Liquid Crystals and their applications in photonics

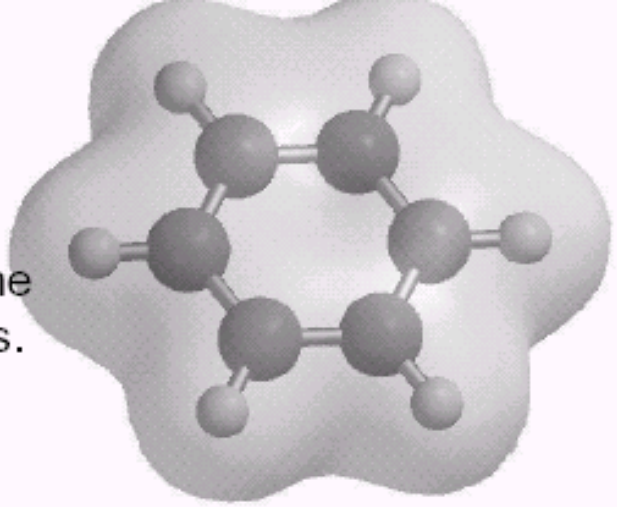
Discovery:

- F. Reinitzer (1888), discovered an anomal two-step melting property of synthesized cholesteryl benzoate. At first changed into a milky substrate (at 145°C) and later into opaque (179°C).
- The „liquid crystal” term was given by Otto Lehman

Liquid Crystals

- State between solid crystal and isotropic liquid,
- Flowability with far-range ordering of the structure,
- Liquid crystal phase – mezophase,
- Generation of liquid crystal phases
  - Thermotropic
  - Liotropic

Liquids *versus* Liquid Crystals

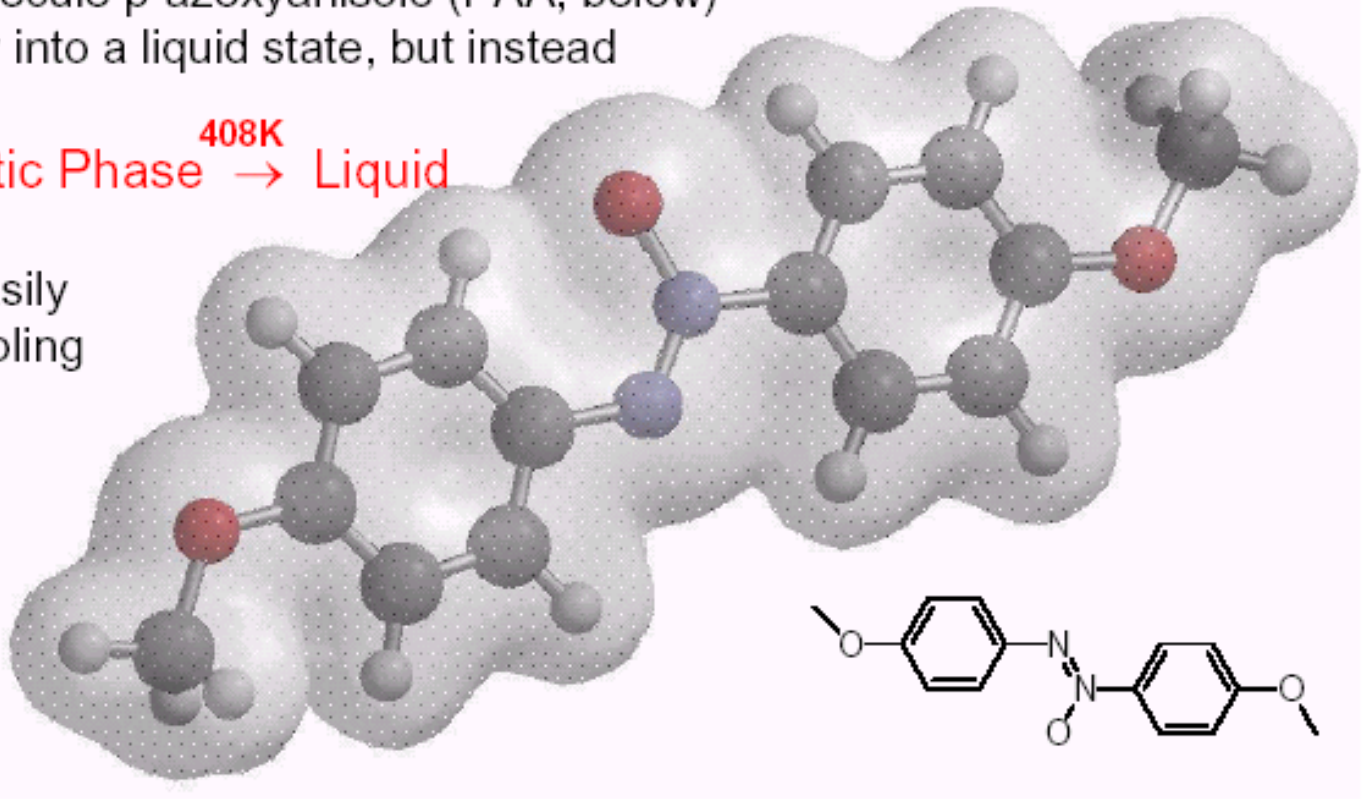


Benzene melts from the crystal into a liquid. Although its aspherical shape allows it to interact with a receptor, in the liquid it adopts an isotropic structure by rotational motions.

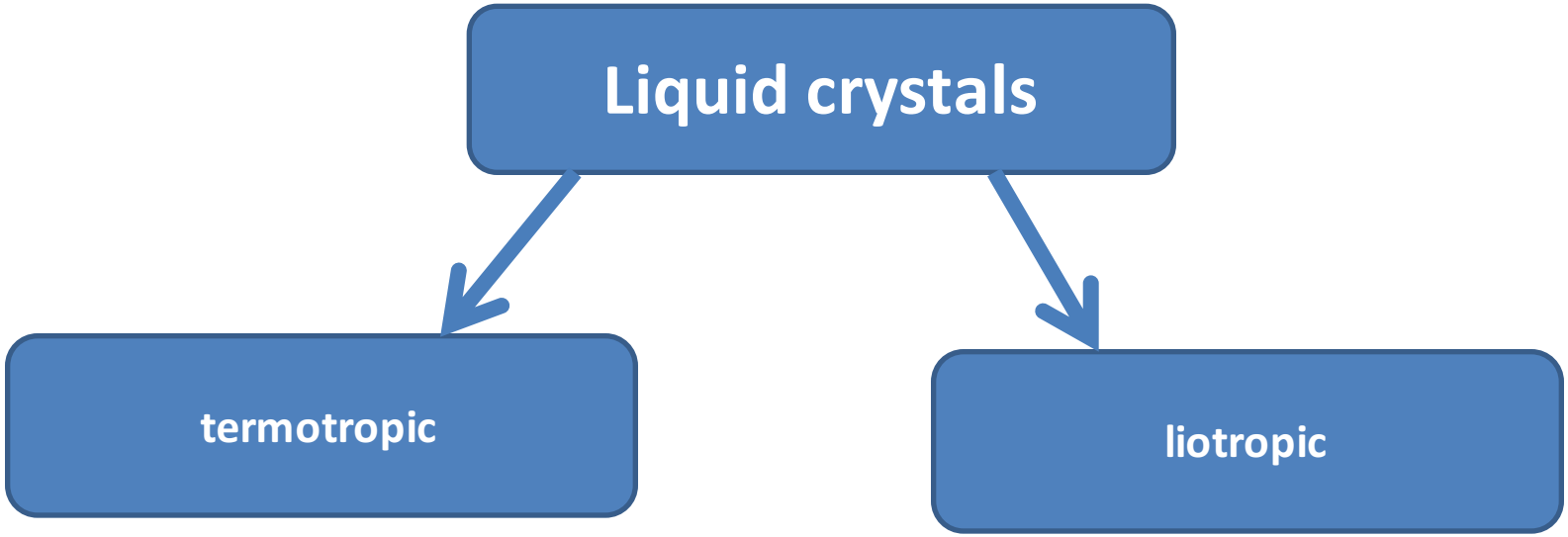
However more anisotropic molecules can form *liquid crystals* due to anisotropic interactions with their neighbours. The molecule p-azoxyanisole (PAA, below) does not melt directly into a liquid state, but instead

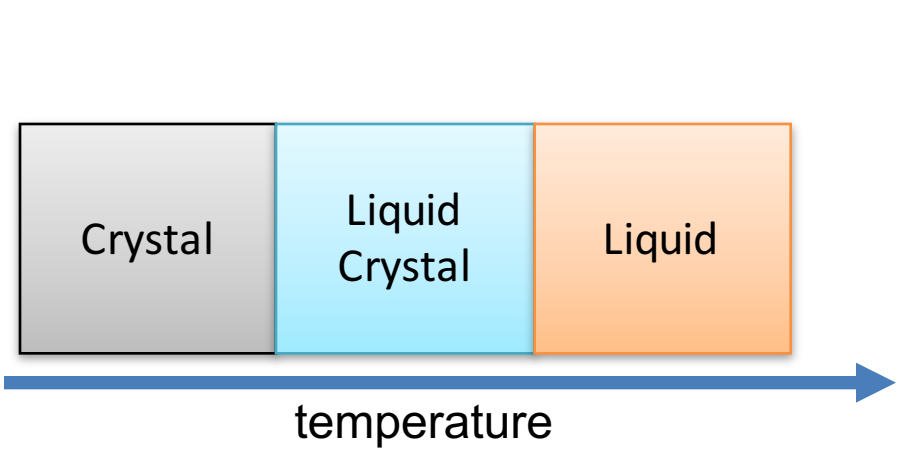
$$\text{Solid} \xrightarrow{391K} \text{Nematic Phase} \xrightarrow{408K} \text{Liquid}$$

