Supermolecular Stereochemistry in Liquid Crystals

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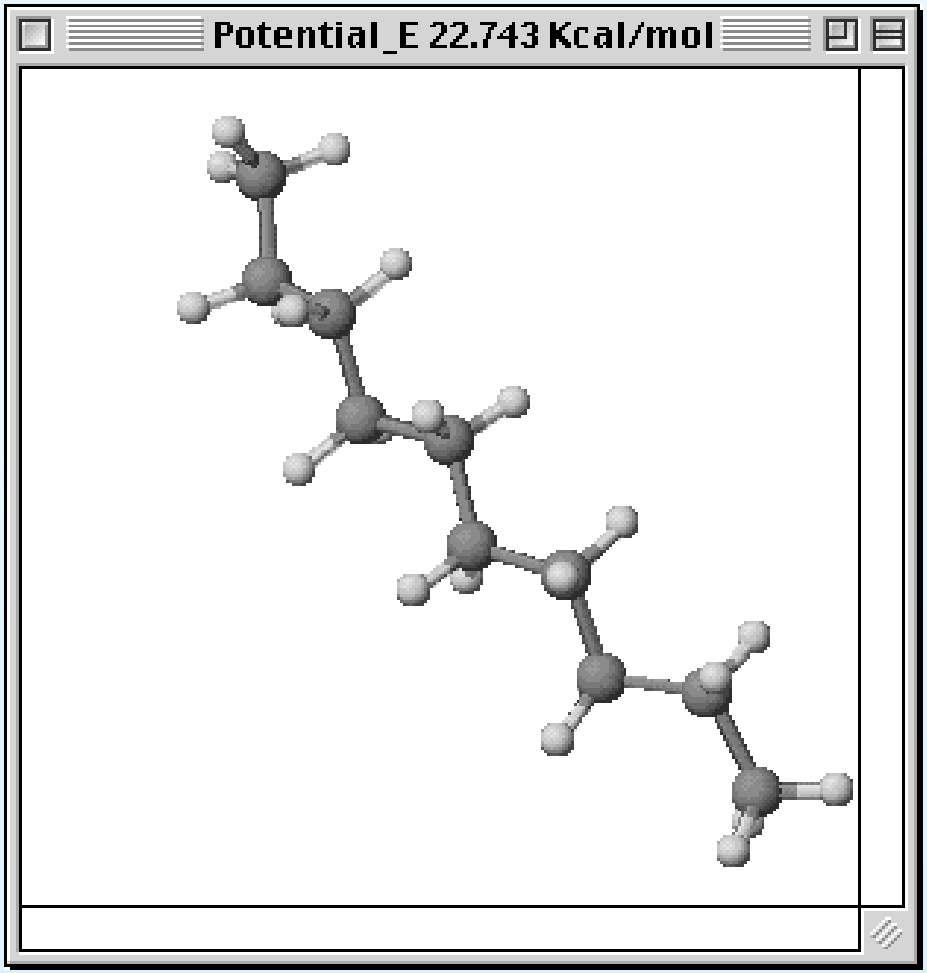
University of Colorado at Boulder

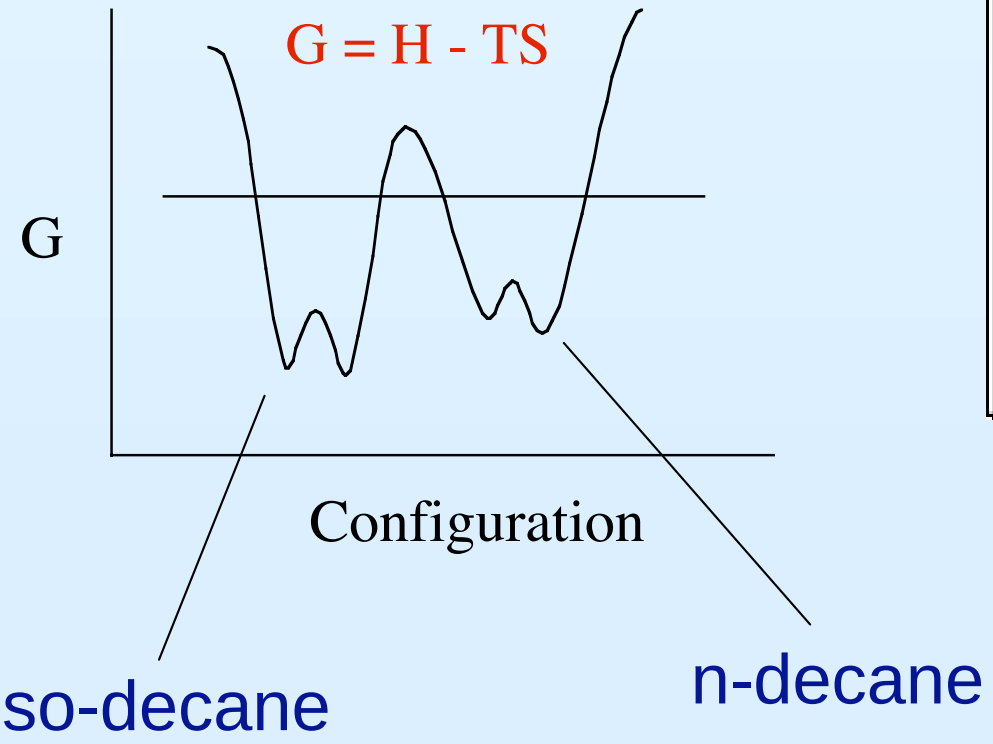
- *Introduction to thermotropic liquid crystals*
  - *What's a liquid crystal?*
  - *What's a liquid crystal texture (birefringence)?*
- *Some applications of ferroelectric liquid crystals*
  - *LC electro-optics*
  - *The SSFLC light valve and LCOS microdisplays*

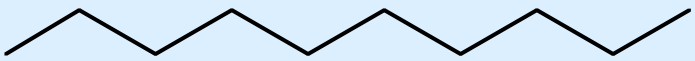
Stereochemical Aspects of Novel Materials
UCSB, August 2005

Molecules can be Very Dynamic

- ***Lots of molecules are very FLOPPY in the gas or liquid phase - time-average structure and symmetry.***
- ***The structure of these molecules in the liquid phase is inherently dynamic in nature.***

