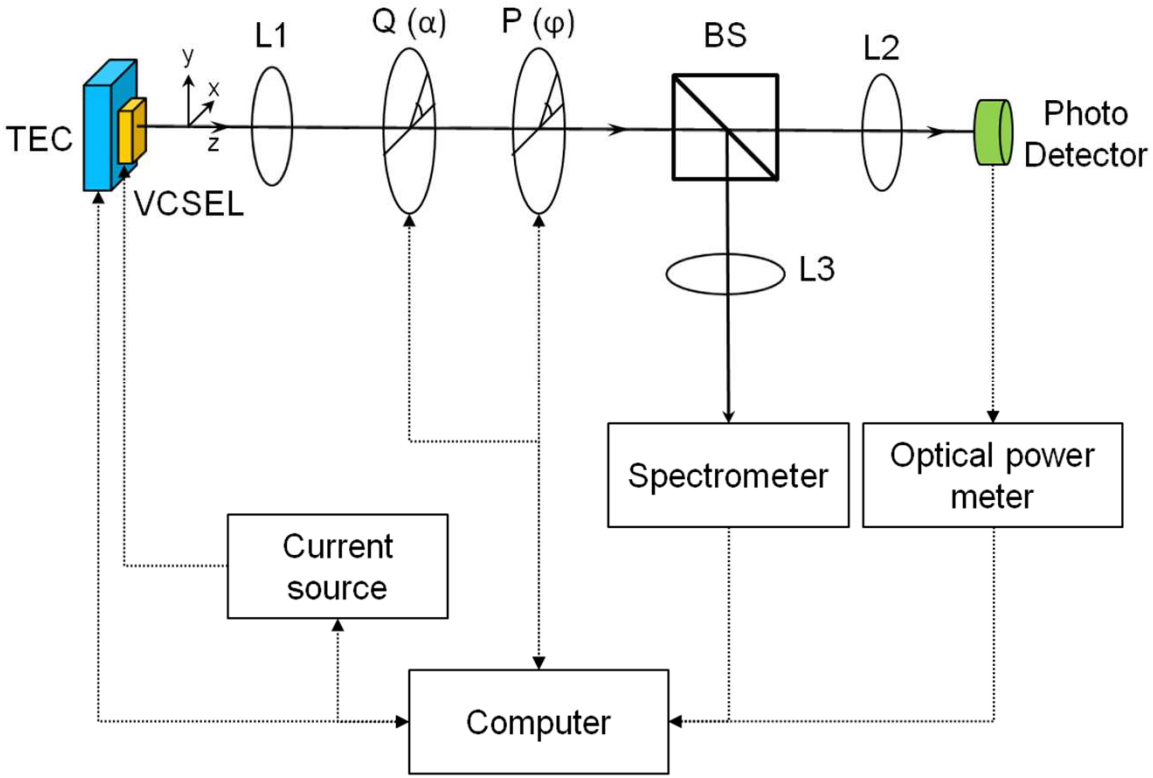
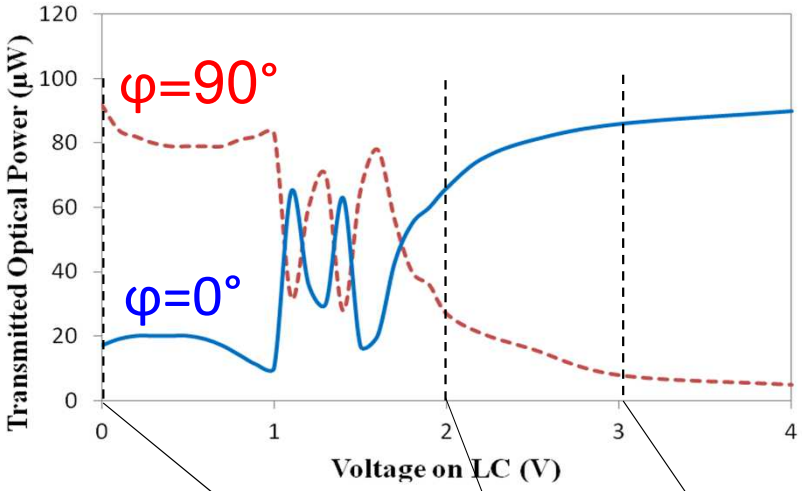
VCSEL WITH LC



Q: quarter wave plate
P: linear polarizer
TEC: temperature controller

VCSEL WITH LC

VCSEL power versus V_{LC}

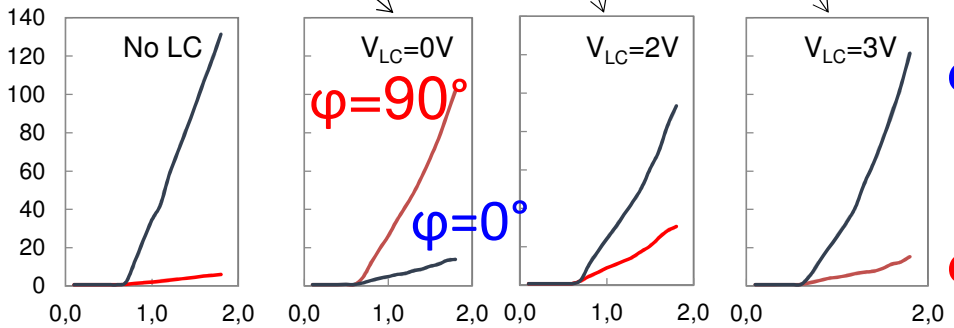


I_{VCSEL}=1.6mA

30μm spacers

but d < 30μm

Laser Optical Power (μW)



φ=0°

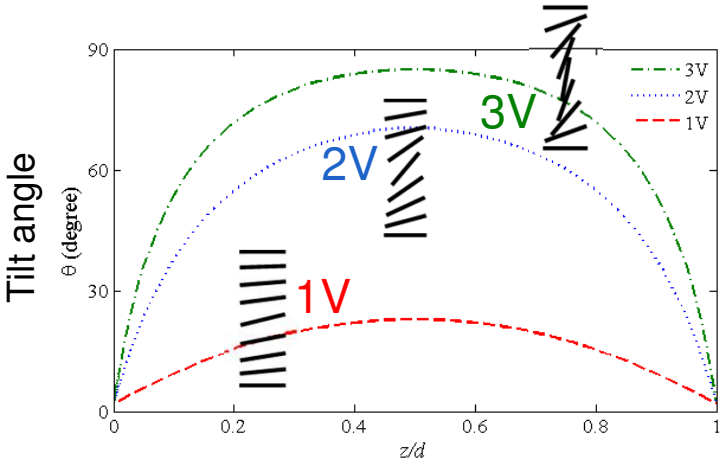
φ=90°

I_{VCSEL} (mA)

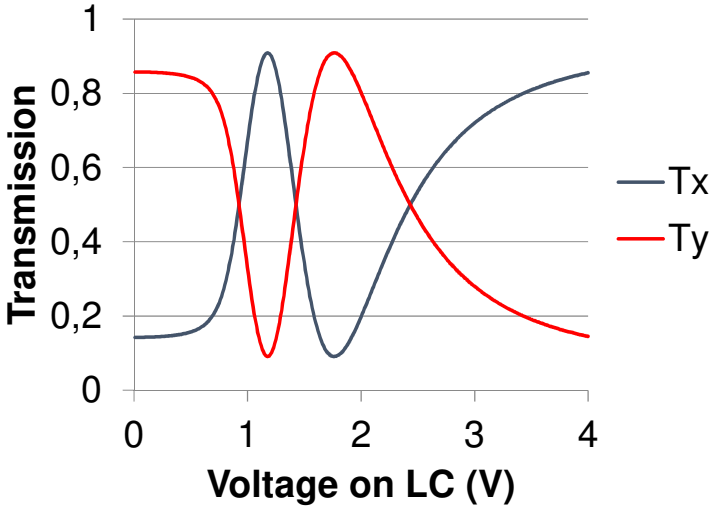
VCSEL WITH LC

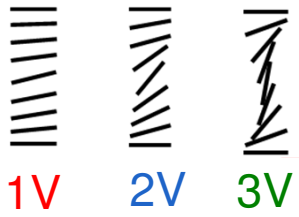
Numerical simulation results

d = 6µm, n_o= 1.5099, n_e= 1.7095



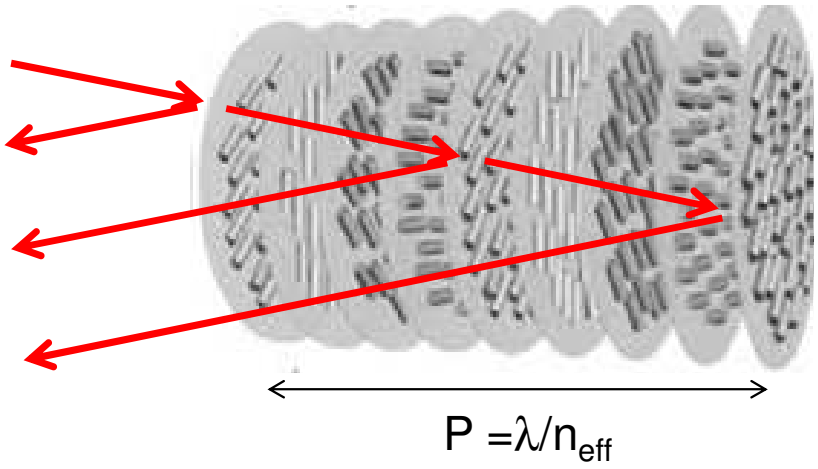
Voltage on LC





CHIRAL LIQUID CRYSTAL RESONATOR

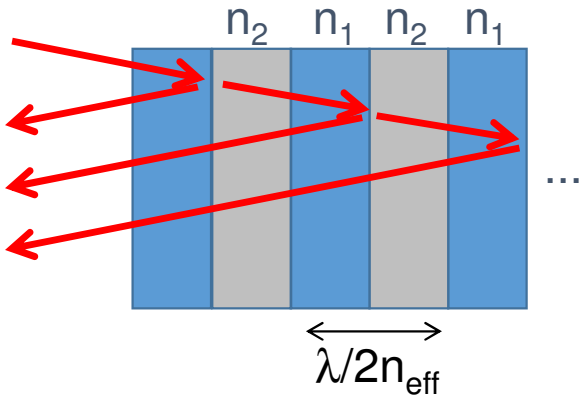
Chiral nematic
=cholesteric liquid crystal
(right handed) with pitch *P*



self-organizing structure
excellent, cheap mirror

structure yields
photonic bandgap

compare



- strong reflection when partial reflections are in phase
- slow light near the band edge