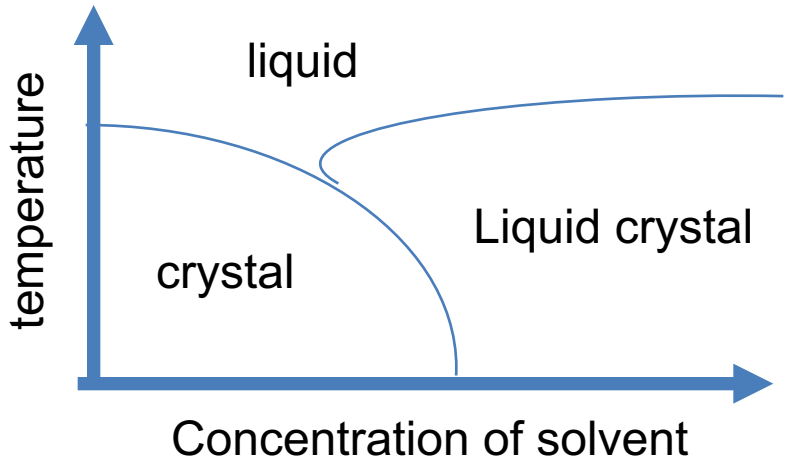
Its shape is not so easily averaged out by tumbling about its long axis.



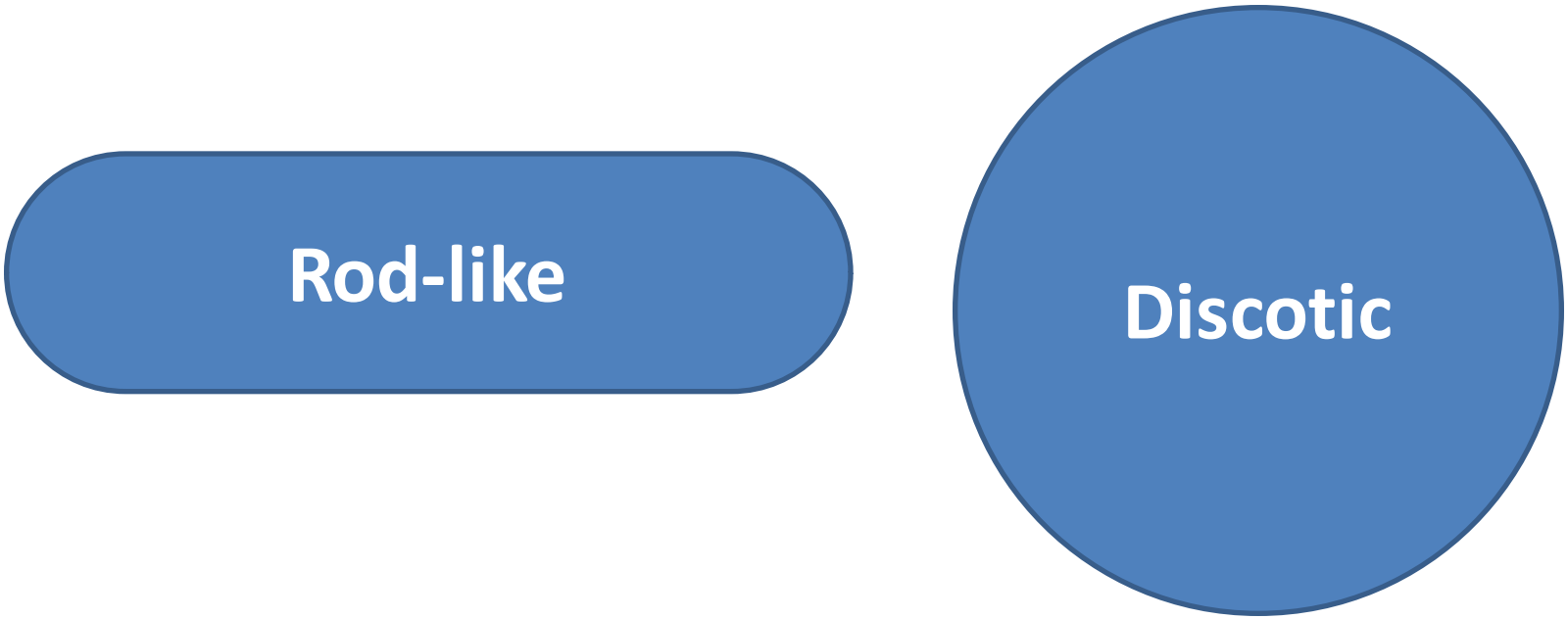
Liquid Crystals





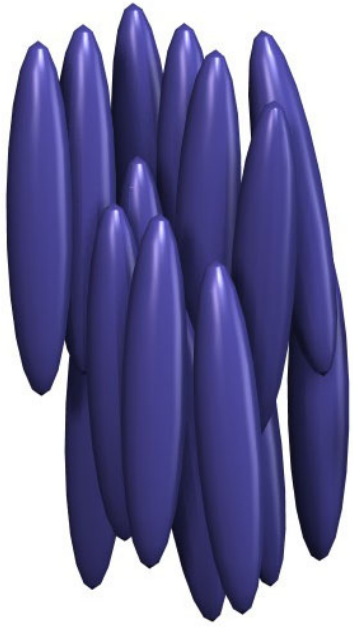


Thermotropic liquid crystals



Thermotropic phases N

- nematic N : all molecules are oriented parallel to each other. Nematics is optically uniaxial
- nematic N* (cholesteric) : chiral molecules are oriented in layers , in each layer the molecules are oriented in one direction, the versor in each layer is changing periodically. Cholesterics N* is uniaxial and optically active.



Thermotropic phases S

- Smectic phases S: molecules are oriented in layers, and the molecule's axes are oriented under 90 degrees in respect to the normal,
  - smectics S_A i S^*_A : molecules are oriented in layers, parallel to each other and to the normal to the layer surface. Smectics S_A is uniaxial, and Smectics S^*_A is uniaxial and optically active.

Thermotropic phases S

- smectics S_B i S^*_B : the same, but the molecules forms a hexagonal structure.
- smectics S_C : like in S_A, but the angle with normal is different from zero.
- Chiral smectics C*: aligned in layers, with different tilt of the director,

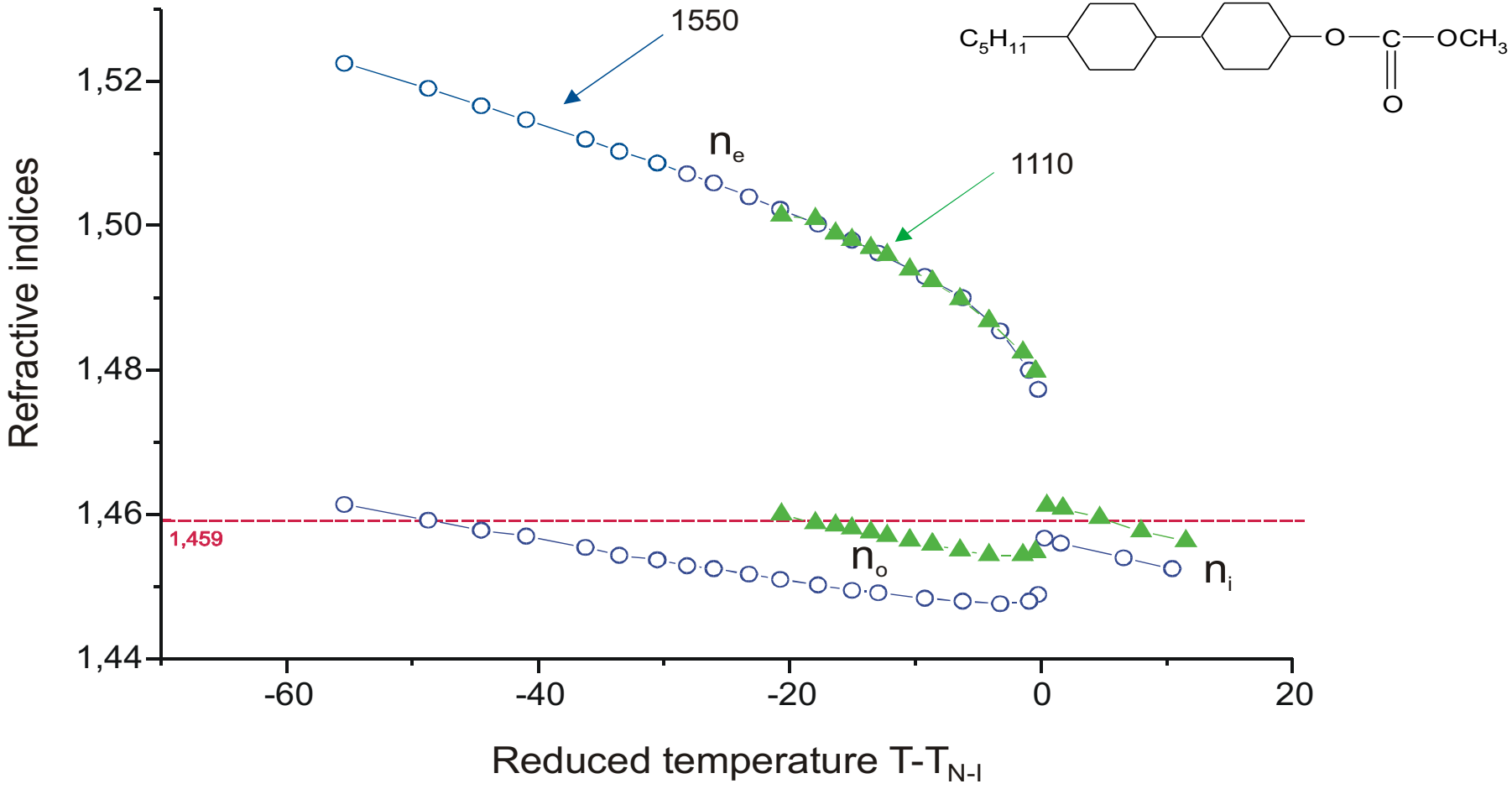
Polymorphism

- Between solid phase and isomorphic may exist one LC phase (monomorphism), two (dymorphism), up to 6 phases (hexamorphism)
- Example S_G-S_F-S_B-S_C-S_A-N