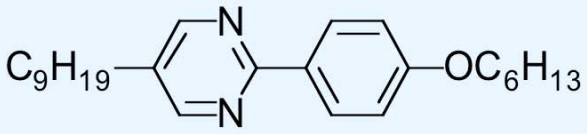




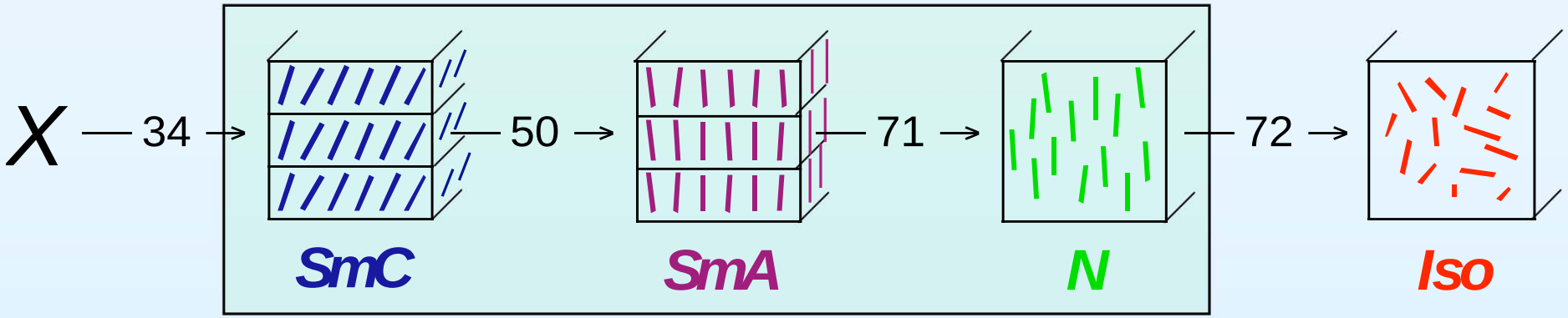


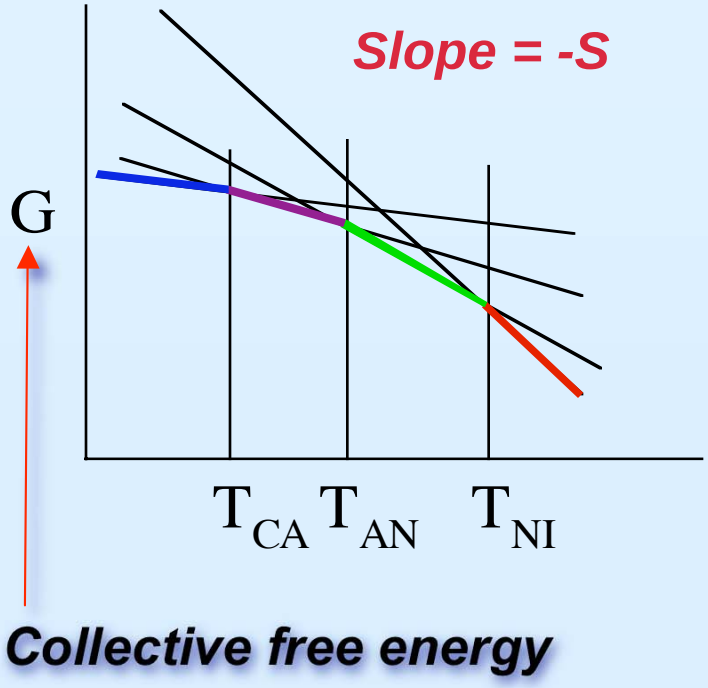
$C_{10}H_{22}$

What's a Liquid Crystal?



PYP906





The classic INAC phases

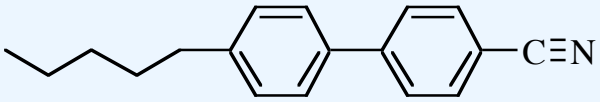
The SmC is the most ordered, with

C_{2h} symmetry ⇒ Nonpolar

$C_{\infty v}$ or lower

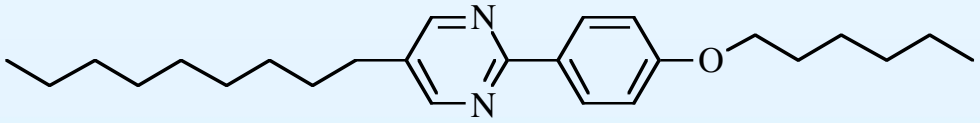
Potpourri of LC Mesogens

N and SmA

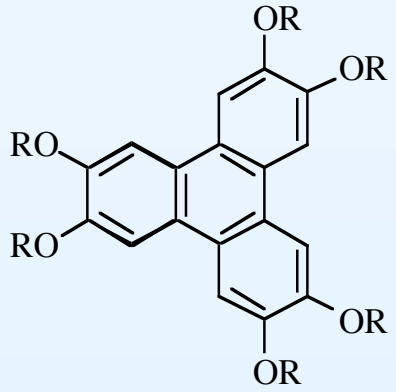


Cyanobiphenyls (Nematics)

INAC

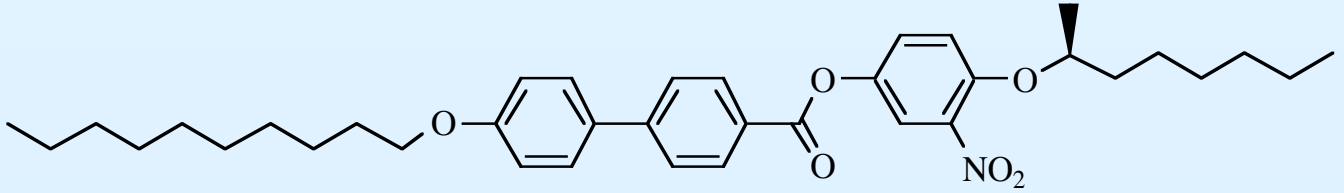


Phenylpyrimidines (Tilted Smectics)



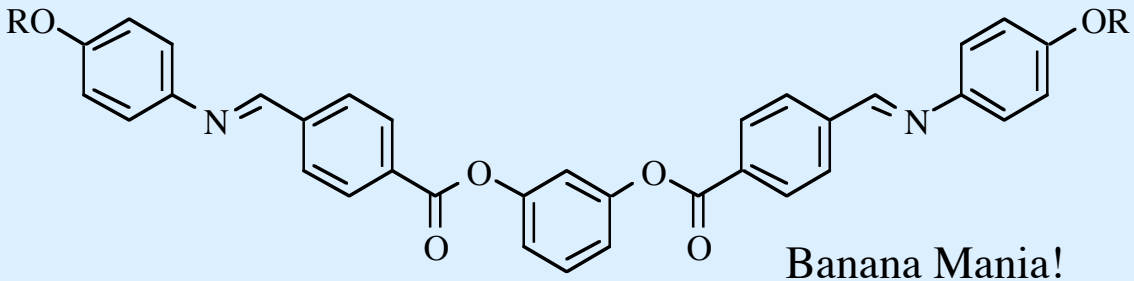
Discotics (Columnar)

IAC



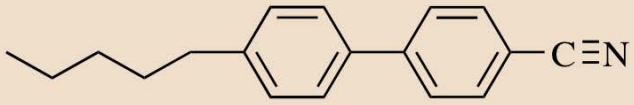
o-Nitrophenyl-biphenylcarboxylates (Chiral Tilted Smectics for NLO)

I-N-"Bn"



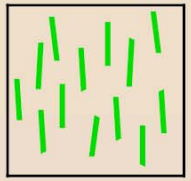
Banana Mania!