Ko and Sambles, JOSA A 1863 (1988)

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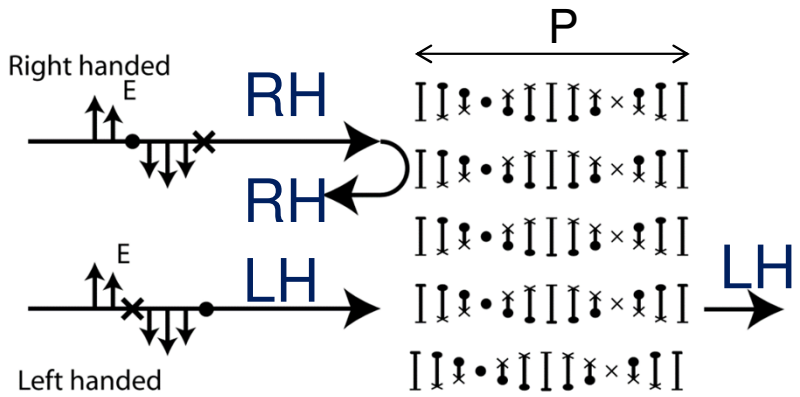
CHIRAL LIQUID CRYSTAL RESONATOR

RH chiral nematic liquid crystal

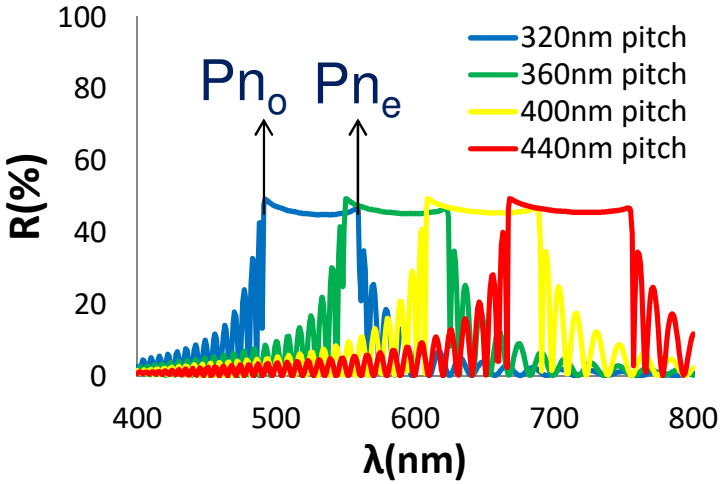
reflects RH circular polarization (RHCP)

when wavelength is in band gap: $P.n_o < \lambda < P.n_e$



right handed liquid crystal

reflection for unpolarized light



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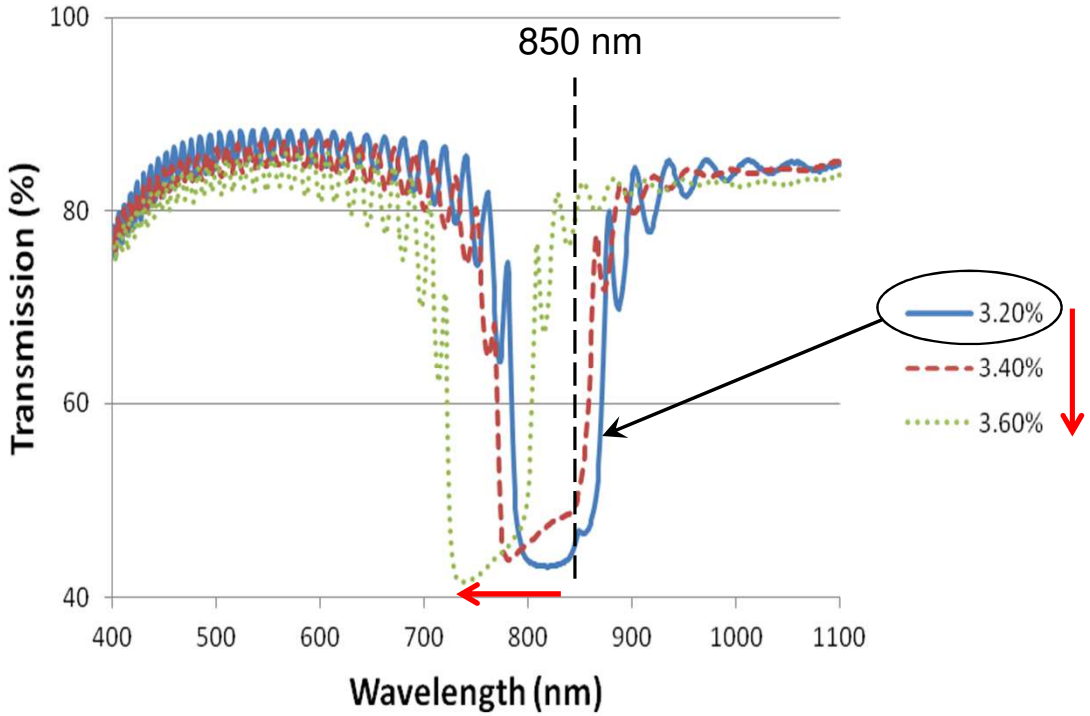
CHIRAL LIQUID CRYSTAL RESONATOR

Dependency on the BDH1305 dopant concentration in 5CB

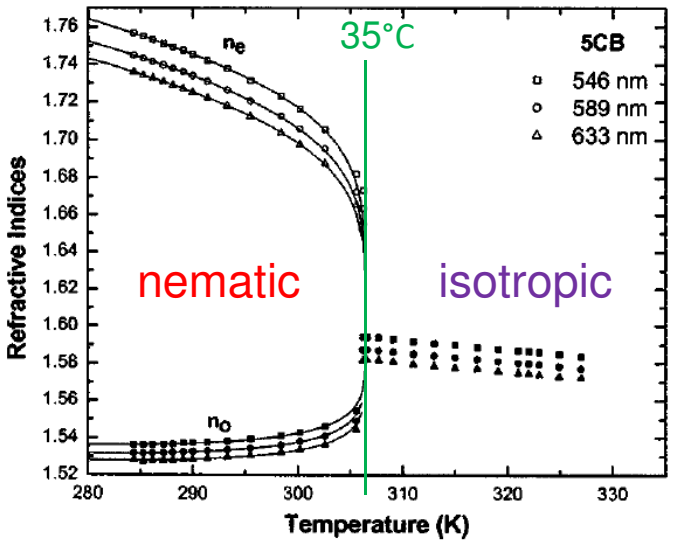


higher concentration of chiral dopant → shorter pitch → Reflection band at lower λ

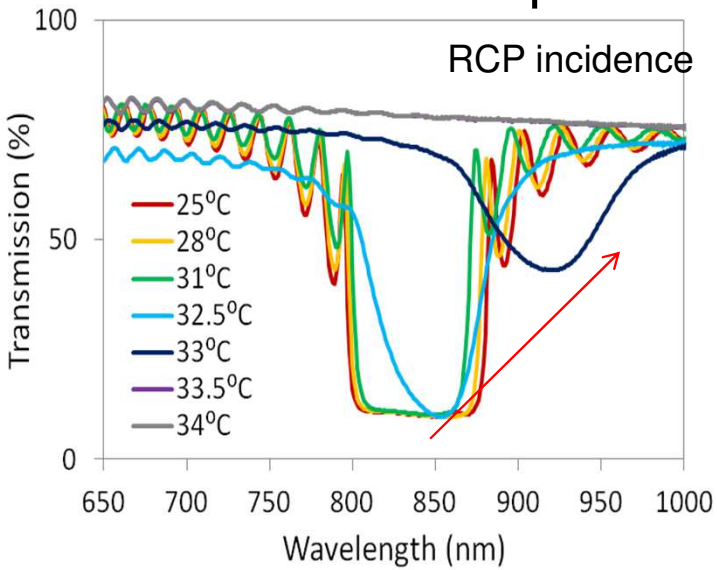
CHIRAL LIQUID CRYSTAL RESONATOR

TEMPERATURE DEPENDENCY

5CB



CLC: 5CB+dopant



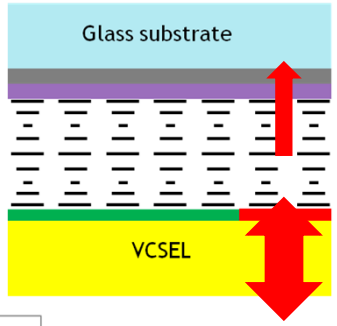
Phase transition from chiral to isotropic at 33°C

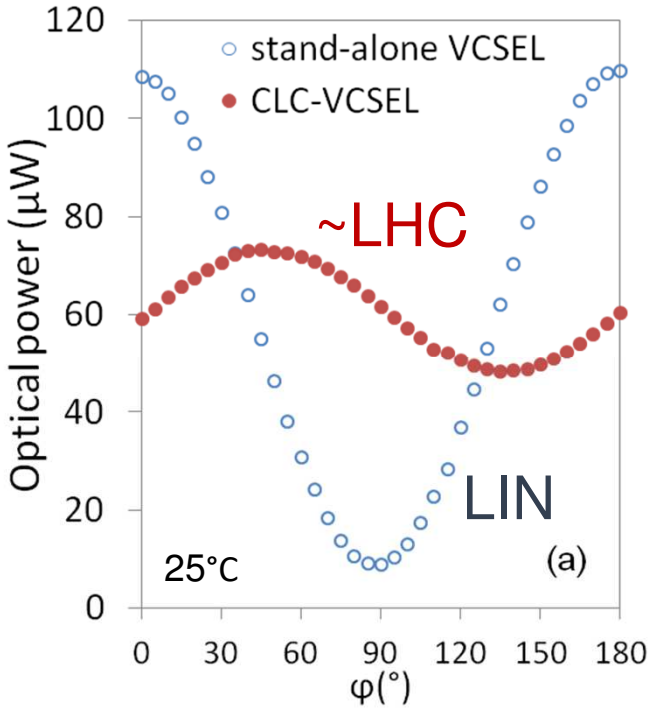
J. Li, et al., J. Appl. Phys. 96, 19 (2004)