Solid → Smectic C → Smectic A → Nematic → Liquid

Optical properties

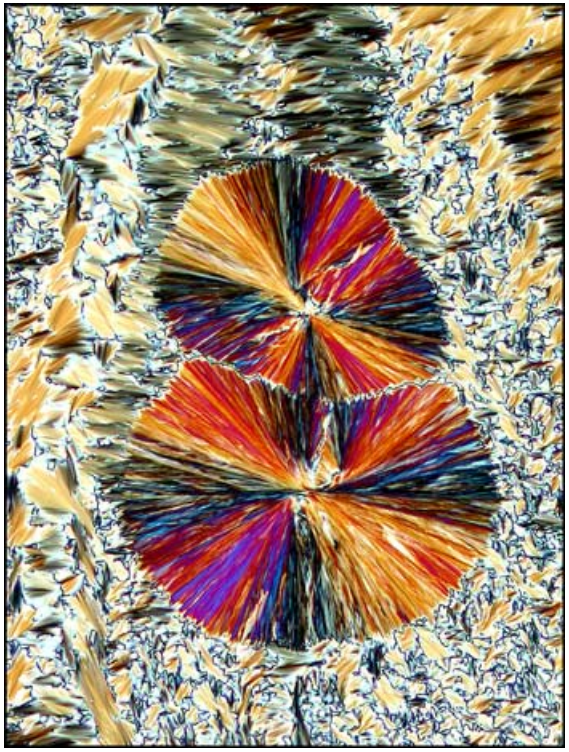
Very high birefringence (natural and induced)

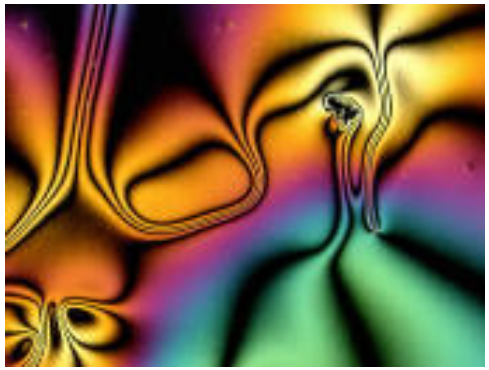
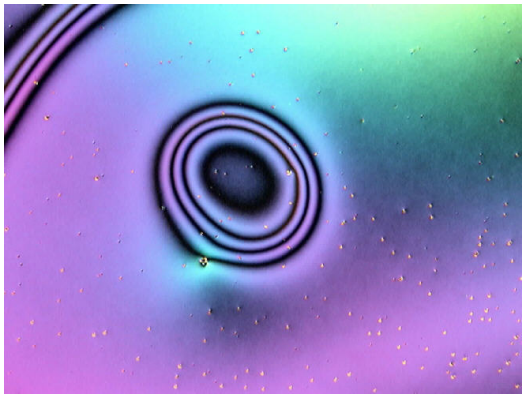
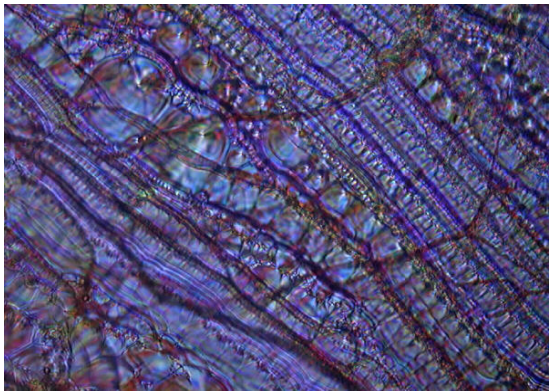


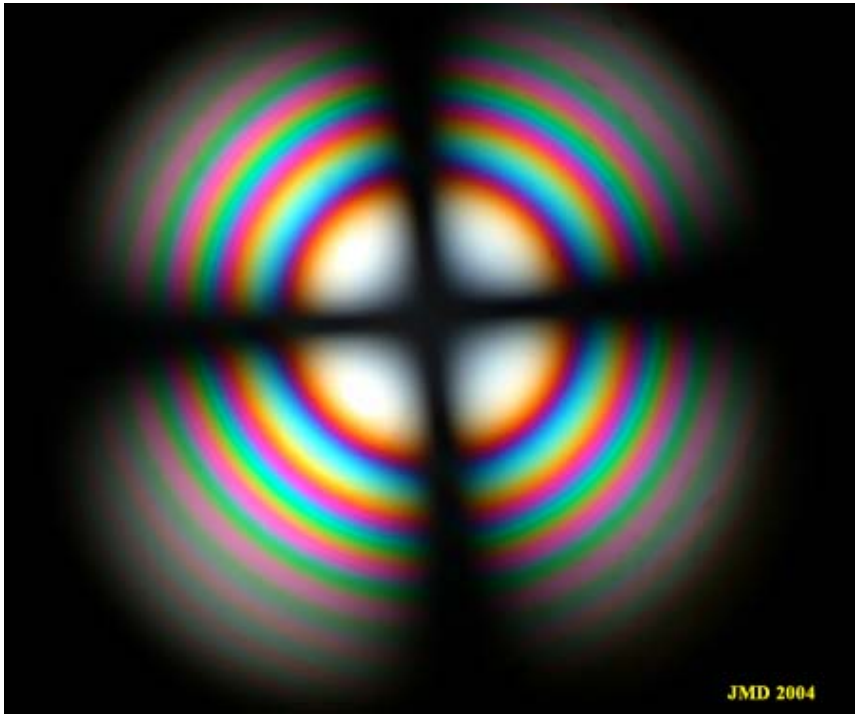
Optical properties

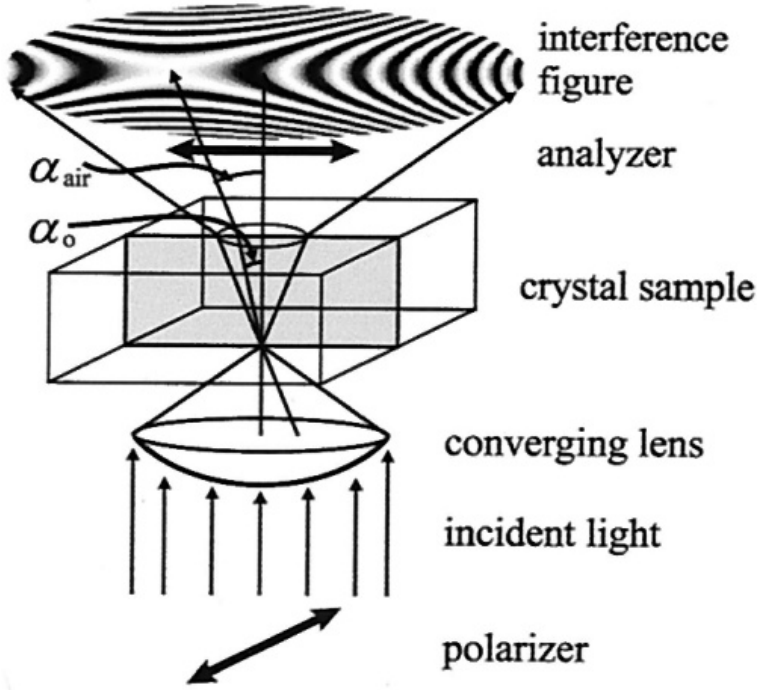
- Optical activity
- Linear and circular dichroism,
- Strong selective light reflection from structures and optically active textures.
- Electrooptic Kerr effect, **100** times stronger than in nitrobenzene
  - Helical pitch change (→ reflected light color)