Nematic and Smectic LCs

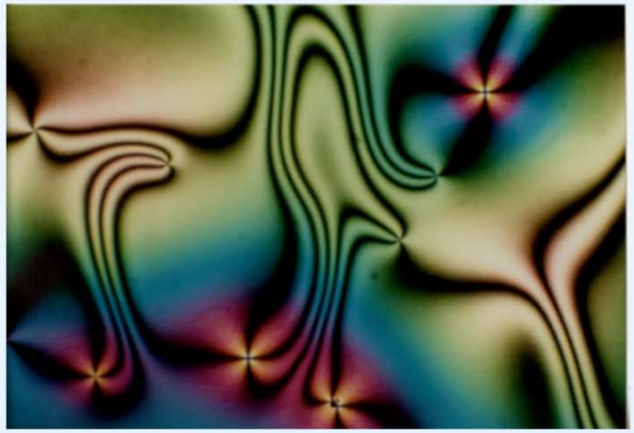


5CB (nematic)

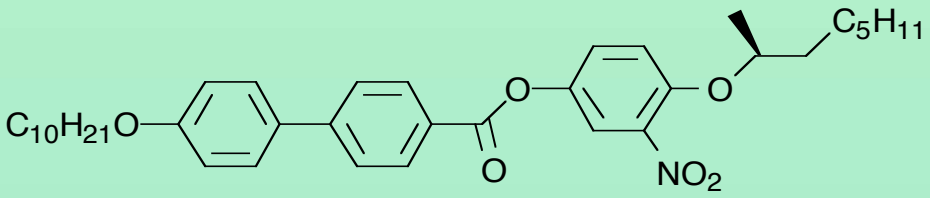
Cr — 24.0 → N — 35.3 → I



N



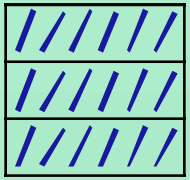
Nematic Schlieren texture
(Photo by Mary Neubert)



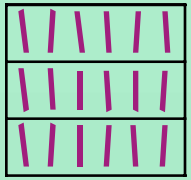
W314 (SmC* - SmA*)

Cr — 63.5° → SmC* — 93.7° → SmA* — 116° → I

Cr ← (20°) — SmC* ← 93.7° — SmA* ← 116° — I



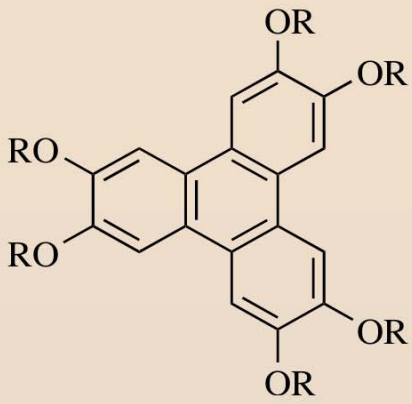
SmC



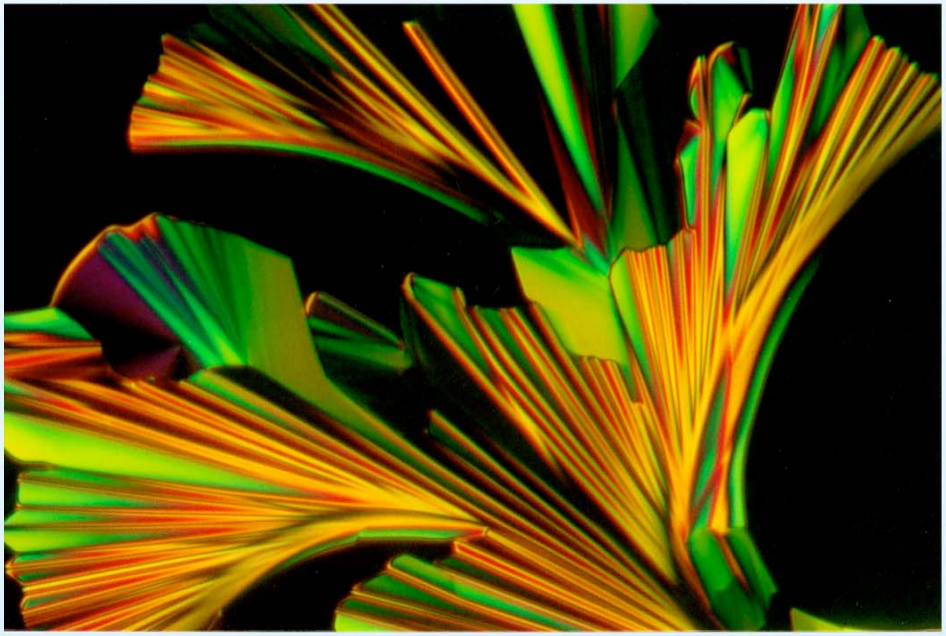
SmA

Smectic A focal conic texture

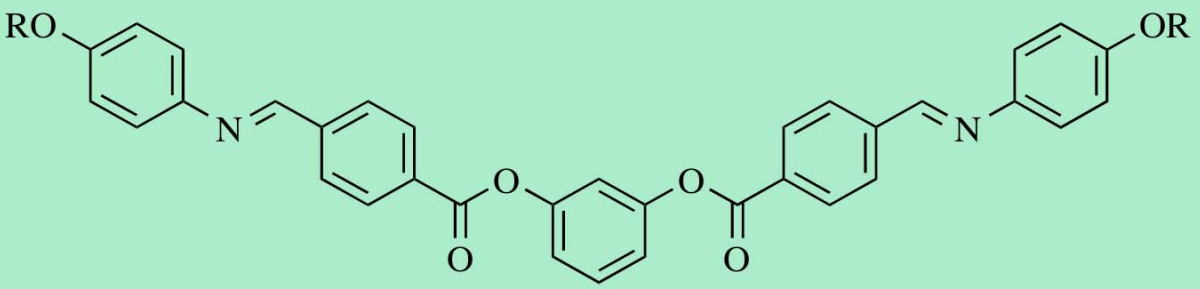
Columnar Phases



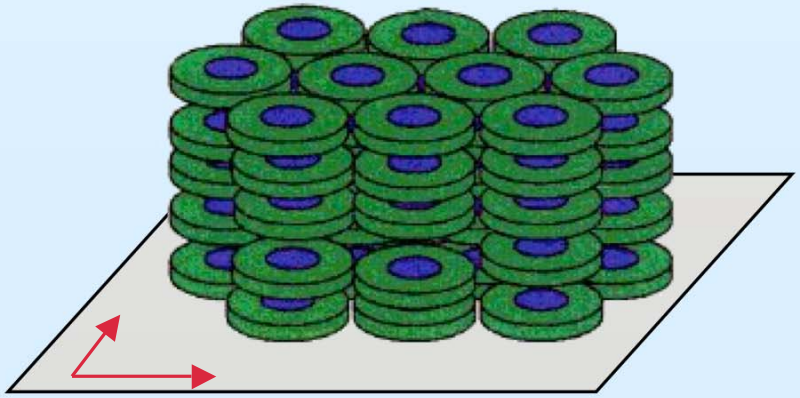
Discotic Mesogens
(columnar phases)



The B1 columnar banana phase
(Photo by Renfan Shao)