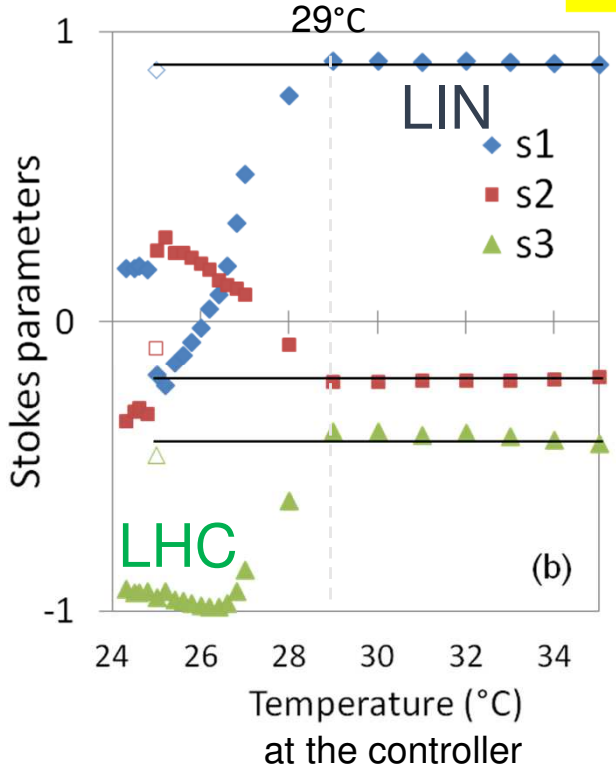
CHIRAL LIQUID CRYSTAL RESONATOR

VCSEL WITH CLC: LH CIRCULAR EMISSION

$I_{VCSEL} = 1.6mA \sim 3I_{th}$

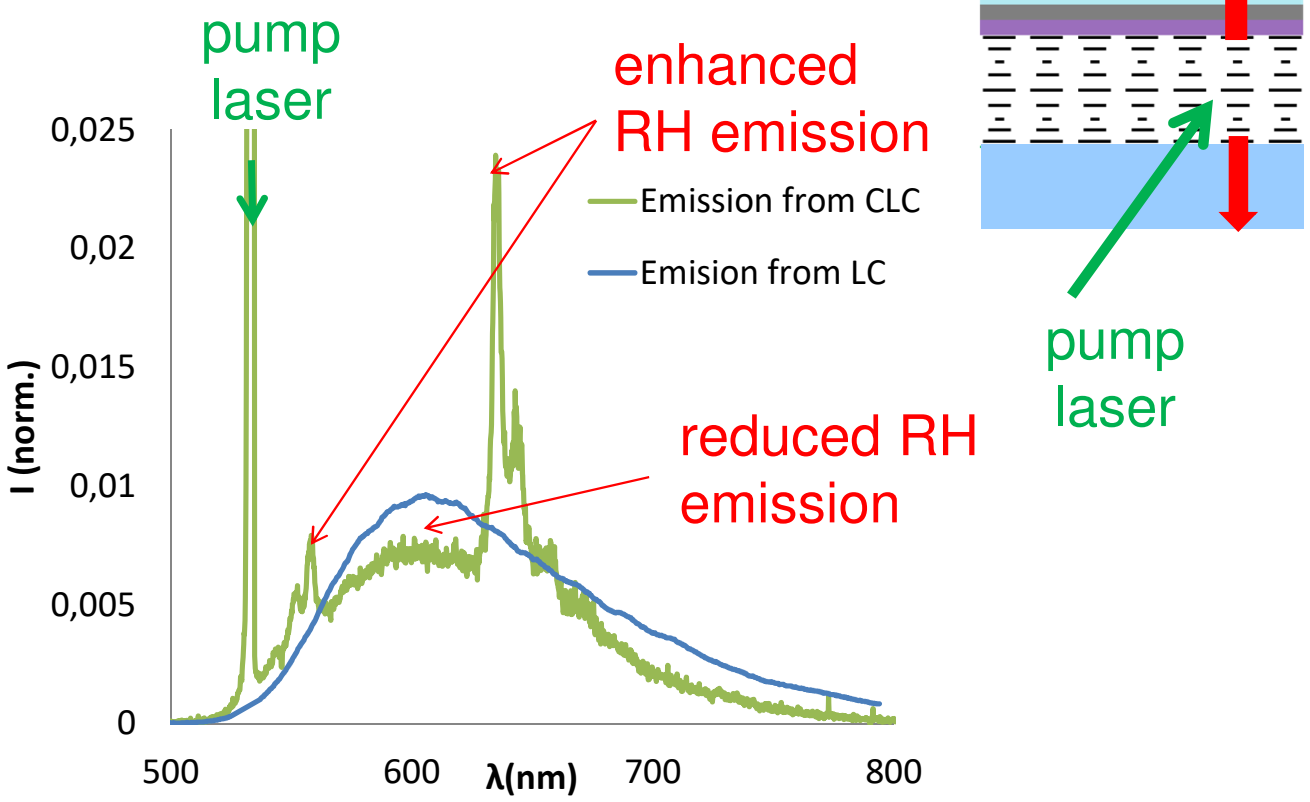






SPONTANEOUS EMISSION FROM CLC

Photoluminescence of 1% DCM (dye) in E7 (6.8µm) with 5% chiral dopant BDH1305, to obtain RH CLC



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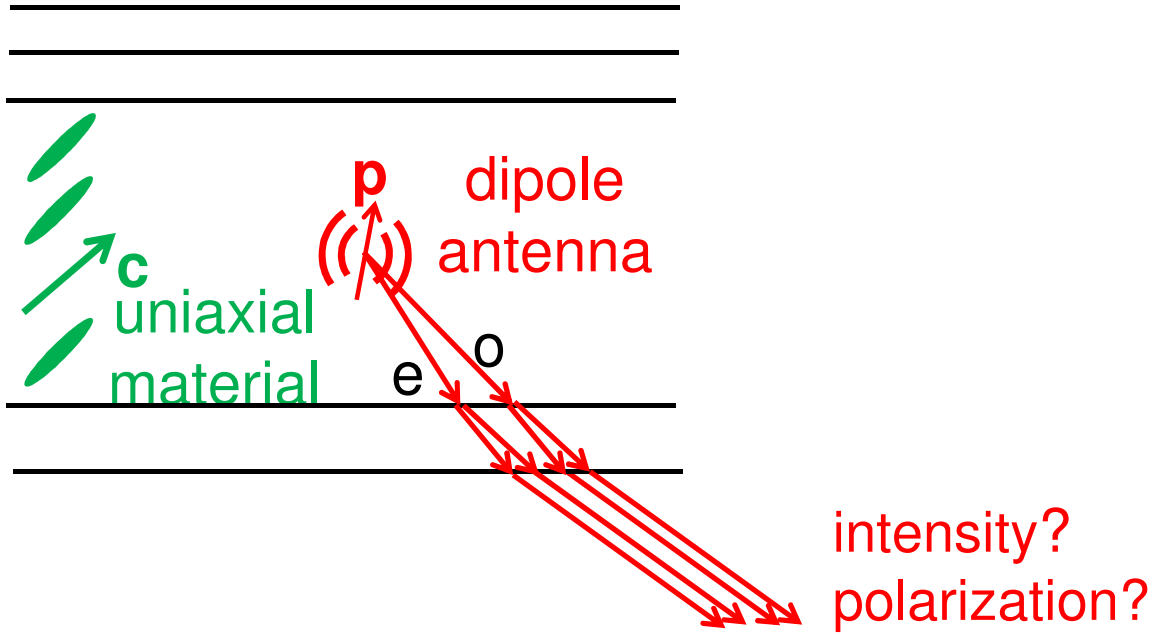
SPONTANEOUS EMISSION FROM CLC

Simulation tool developed at UGent

Dipole antenna **p**

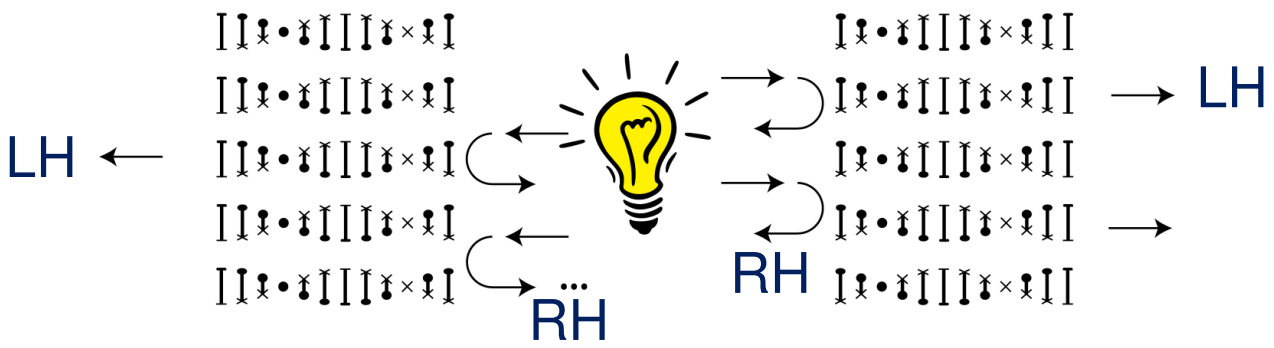
Layered structure, uniaxial material with n_e n_o



Penninck et al., OPTICS EXPRESS 18558, 2011

SPONTANEOUS EMISSION FROM CLC

Light emitting dye in an anisotropic stack



In the band gap: no emission of RH light
in-phase after round trip: enhanced emission
out of phase after round trip: reduced emission

simulation model for 1D stack (for OLEDs/LCs)
based on plane waves E_{o+} E_{o-} E_{e+} E_{e+} in every slab