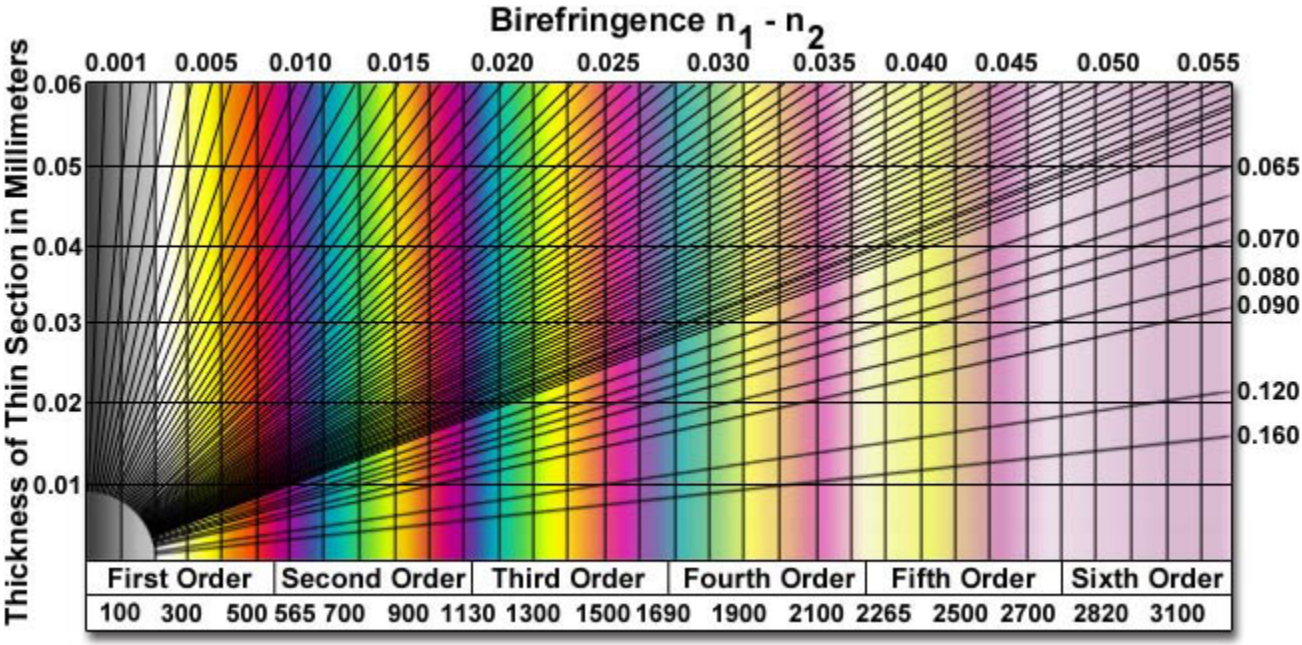
Textures under polariscope



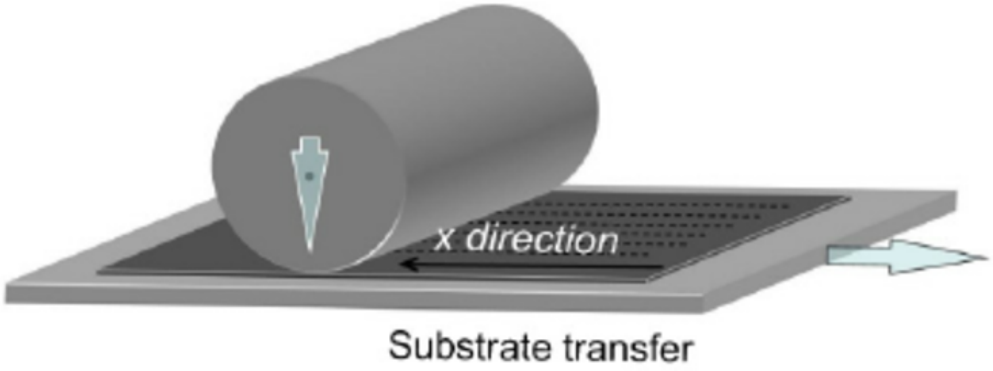

JMD 2004

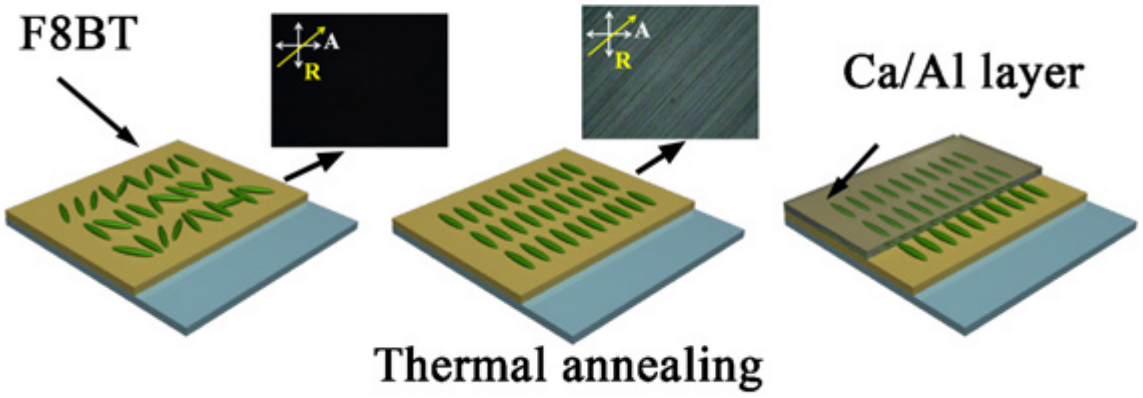

interference figure
analyzer
α_{air}
α_o
crystal sample
converging lens
incident light
polarizer


Birefringence $n_1 - n_2$
0.001 0.005 0.010 0.015 0.020 0.025 0.030 0.035 0.040 0.045 0.050 0.055
Thickness of Thin Section in Millimeters
0.06 0.05 0.04 0.03 0.02 0.01
0.065 0.070 0.080 0.090 0.120 0.160
First Order | Second Order | Third Order | Fourth Order | Fifth Order | Sixth Order
100 300 500 565 700 900 1130 1300 1500 1690 1900 2100 2265 2500 2700 2820 3100