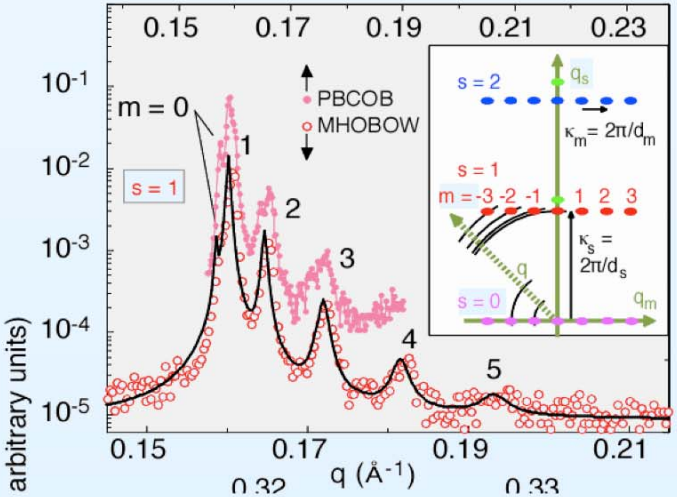
Bent-core Mesogens
(smectic and columnar banana phases)



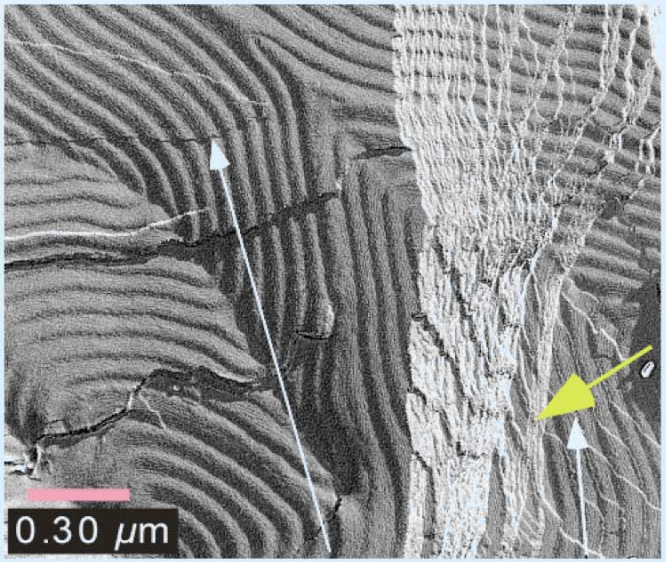
Long-range positional order
in two dimensions

Some Techniques used to Study LCs

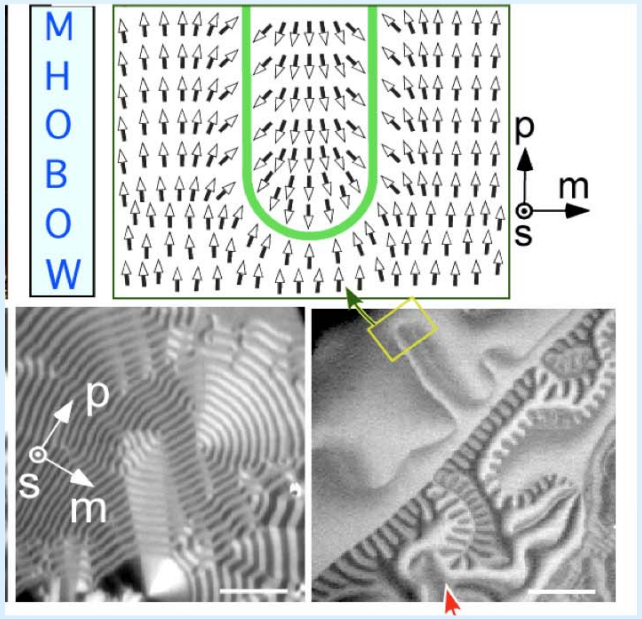
- Polarized light microscopy (PLM)
- Electro-optics
- Cross-polarization magic angle spinning ^{13}C NMR (CP-MAS)
- Dielectric spectroscopy
- X-ray diffraction (XRD)
- Depolarized reflected light microscopy from freely suspended films (DRLM)
- Freeze fracture transmission electron microscopy (FFTEM)