Penninck et al., OPTICS EXPRESS 18558, 2011

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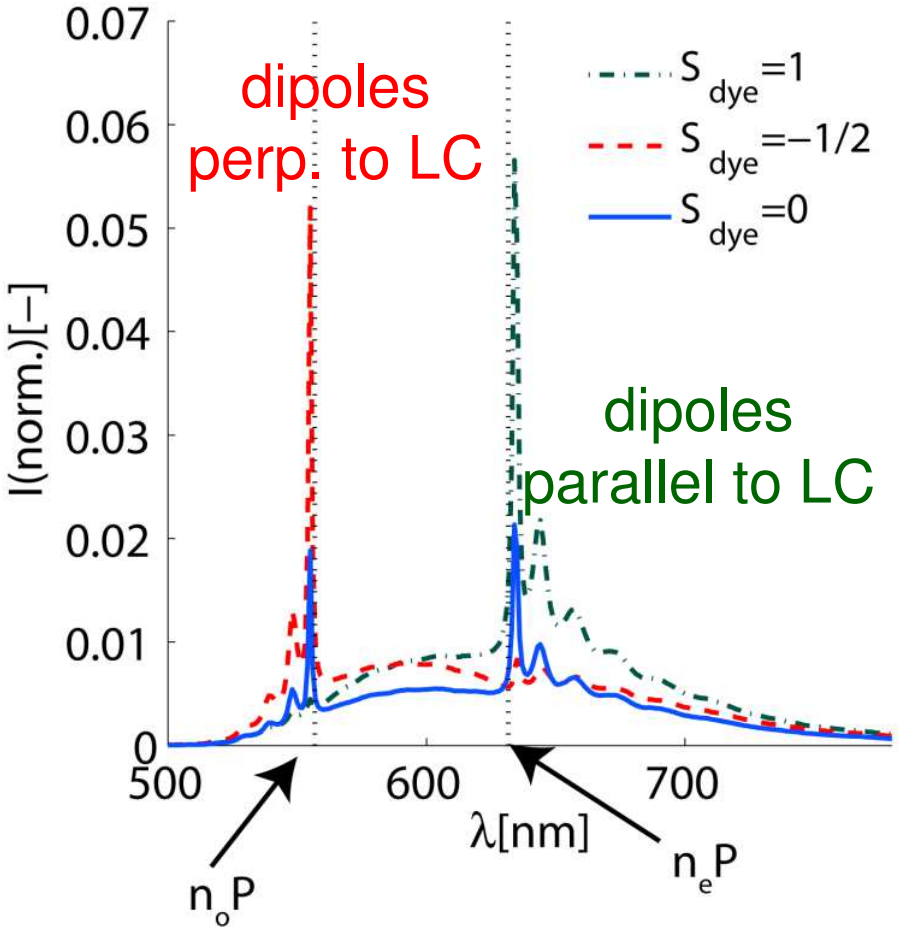
SPONTANEOUS EMISSION FROM CLC

Simulation

Importance of dye molecule orientation



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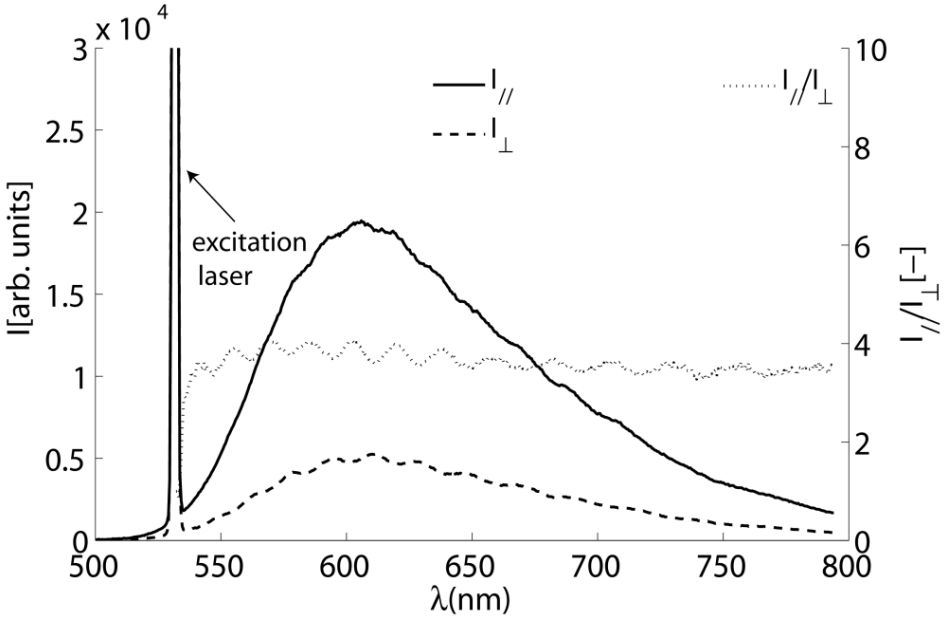
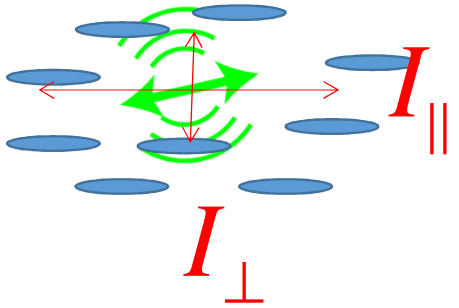
SPONTANEOUS EMISSION FROM CLC

Reference measurement: DCM dye in nematic LC
absorption maximum: 500 nm, emission maximum: 600 nm





order parameter

$$S_{dye} = \frac{3\frac{I_{\parallel}}{I_{\parallel}+2I_{\perp}} - 1}{2} \approx 0.47$$

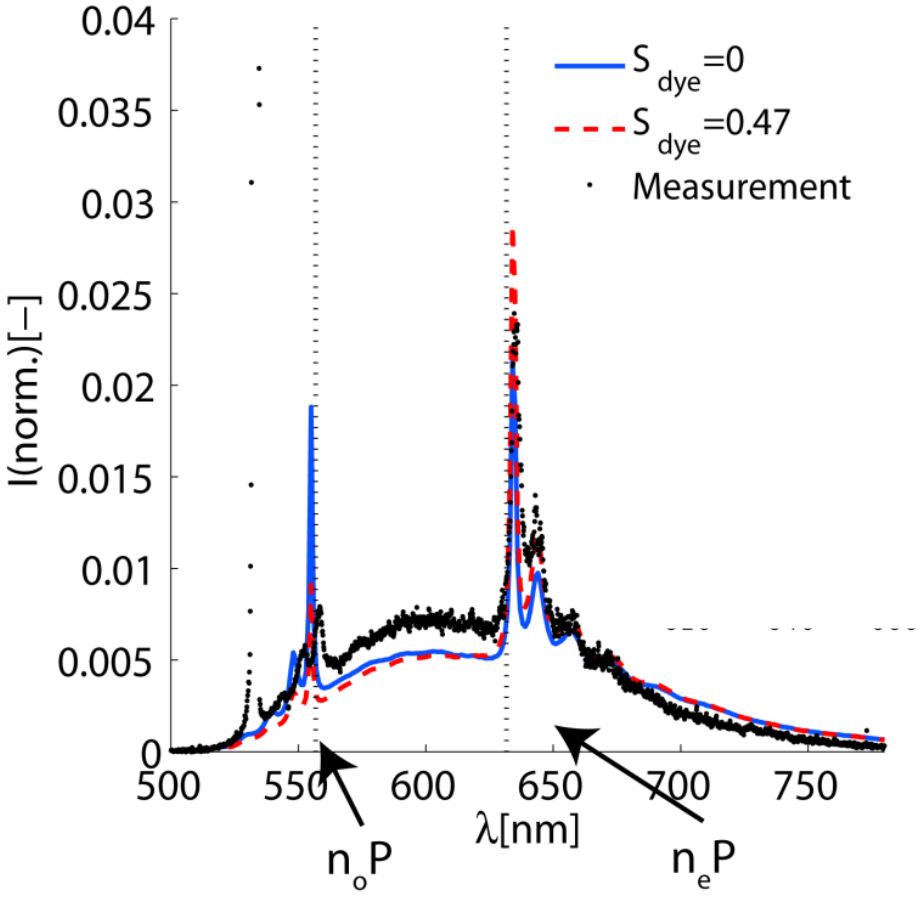
L. Penninck *et al.*; Phys. Rev. E 85; 041702 (2012)

SPONTANEOUS EMISSION FROM CLC

Experiment

spontaneous emission spectrum

good agreement with S=0.47



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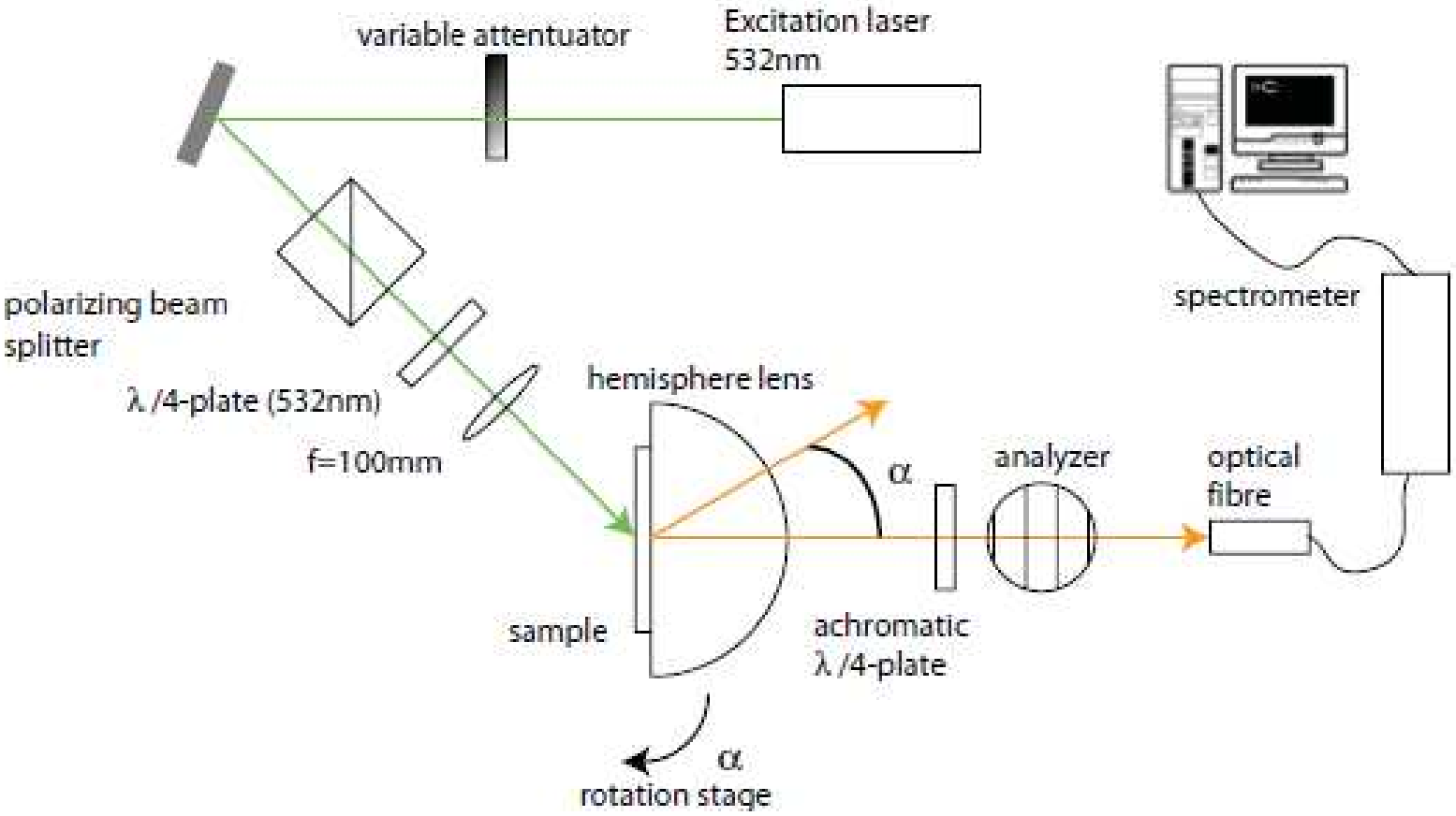
SPONTANEOUS EMISSION FROM CLC