Aligning LC molecules

- Rubbing method,
- Termo-alignment,
- Photo-alignment,



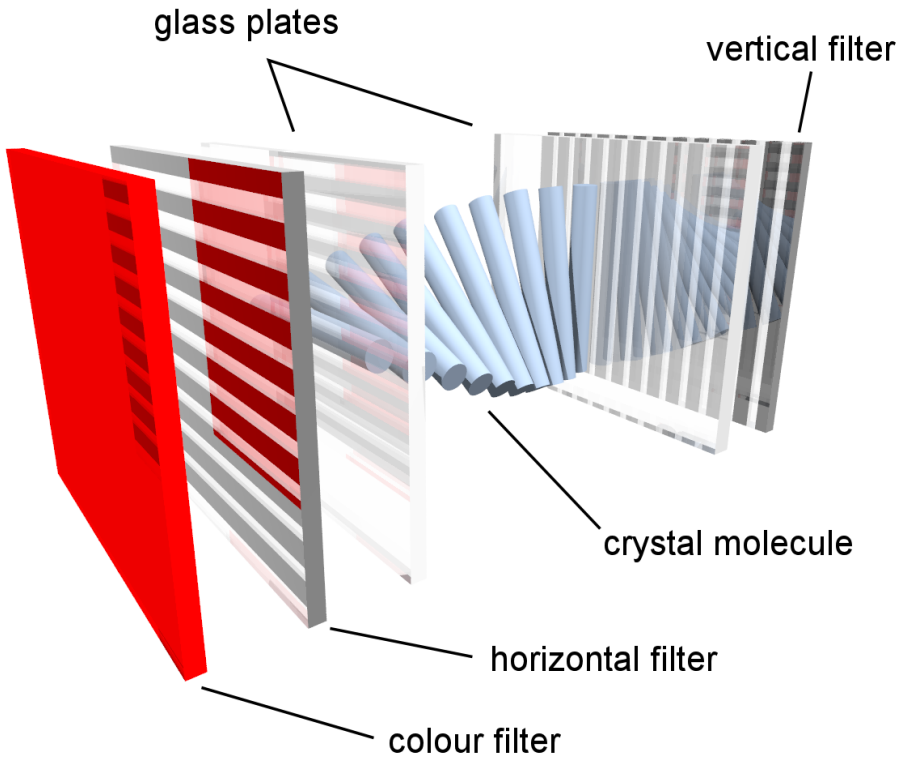


Textures

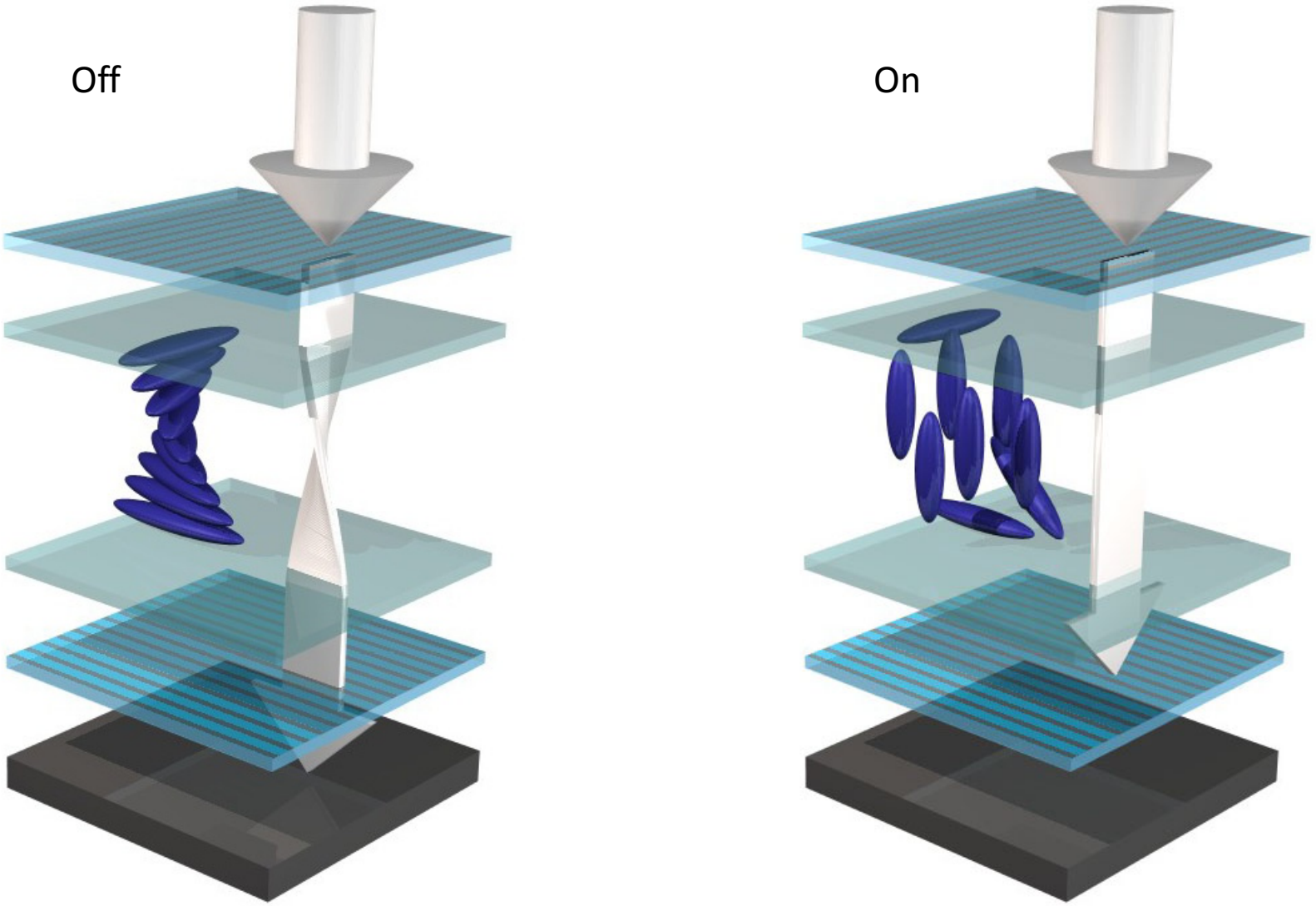
- Homeotropic texture: optical axis is parallel to the direction of observation, so the view is dark (under the polarization microscope)
- Planar texture : optical axis lays in the plane of liquid surface.
- Marble texture: isotropic, separated domains, in each domain the versor may have different direction.
- Filamentous texture: inside the thick samples a thin lines with nonregular shape are observed.
- Nodal texture: in thin samples an order deffects are observed.
- Confocal texture,
- Polygonal texture,
- Fingerprint texture.

From textures to LC cells

- Two thin glass plates, with electreodes, and liquid crystal layer between them.
- Anchoring phenomenon: the LC molecules are anchored on the glass plates.



LC displays

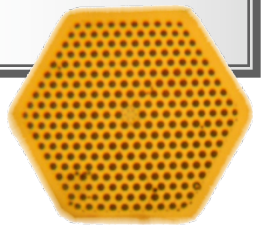


Liquid crystals in photonic crystal fibers

Photonic Crystal Fiber

Advantages of both **mTIR** and **PBG** phenomena

Variety of PCF structures (birefringence, SM, nonlinearity, etc.)

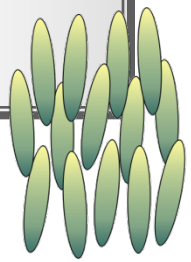


+

Liquid Crystals

Thermal, external ac & dc fields, optical field sensitivity

Variety of LC materials and LC structures; influence of molecular ordering

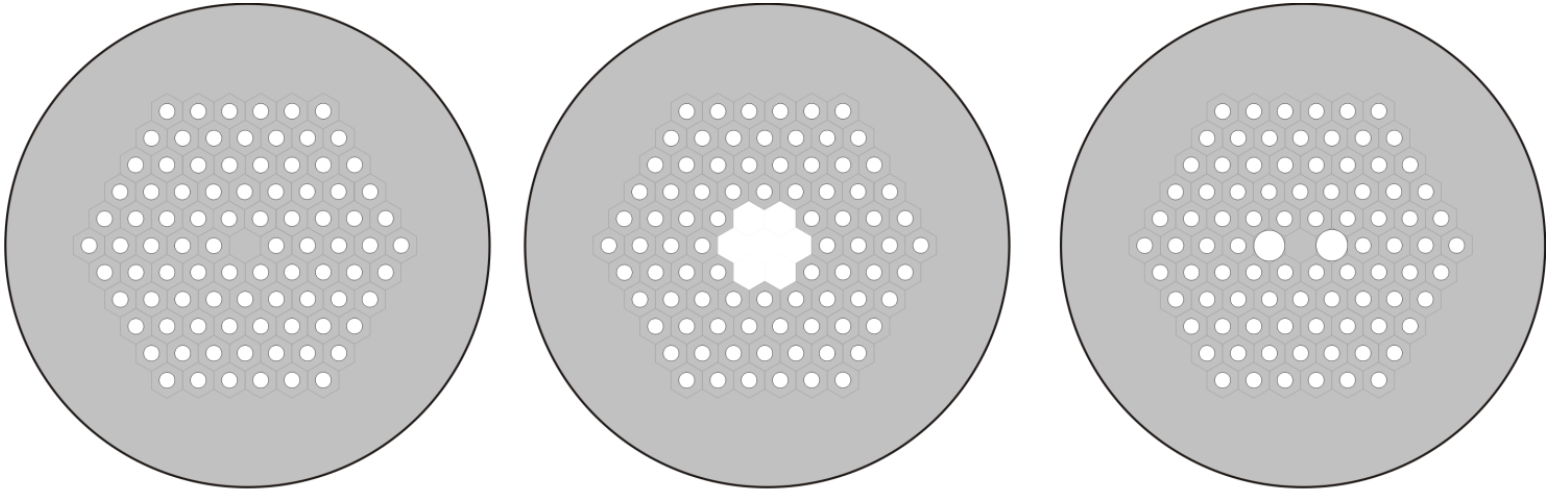


The highest level of tunability of propagation and polarization properties by external fields

Photonic Crystal Fibers

- 2-dimmensional photonic crystals with deffect along the fiber length inside the core region,
- made of one type of glass material with periodic matrix of air micro-holes forming a structure of photonic crystal,

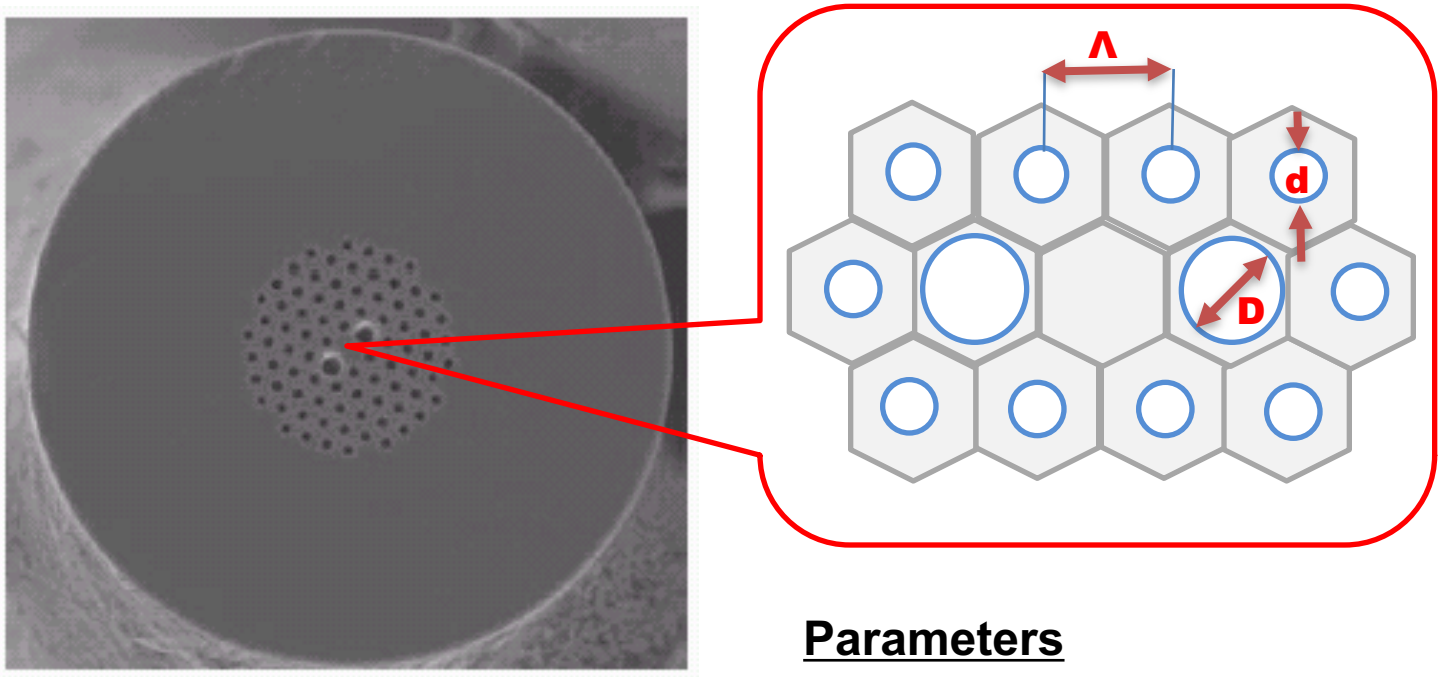
<u>3 main types of Photonic Crystal Fibers</u>