Powder XRD



FFTEM
Zasadzinski
and Clark



DRLM from freely suspended films

A Polarized Light Microscope

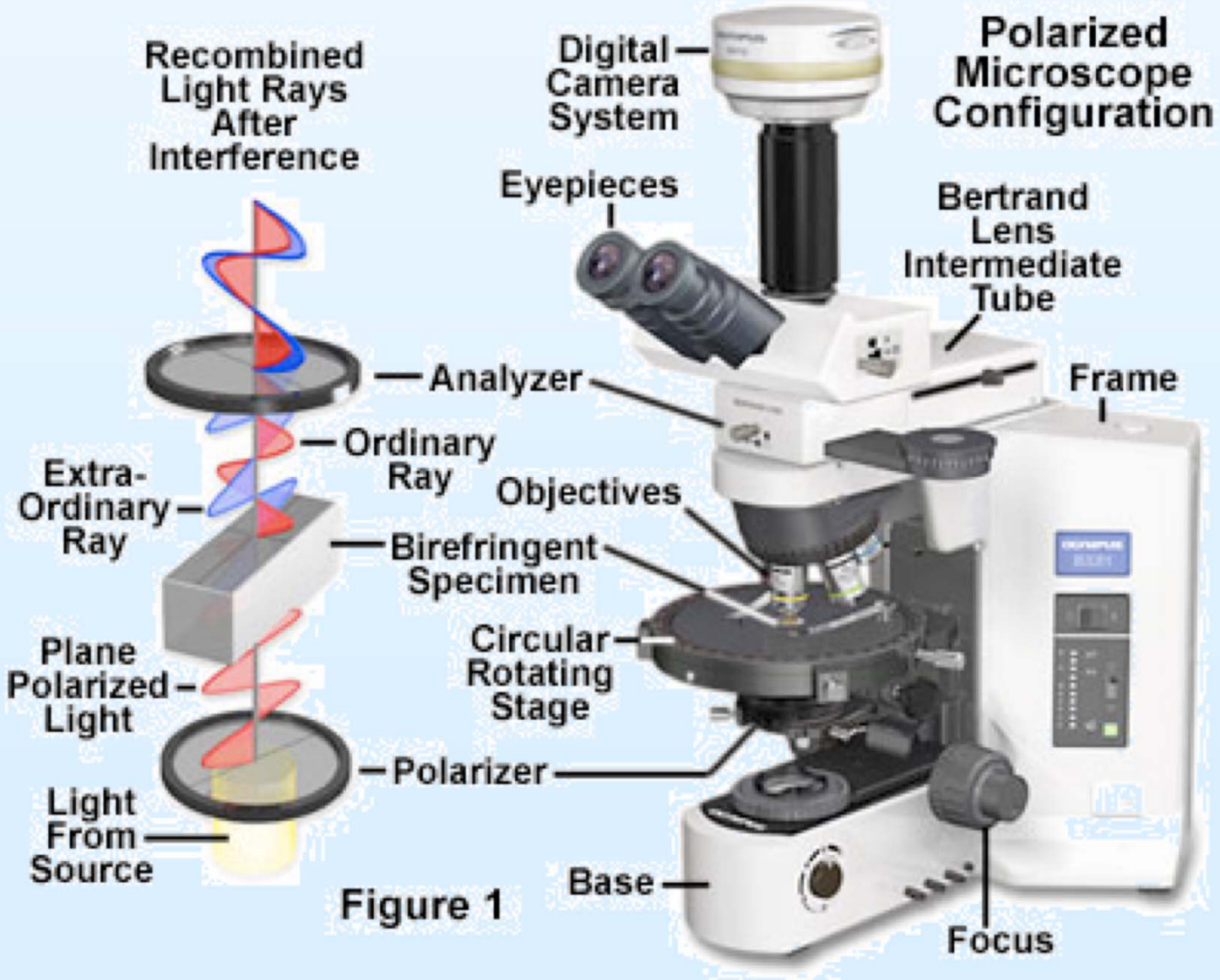
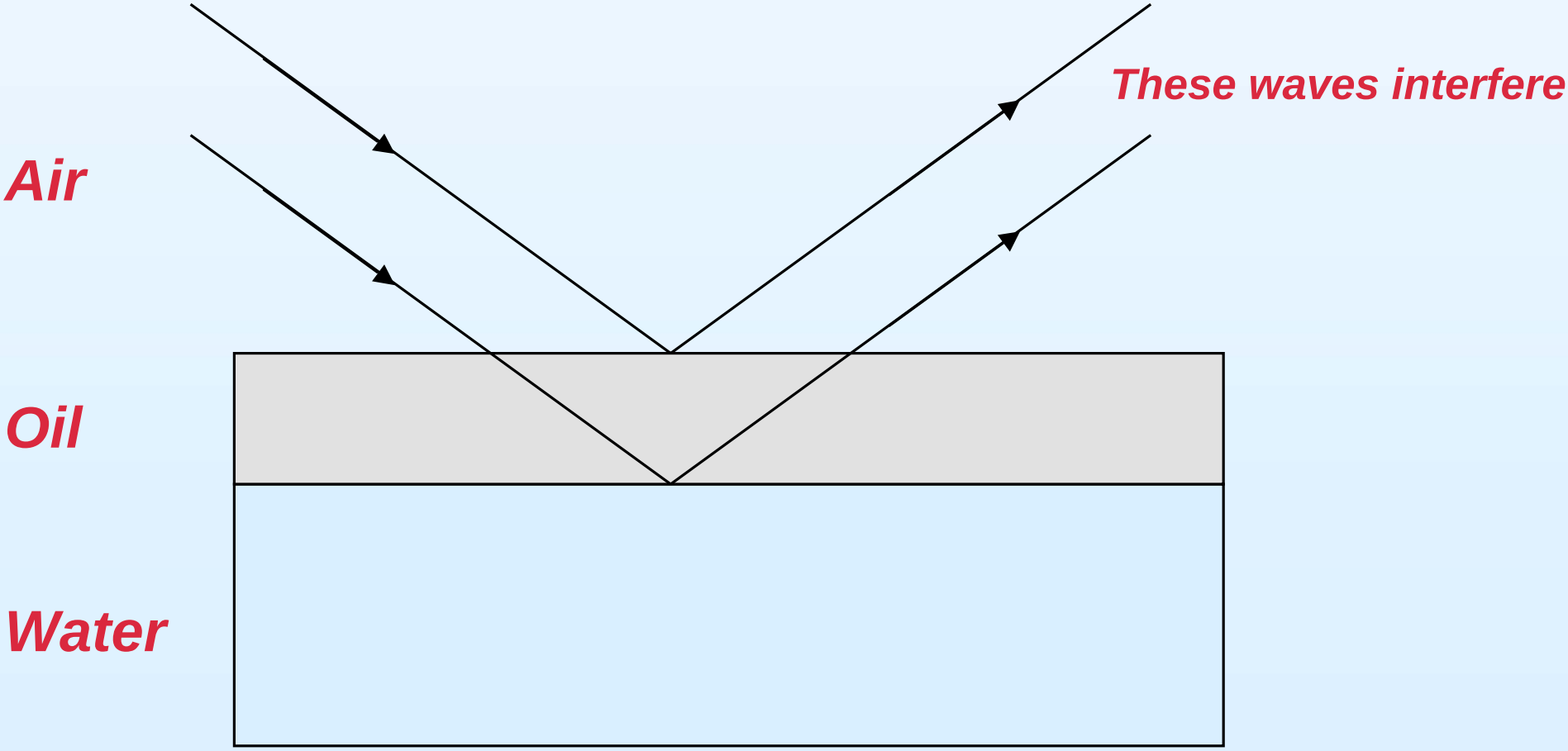


Figure 1

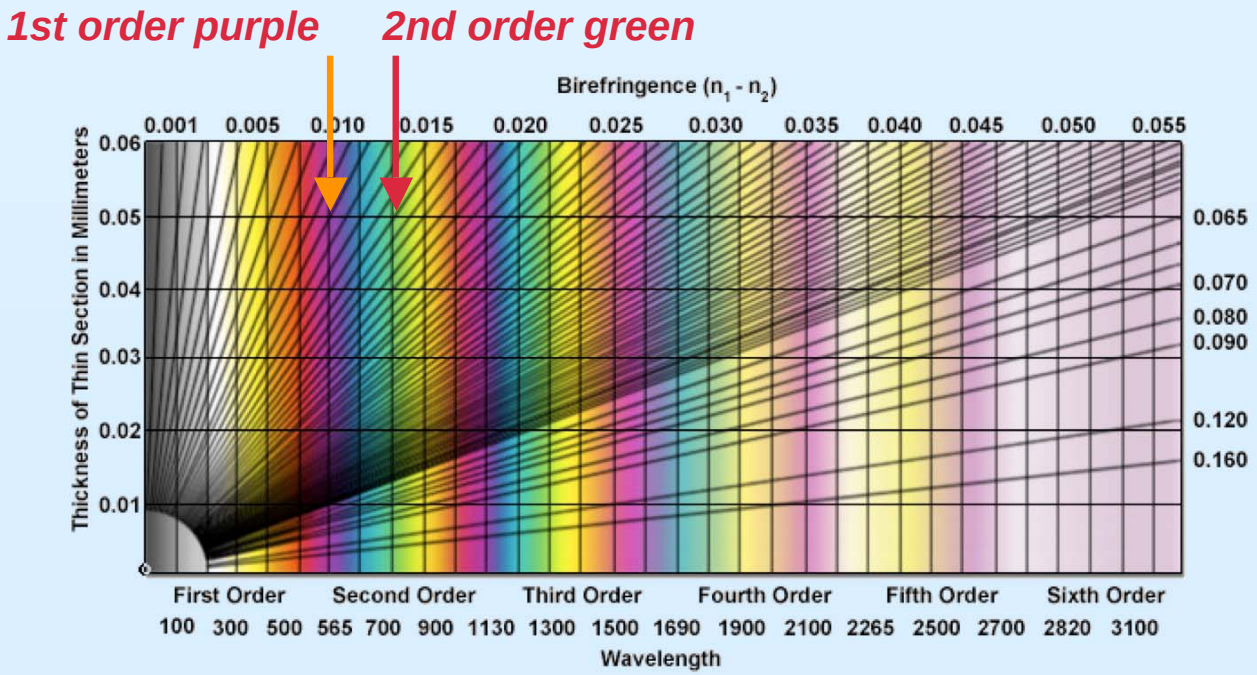
Interference Colors



Since the speed of light (refractive index) in air and oil are different, a thin film of oil causes a retardation of one wave with respect to the other