setup for measuring PL emission



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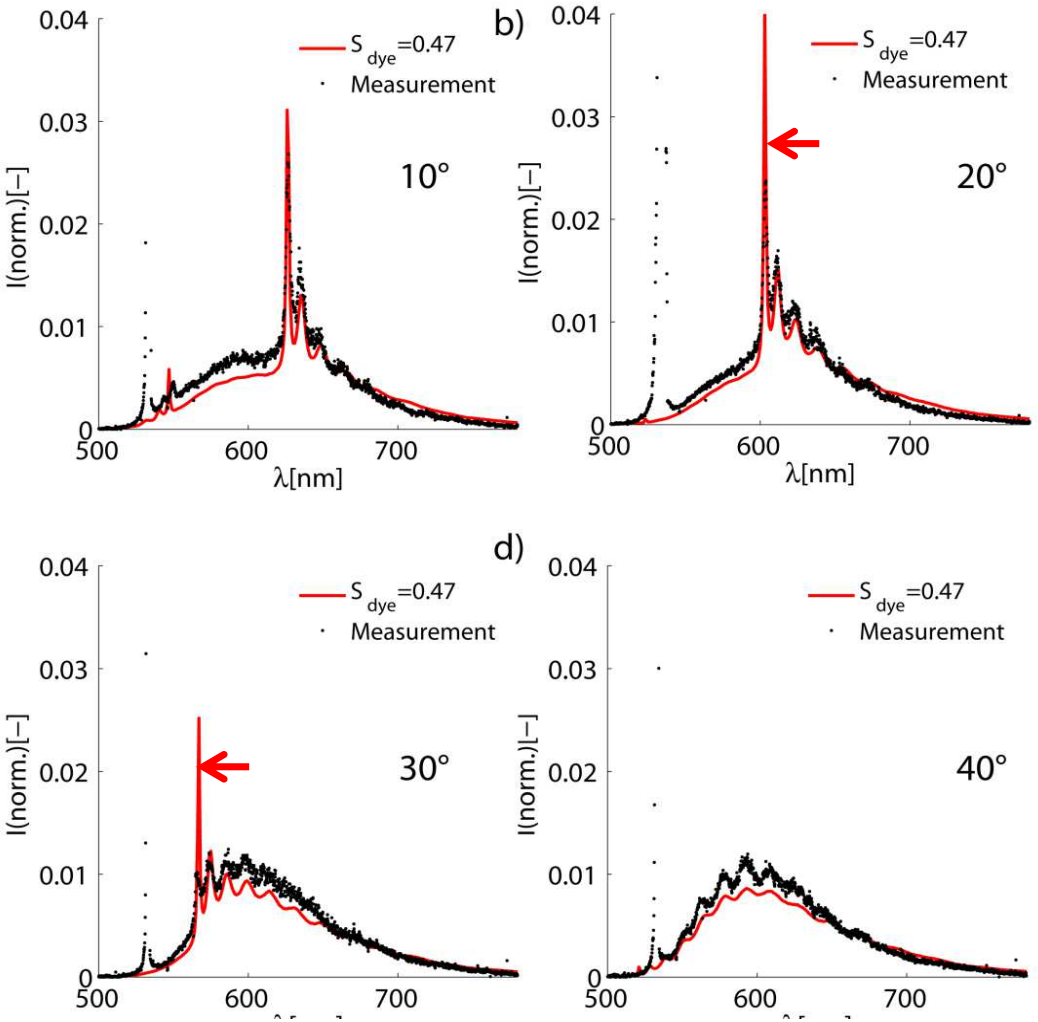
SPONTANEOUS EMISSION FROM CLC

Emission at higher angles in glass

bandgap is blue-shifted



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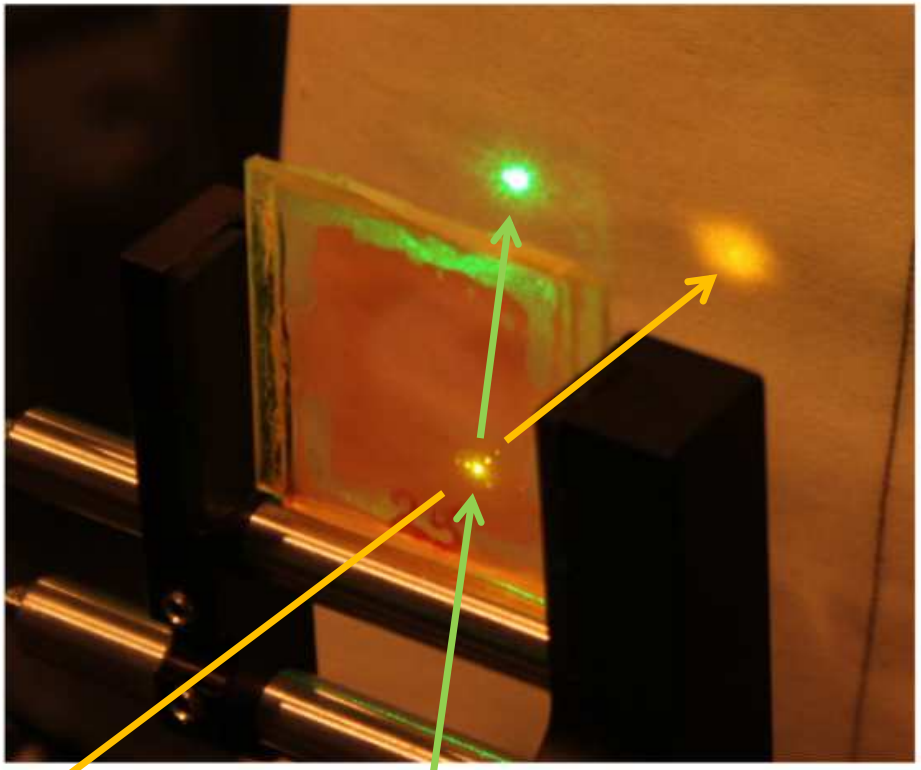
LASING FROM CLC

see papers by
- Ilchishin
- Palffy-Muhorray
- Schmidtke
- Coles



chiral nematic liquid crystal lasing

excitation pulse 0.5ns, 532nm, 30µJ

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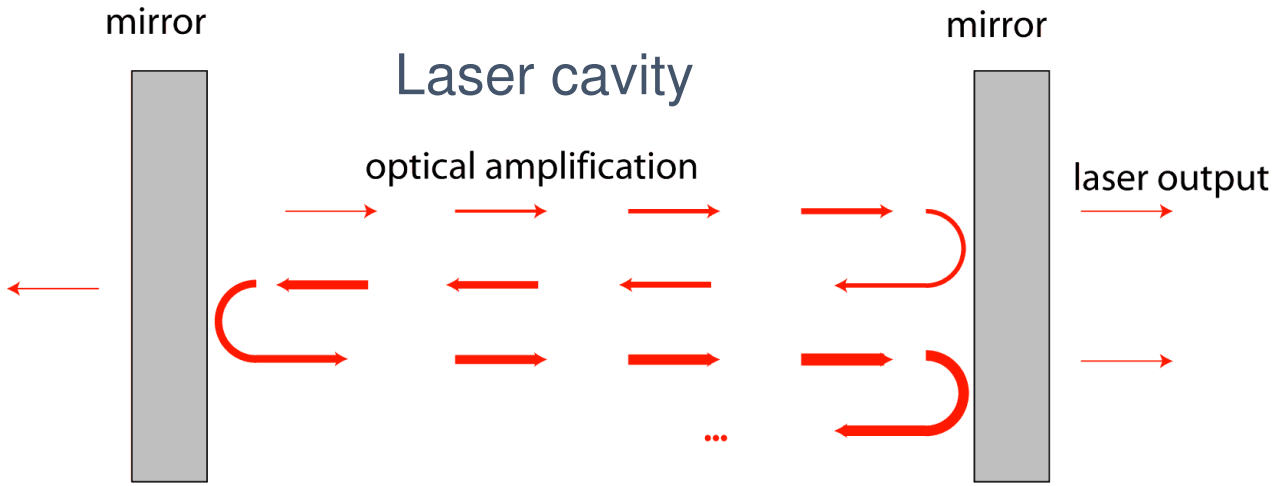
LASING FROM CLC

How to reduce lasing threshold?