Isotropic with solid core **Hollow-core** **Birefringent with solid core**

Photonic Crystal Fibers

Commercially available birefringent PCF from NKTPhotonics



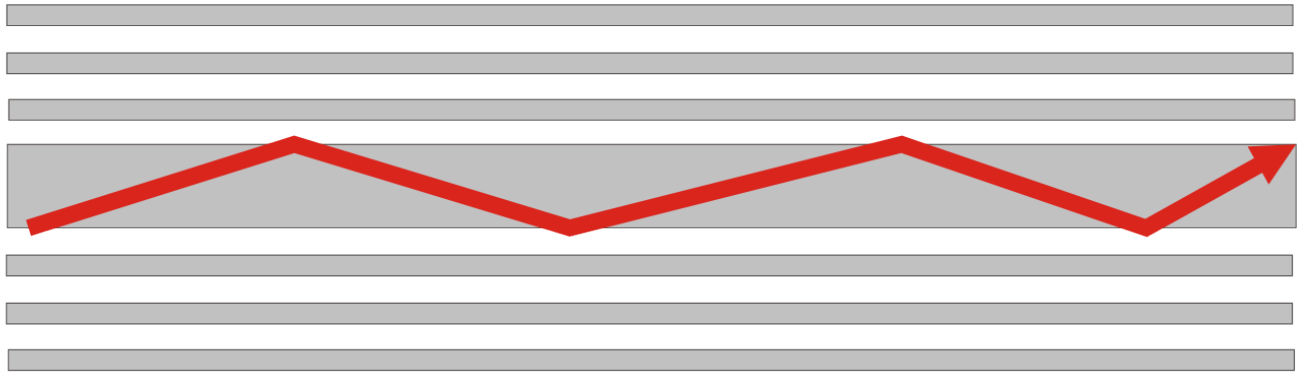
Parameters

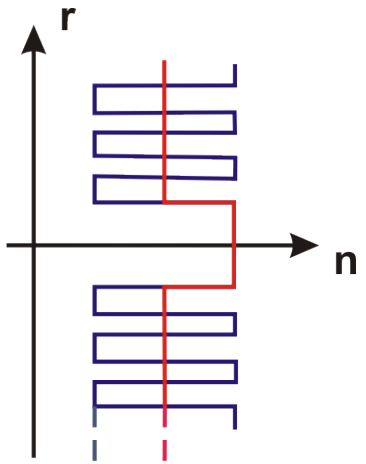
- Pitch, Λ → 4.4 μm
- Large hole diameter, **D** → 4.5 μm
- Small hole diameter, **d** → 2.2 μm
- Diameter of holey region → 40 μm
- Filling factor, d/Λ → 0.5

Propagation mechanisms in PCF

m-TIR (modified Total Internal Reflection) – characteristic for PCFs with solid core,

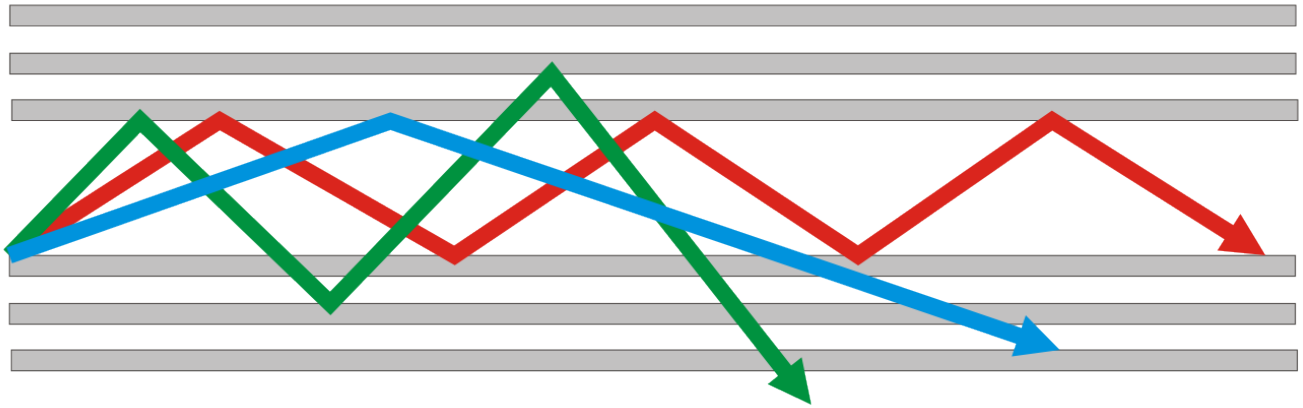
a).

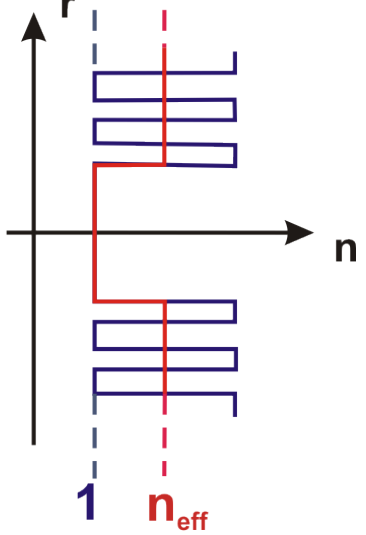




PBG (Photonic Band Gap) – characteristic for „hollow-core” PCFs,

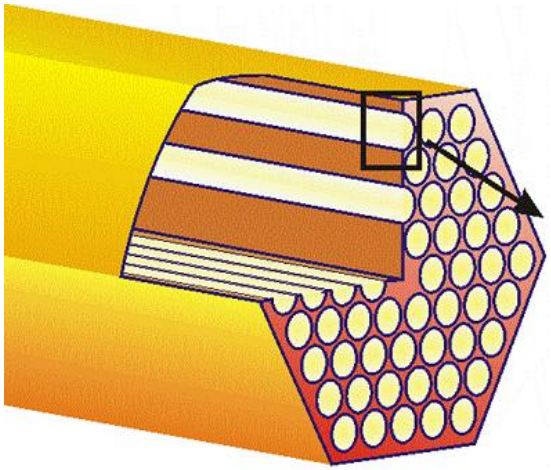
b).

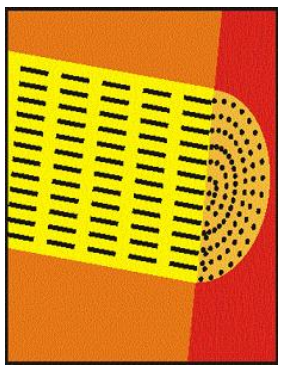


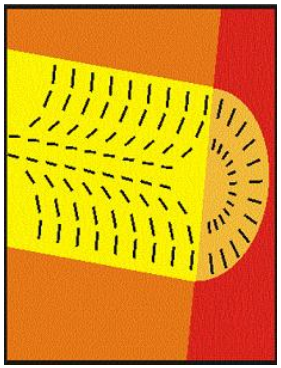


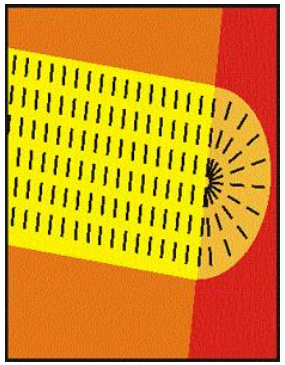
Orientation of LC molecules in PCF

Isotropic molecules orientation in PLCFs:

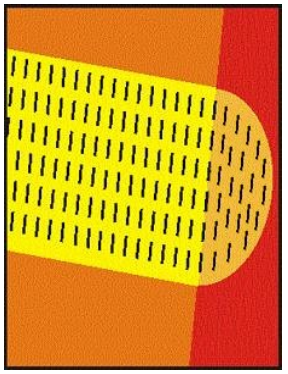




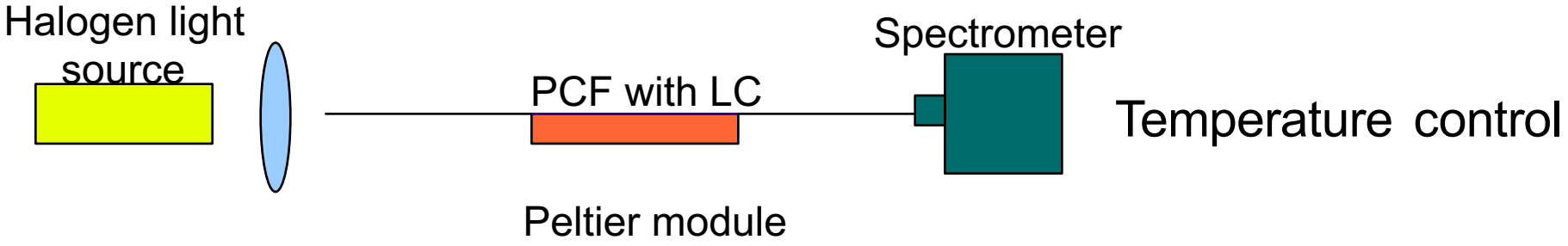


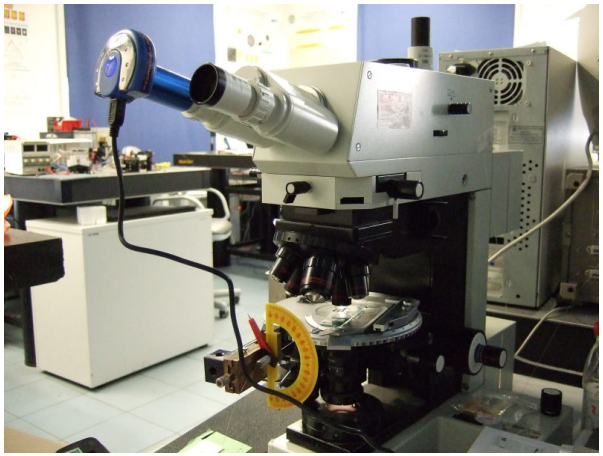


Transverse molecules orientation in PLCFs observed under influence of external electric field



Light propagation in PLCF

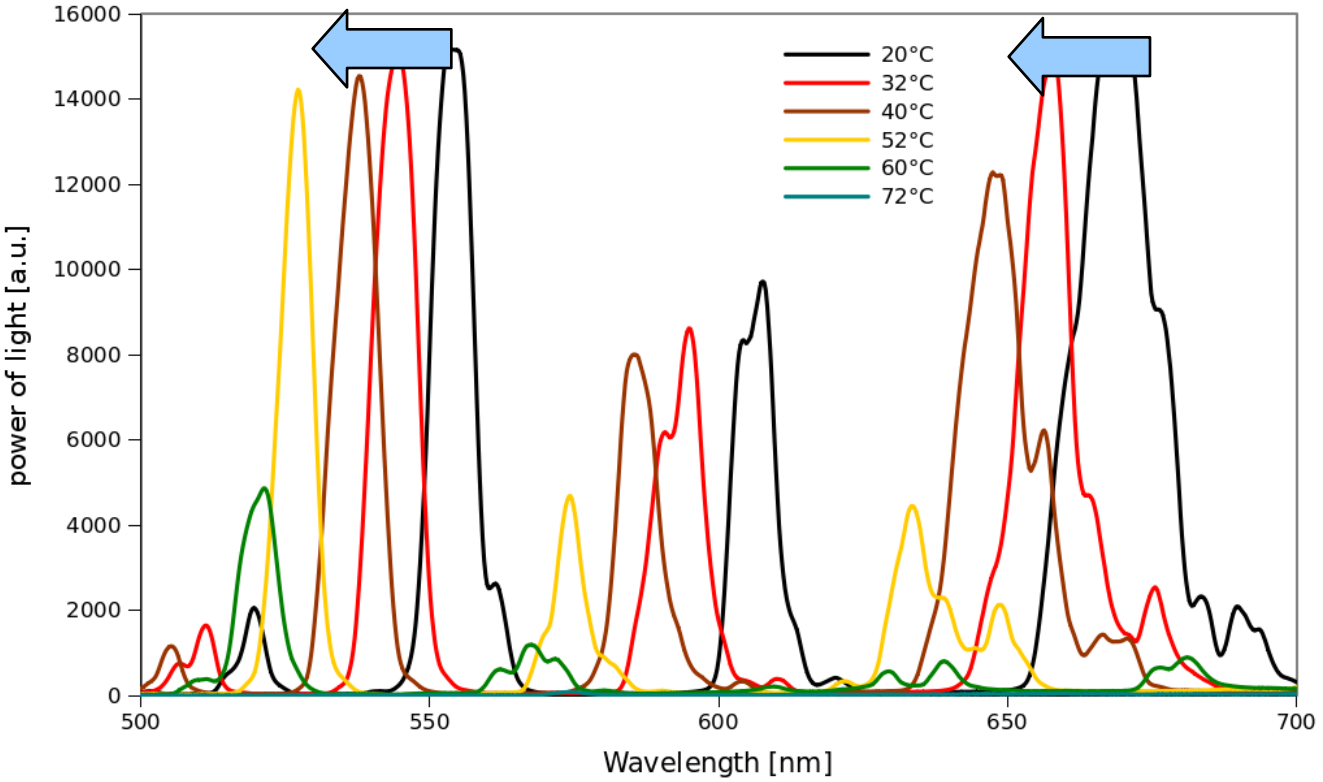




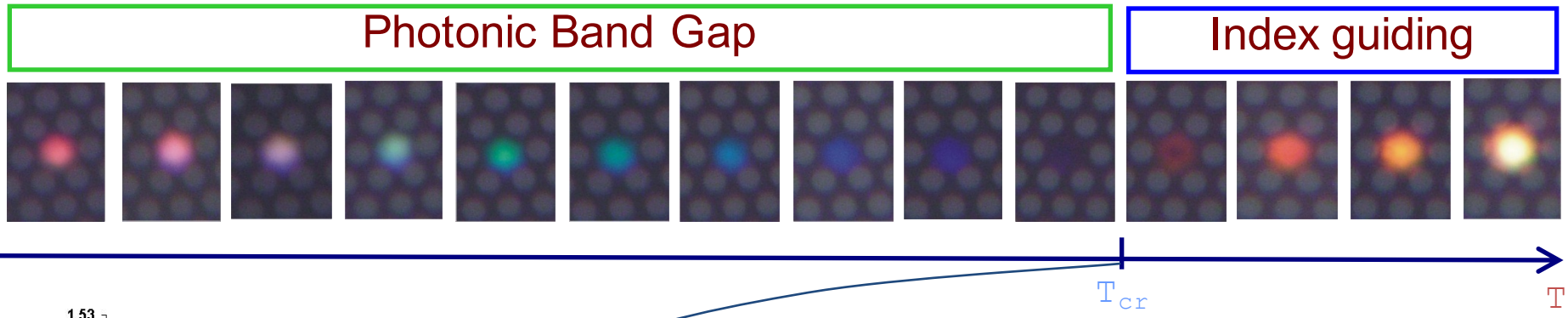
Polarizing microscope

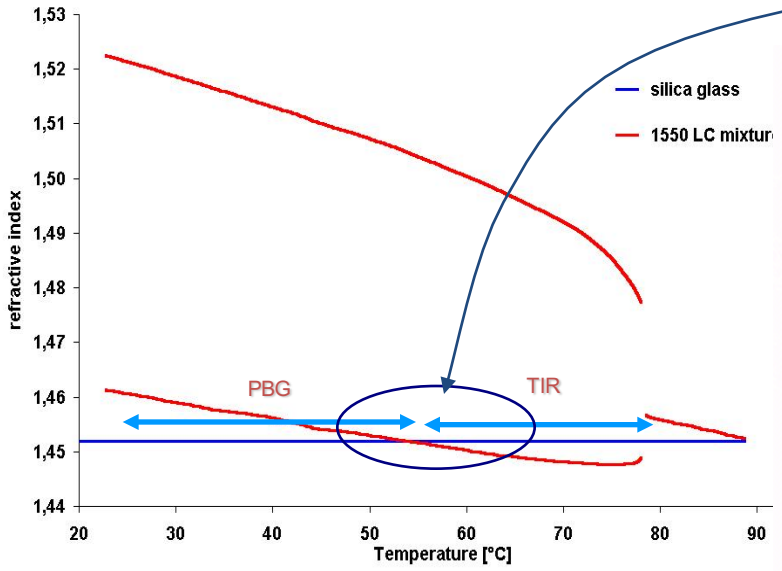
Transmision spectra under influence of temperature

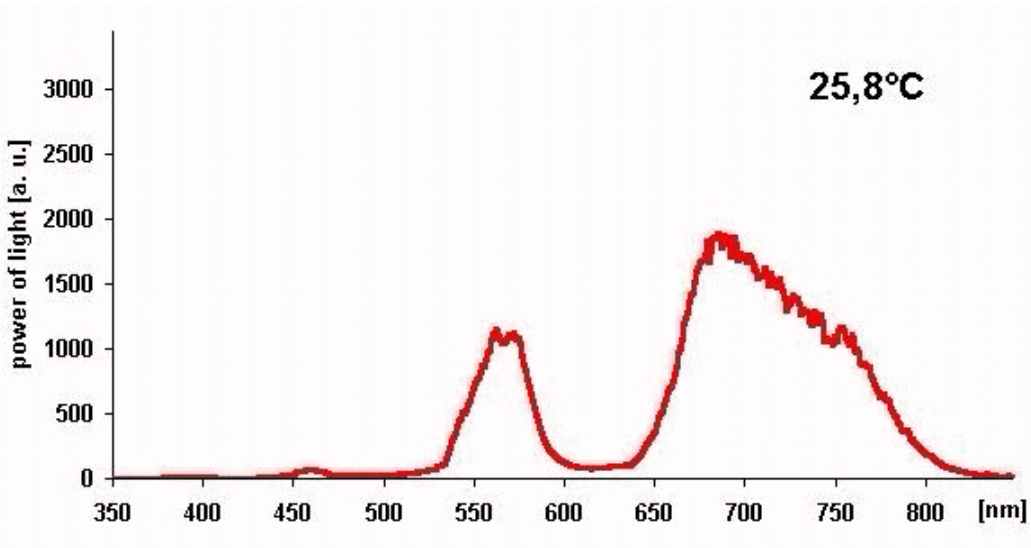
PCF with 3 rings of holes filled with PW500 LC (2.5 cm)