Birefringent Materials Give Interference Colors in the PLM

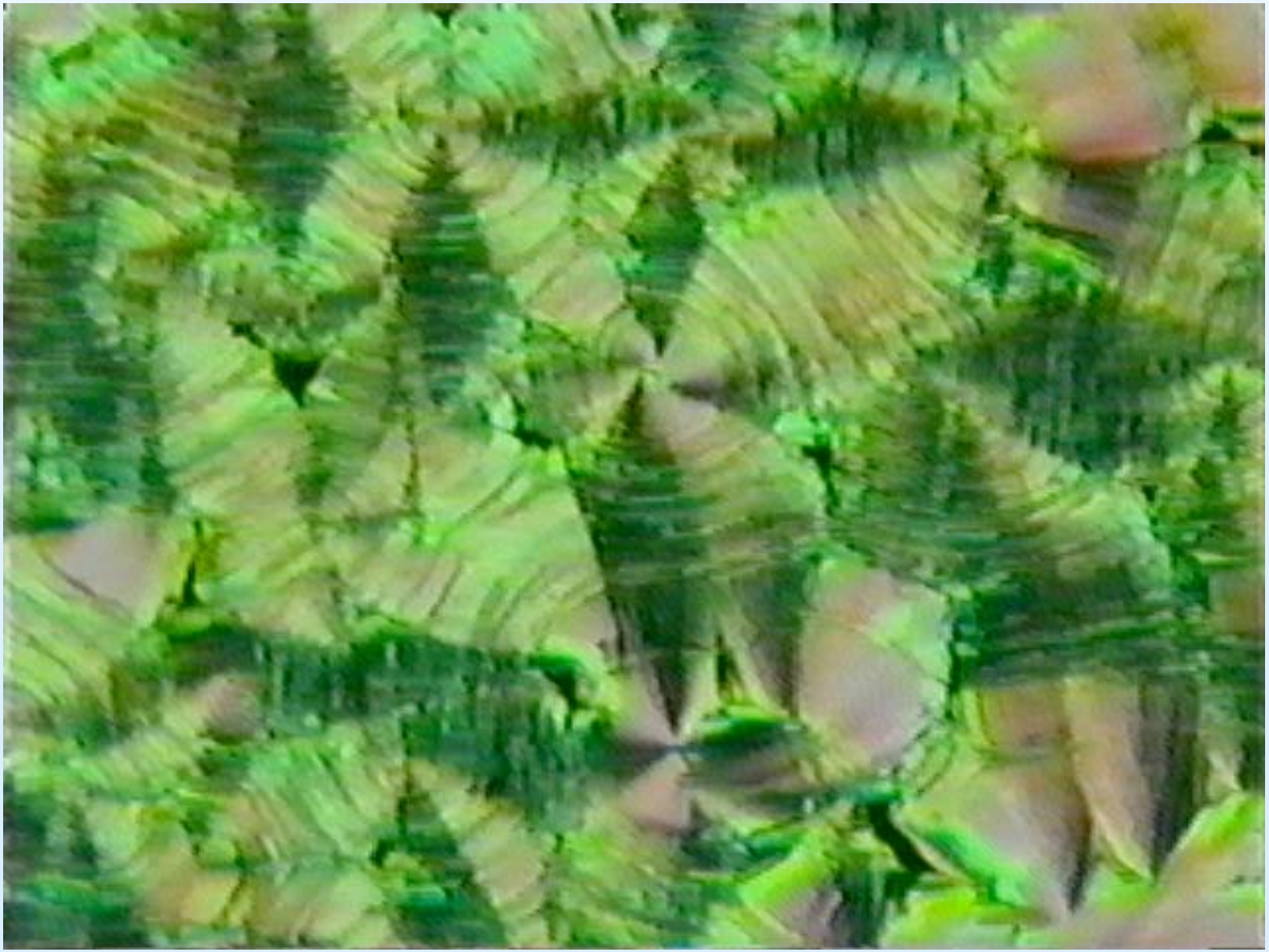
- **All birefringent materials have something in common: They are all anisotropic**
  - Piece of stretched plastic (**LC polymers** are a special kind of plastic which can have very special properties, like **kevlar**)
  - Mica crystal
  - Organic crystals
  - **Liquid crystals** - the only birefringent liquids
- **The color you see is related to the birefringence (Δn) and the thickness of the sample (d)**



Birefringence Color and Extinction Brushes

When the optic axis of the birefringent sample is parallel or perpendicular to the polarizer in the PLM, you see dark features known as extinction brushes

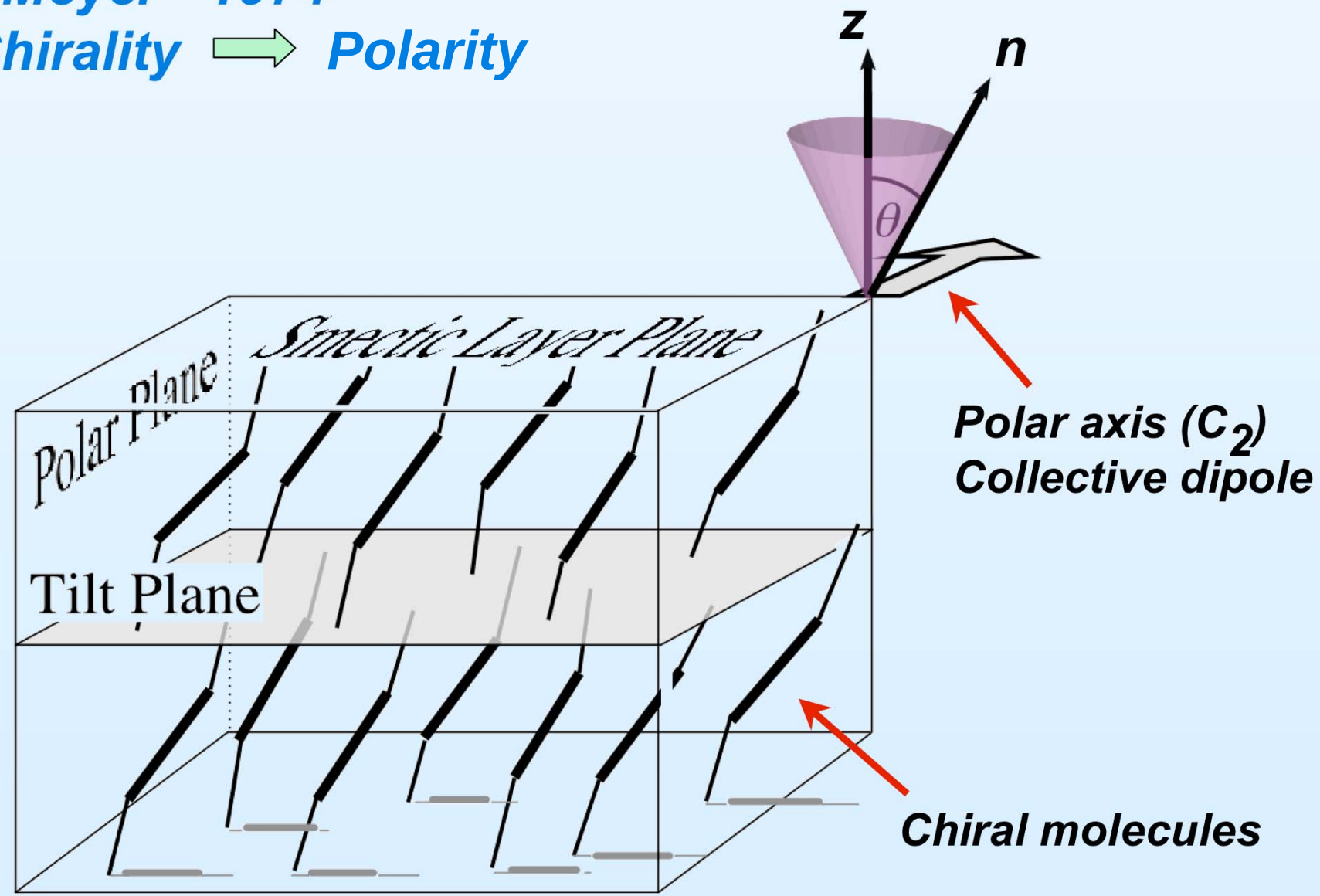
Electro-optics - Birefringence Changes and Brush Rotation