- Beam travels right and is amplified
- Part is transmitted
- Beam travels left and is amplified
- Part is transmitted

} Round trip

Laser threshold:

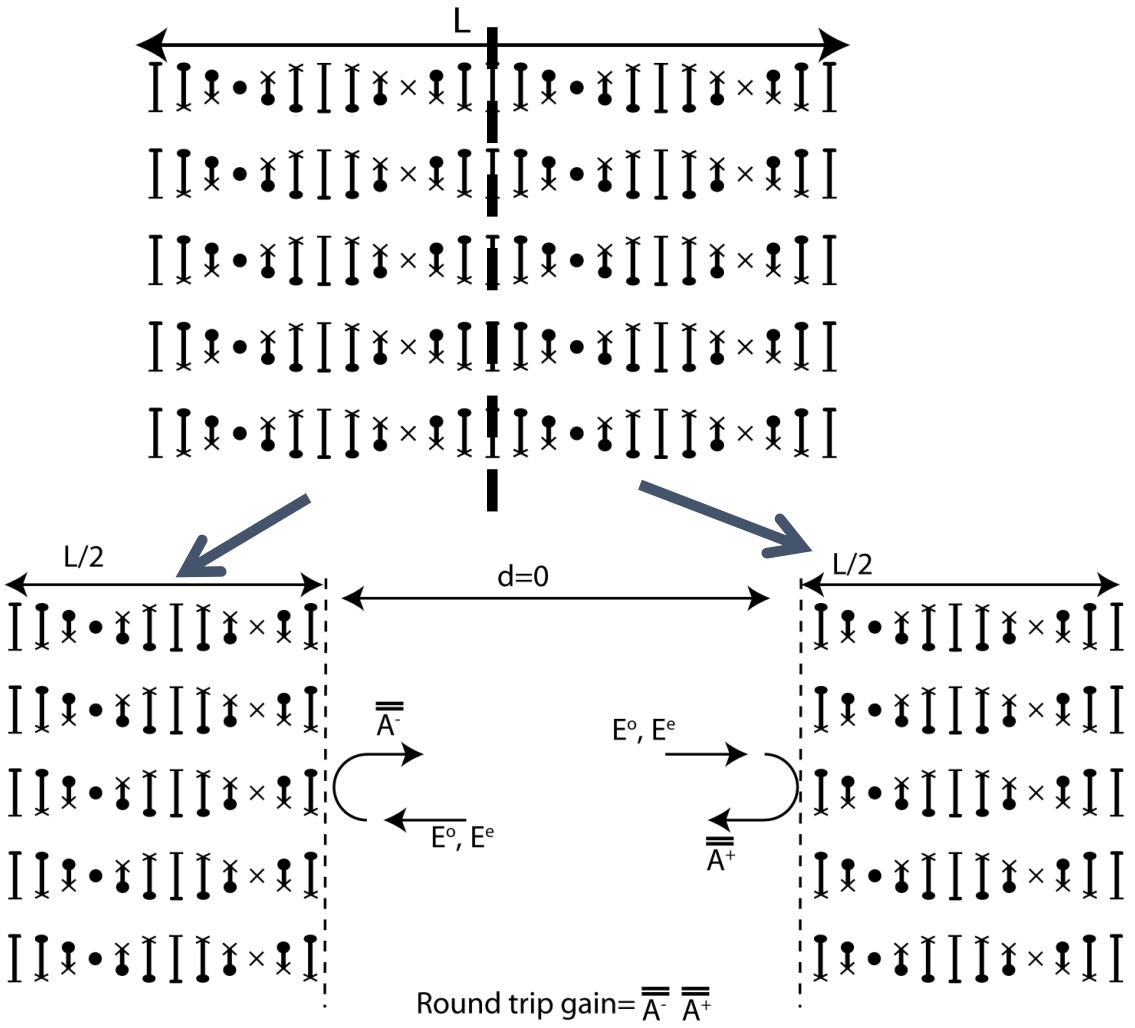
amplification compensates transmission loss in 1 round trip

LASING FROM CLC

Split CLC
1D plane wave model

anisotropic gain
$g_e(\lambda)$ and $g_o(\lambda)$

lasing condition
tensor $\mathbf{A}^-$ $\mathbf{A}^+$
has eigenvalue 1
for one λ



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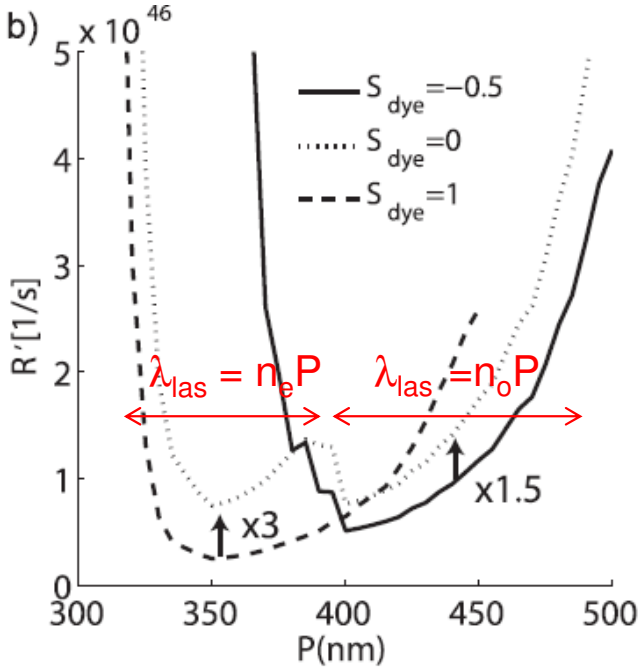
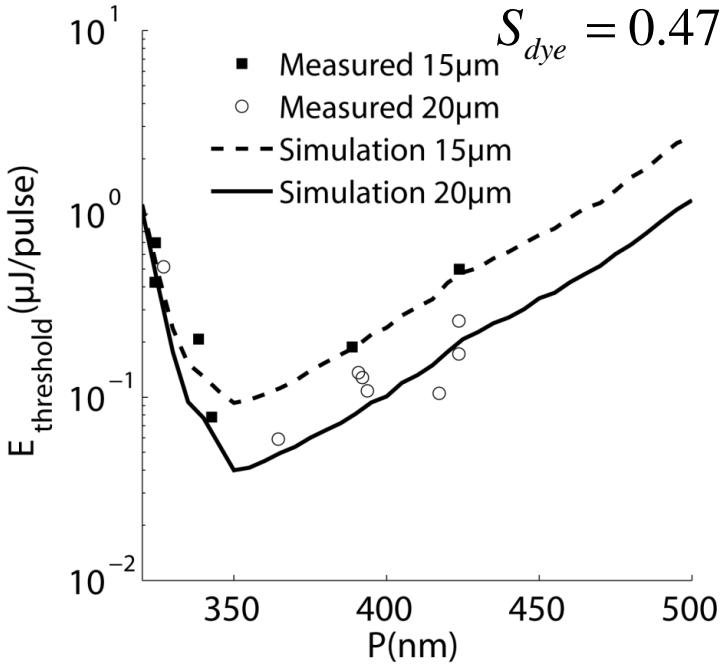
LASING FROM CLC

Laser threshold

laser pump power threshold versus pitch and order param.

measurement & simulation





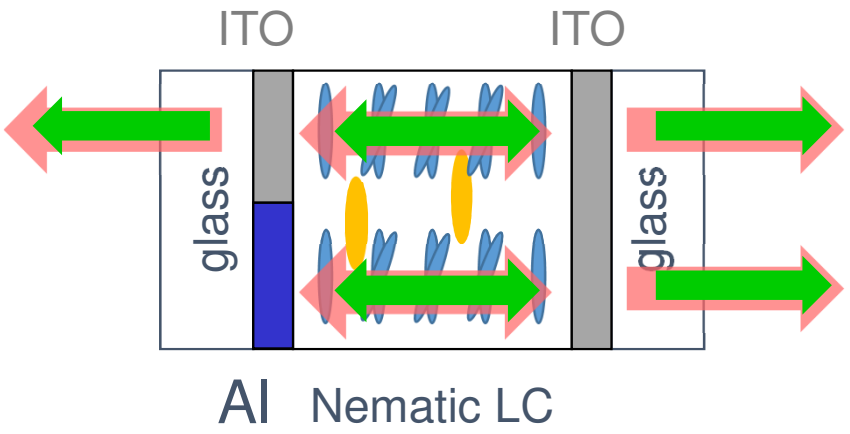
Penninck, J. Appl. Phys. **113,** 063106 (2013)

LASING IN NON-CHIRAL LC

Partial reflection at ITO electrode / full reflection at Al

- higher reflectivity (Al) → lower threshold
- voltage tuning

LC tilt → shorter optical path length → shorter wavelength λ_{lasing}



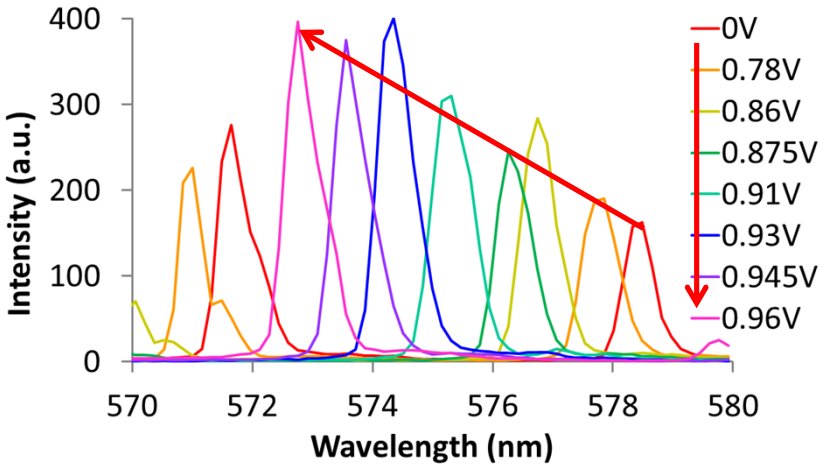
*Inge Nys et al., JOSA B **31**, p.1516 (2014)*