1023 PCF + 1550 LC, temperature-induced switching



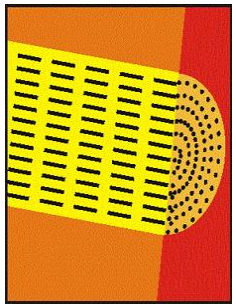


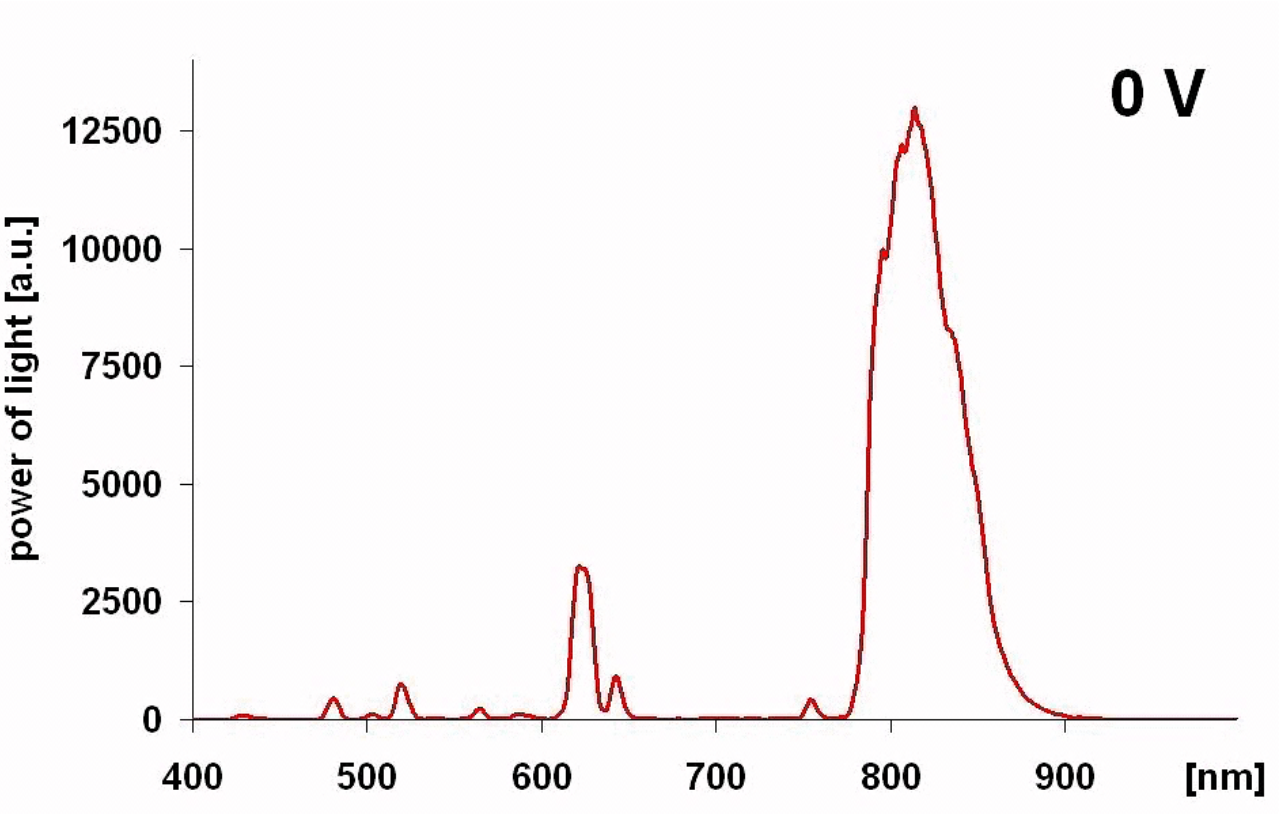


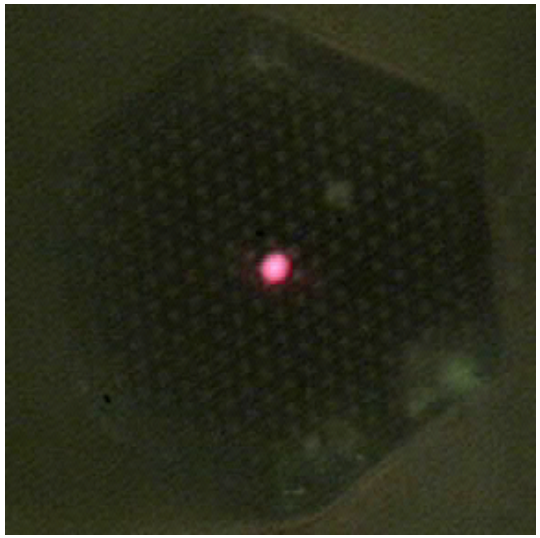
Wolinski T.R., et al, *Measurement Science and Technology* 17, 985–991 (2006)

E-tuning in photoaligned PLCFs

DP2000 PCF + 6CHBT; PVCi layer irradiated with UV light polarized **parallelly** to the fiber axis – results similar to PCF without photoaligning layer – planar molecules orientation







Other applications

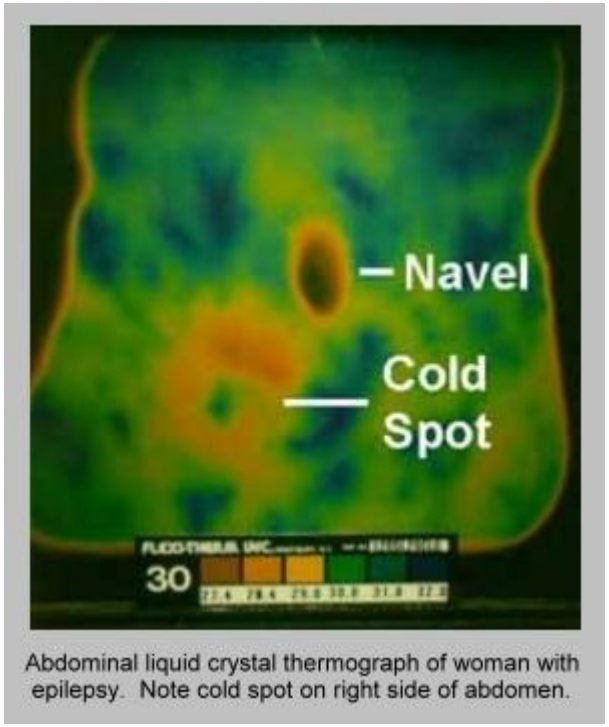
- thermography
  - medicine
  - heating
- LC blinds
- Electronic paper (e-paper)

LC Privacy Glass

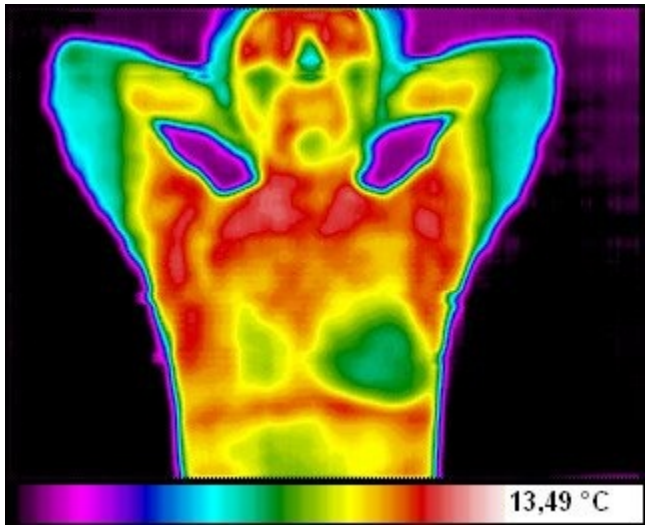
INNOVATIVE GLASS

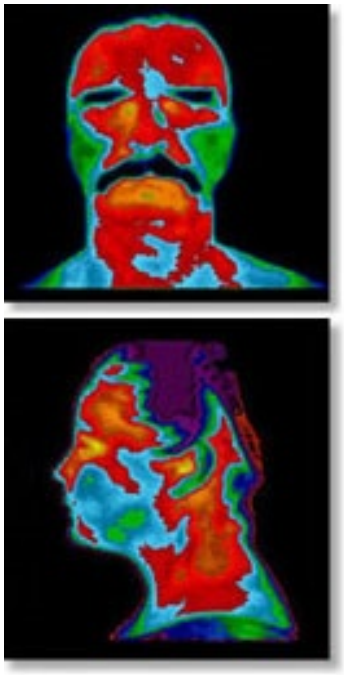
LC Privacy Glass - OFF
(Private)

Termogrphy



Abdominal liquid crystal thermograph of woman with epilepsy. Note cold spot on right side of abdomen.





Termography