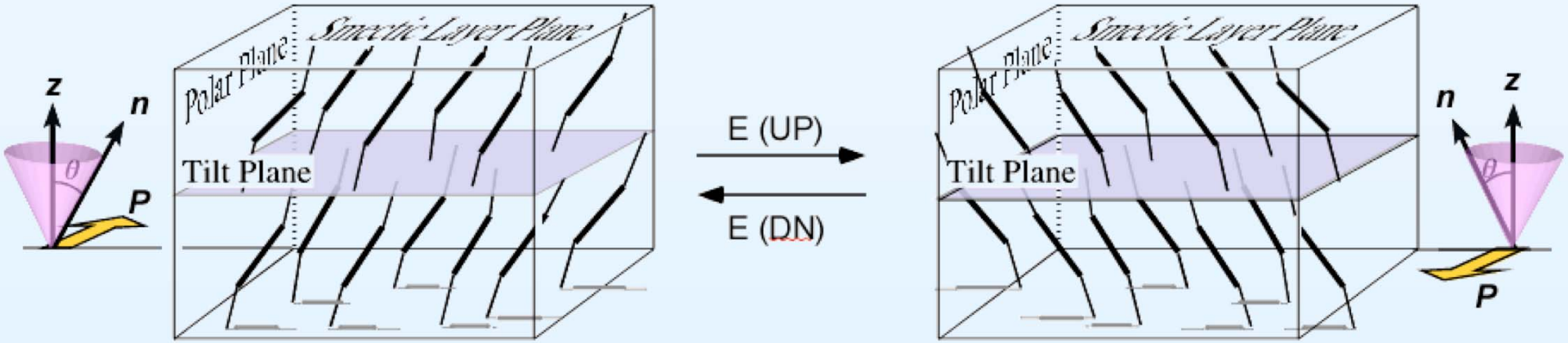
The SmC* Polar Fluid

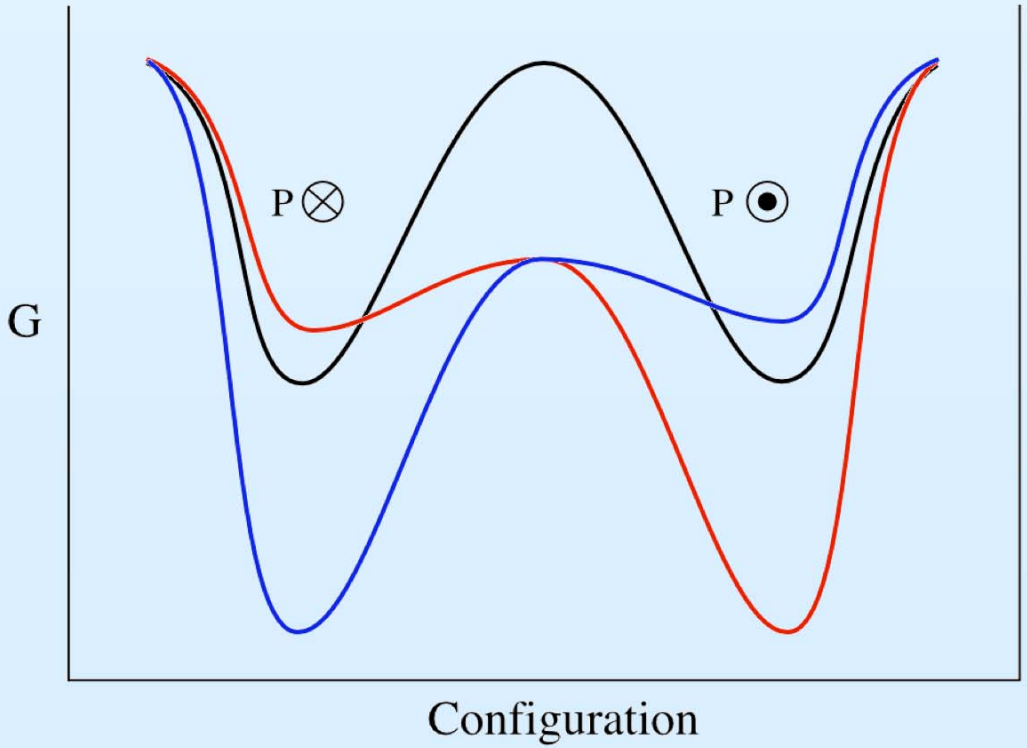
Robert Meyer - 1974

Tilt & Chirality ⇨ Polarity



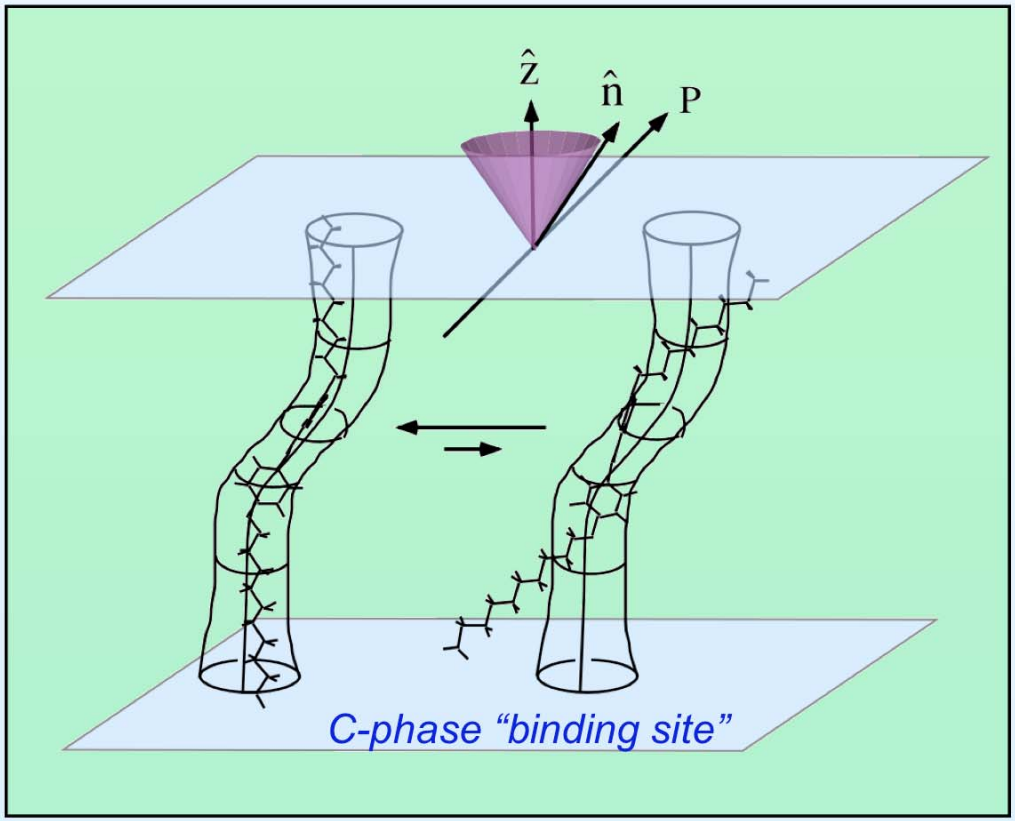
Between Glass Plates the SmC* is Ferroelectric

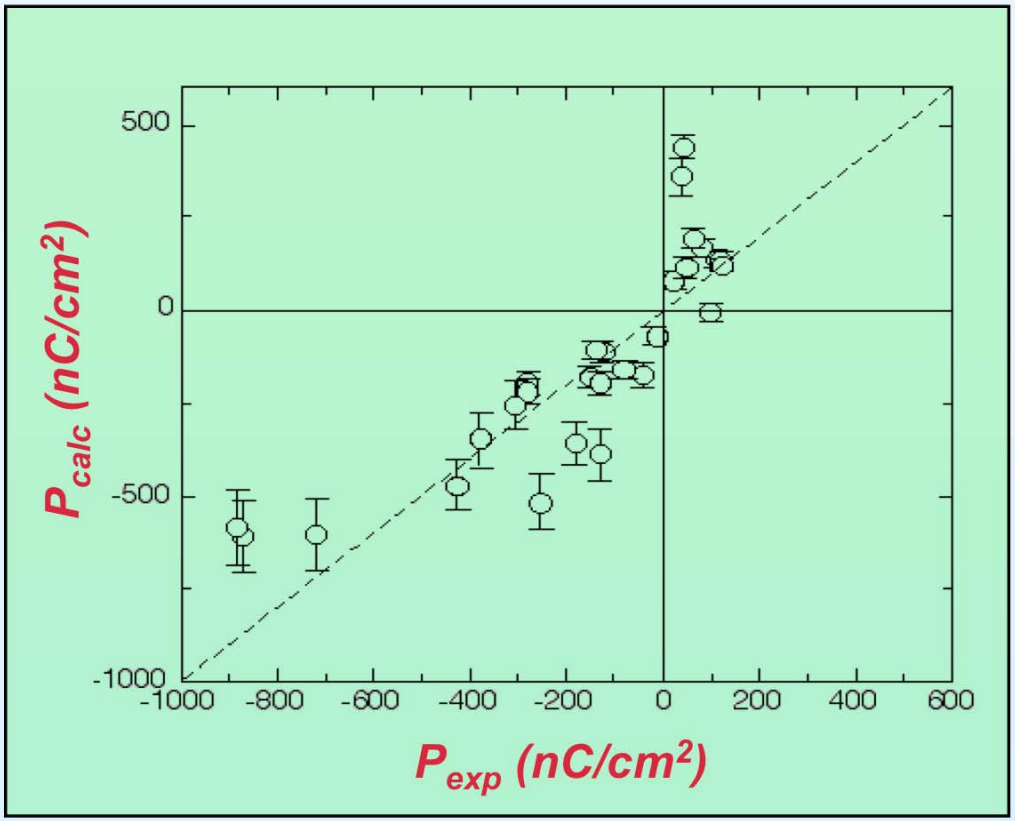