LASING IN NON-CHIRAL LC

Voltage tuning

LC tilt → reduction of cavity length → shorter wavelength

λ_{lasing}



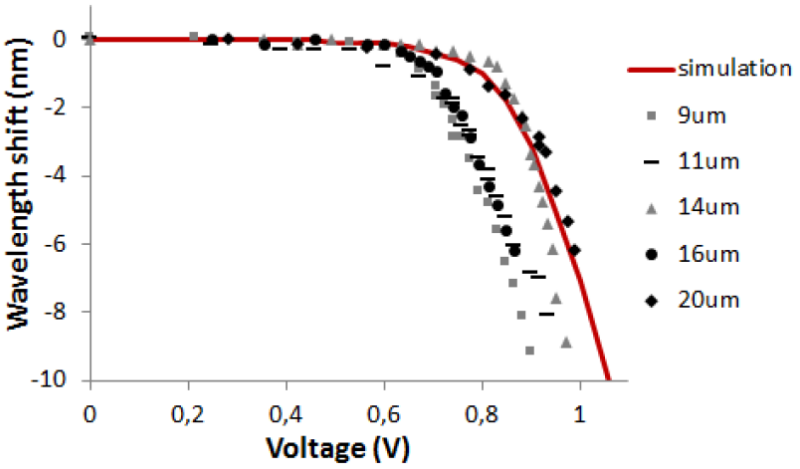
14 µm thick LC

8 nm tuning

thinner cavity

→ wider free spectral range

→ wider wavelength tuning



SMART WINDOWS

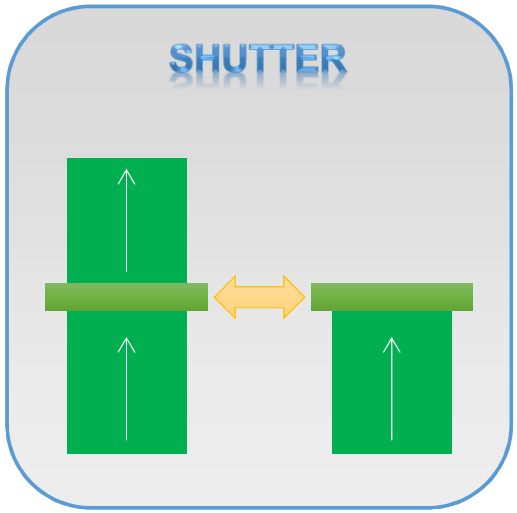


Image: Peer+, Merck Window Technologies

VIS / IR SWITCHING FOR 3D CAMERA

3D camera

SAMSUNG ADVANCED INSTITUTE OF TECHNOLOGY

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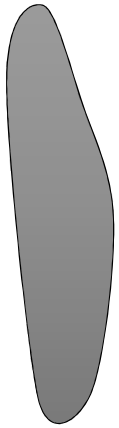
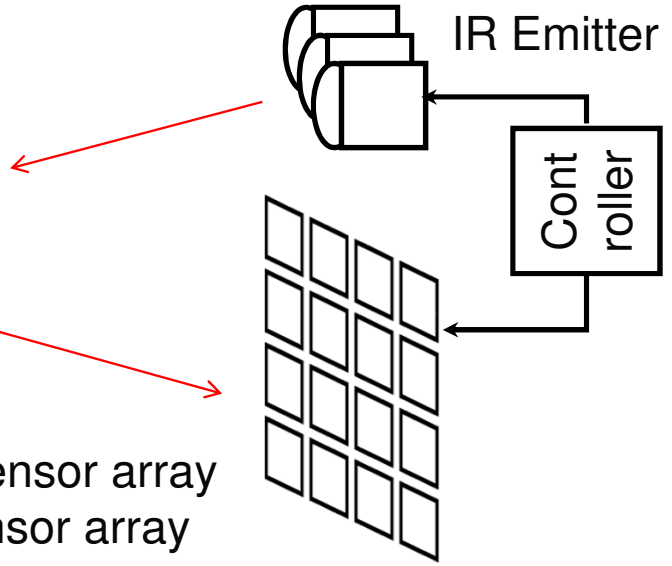
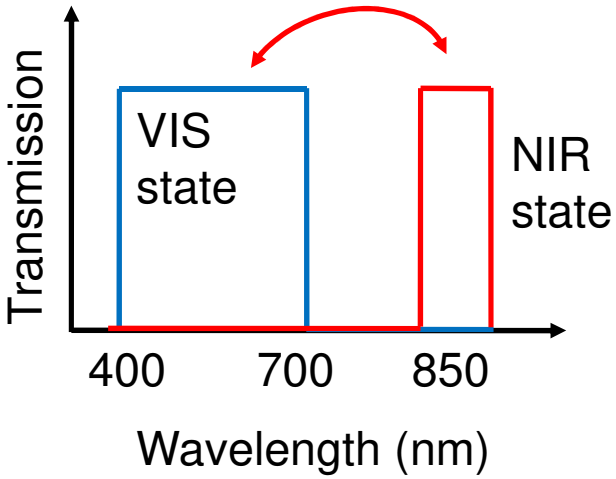
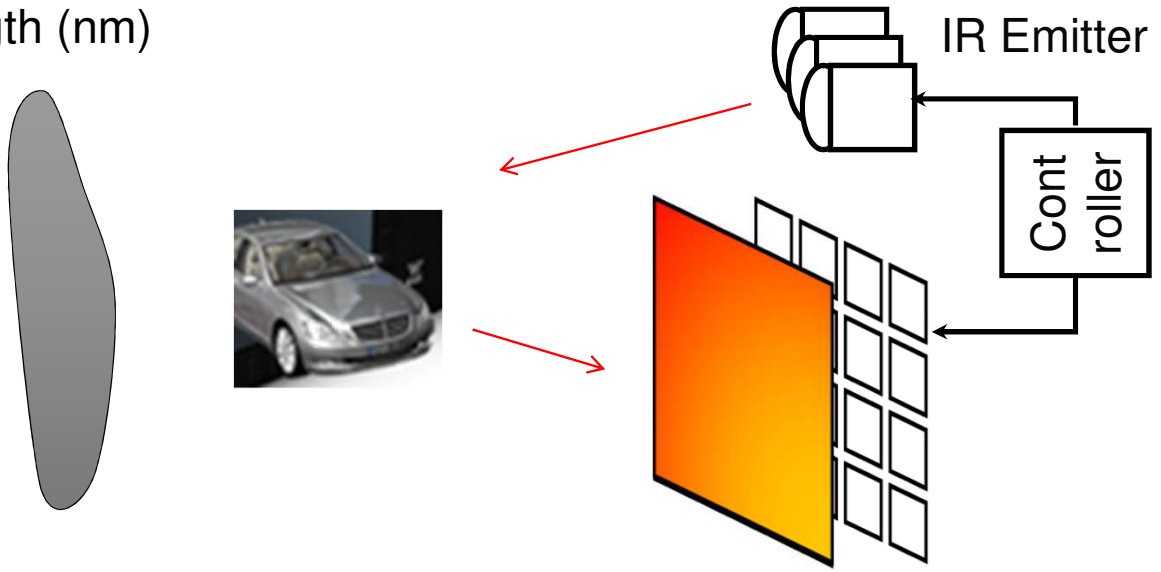




VIS / IR SWITCHING FOR 3D CAMERA



Switching between VIS state and NIR state (3D camera application)



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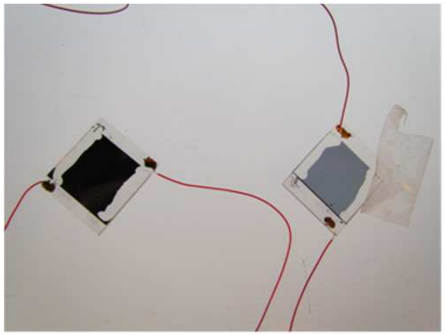
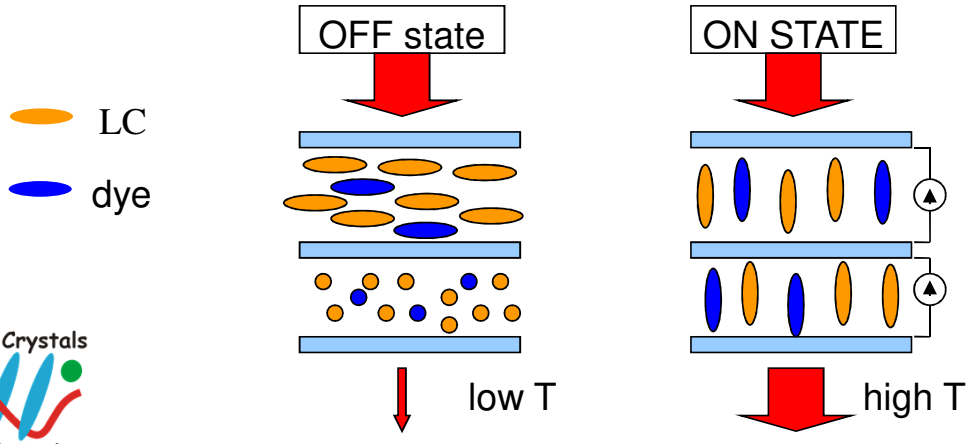
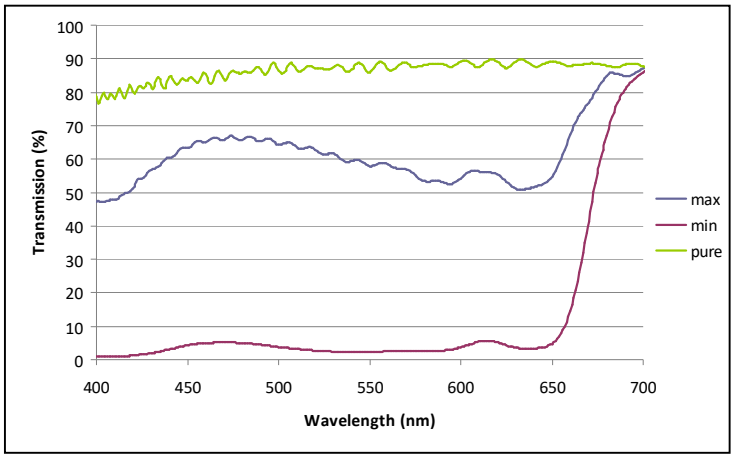
VIS / IR SWITCHING FOR 3D CAMERA

switching in the visible







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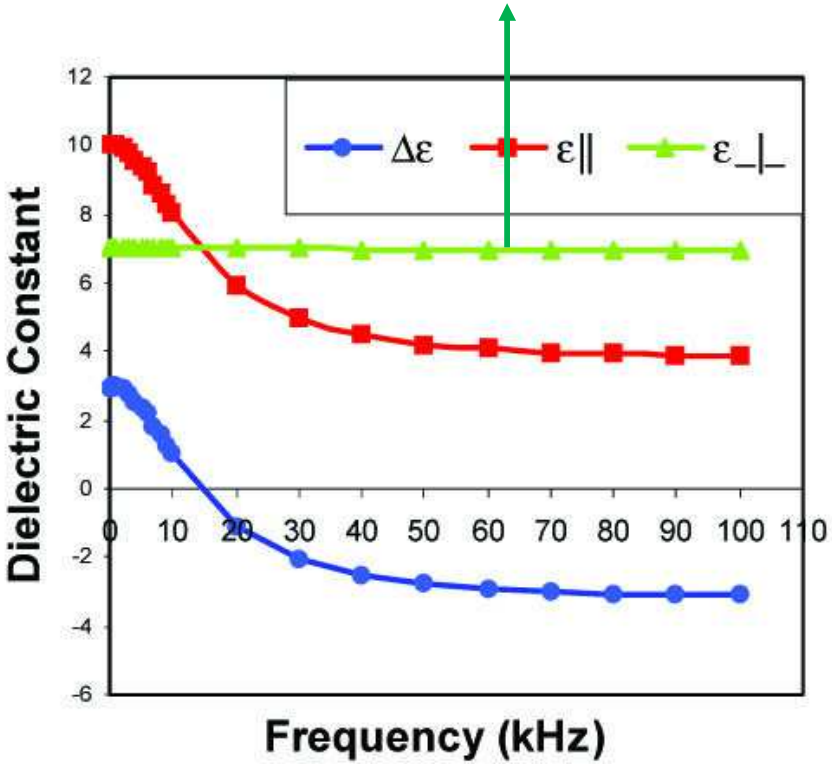
Dual frequency LC (Dabrowski), faster switching

DUAL FREQUENCY LIQUID CRYSTAL

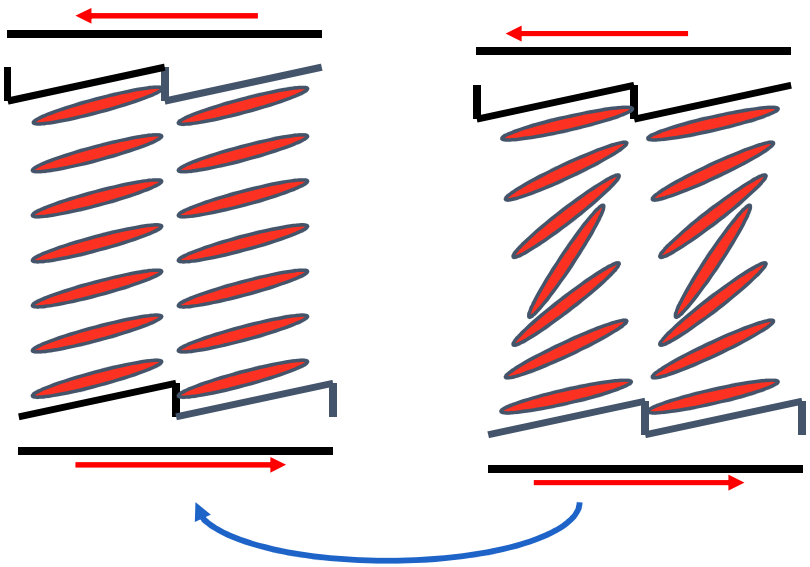
dual frequency liquid crystal

fast rotation around the axis



low frequency V

$\Delta\varepsilon > 0$



high frequency V

$\Delta\varepsilon < 0$

Liquid Crystals and Photonics

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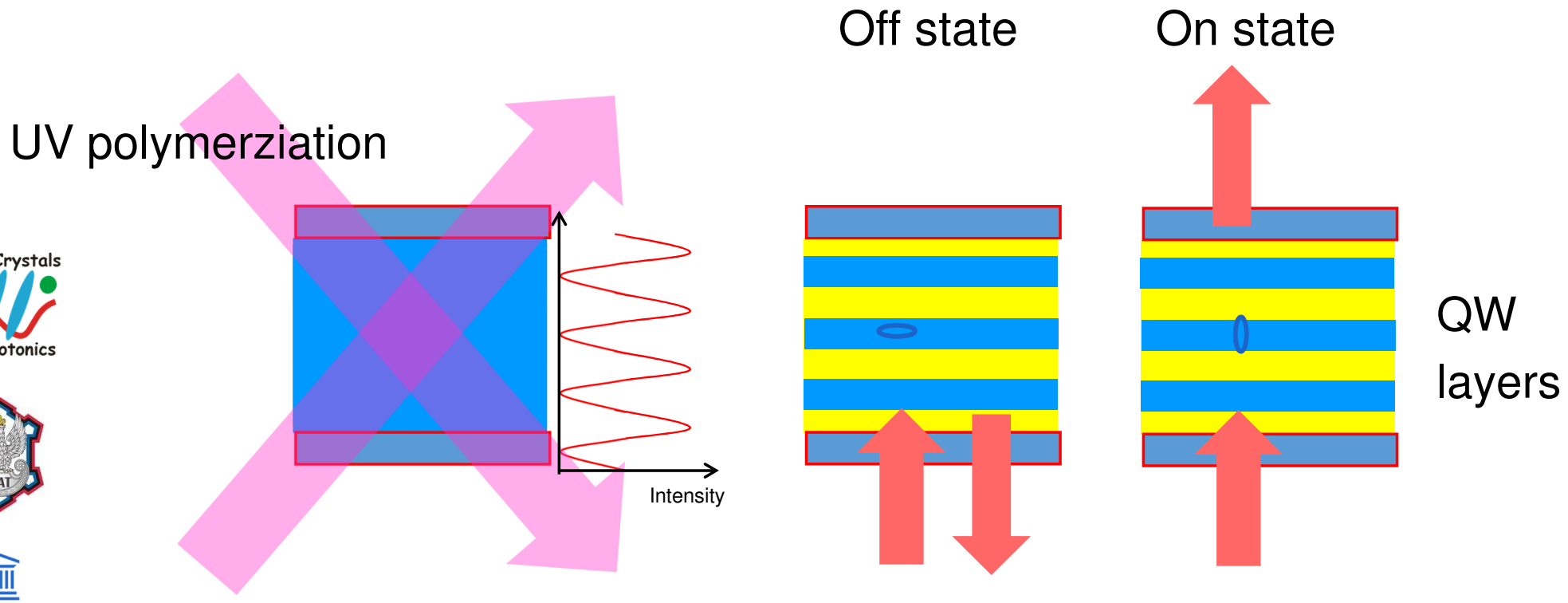
VIS / IR SWITCHING FOR 3D CAMERA

switching in the near infrared (not manydyes in IR)

HPDLC = Holographic Polymer Dispersed Liquid Crystal



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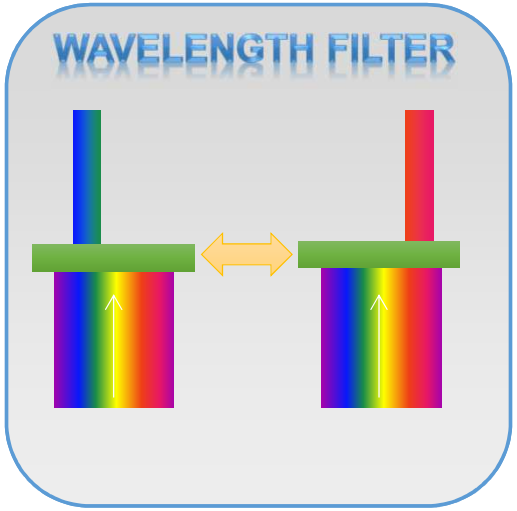
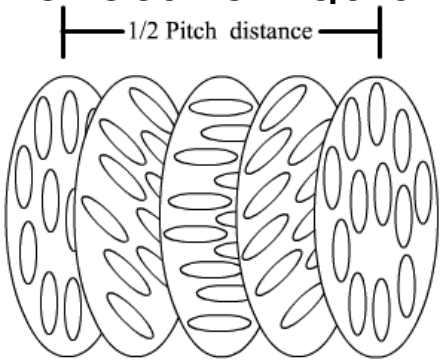
WAVELENGTH FILTER

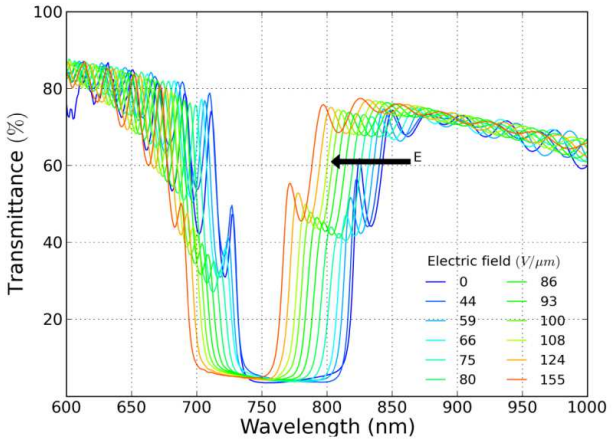


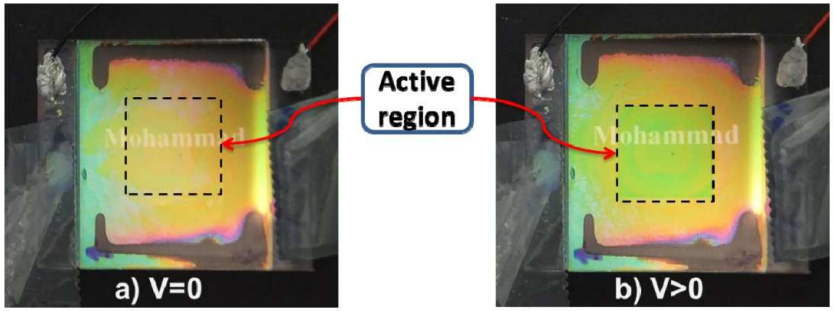
Based on chiral liquid crystals
= 'reflective' liquid crystals



http://physicsworld.com Jul 23, 2009

Reflection of circular polarization





*M. Mohammadimassoudi et al,, Opt. Express **22** 19098 (2014)*

LIQUID CRYSTALS AND PHOTONICS GROUP

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WAT

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Thank you