$$\tau = \frac{\eta}{P * E}$$

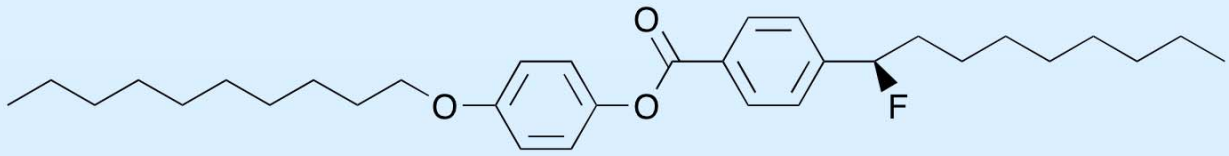
"Single Molecule in a Binding Site" Model for P





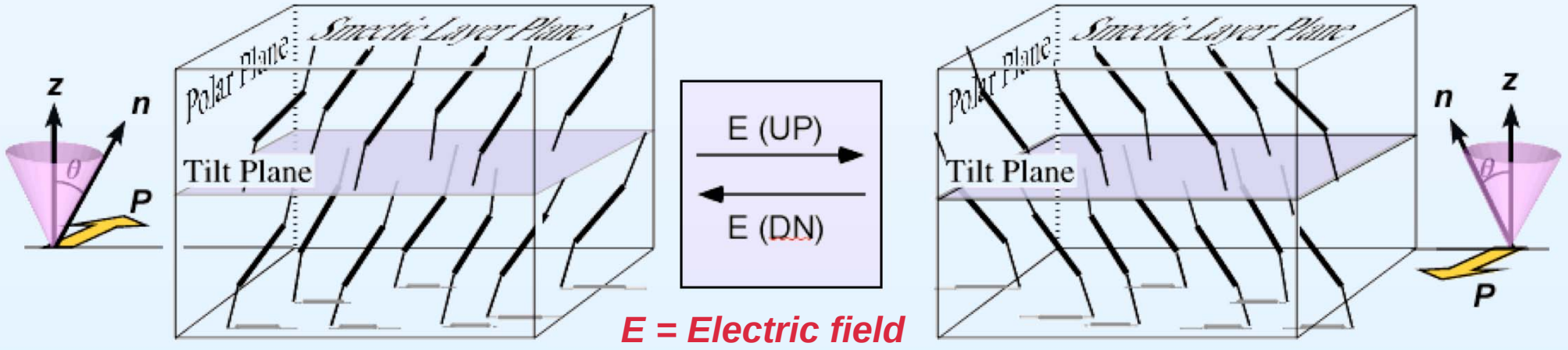
$$\mathbf{P} = \sum_{\text{i conformations}} \mathbf{P_i} * \mathbf{D_i}$$

$$\mathbf{P_i} = \mu_i \langle \cos \alpha \rangle$$



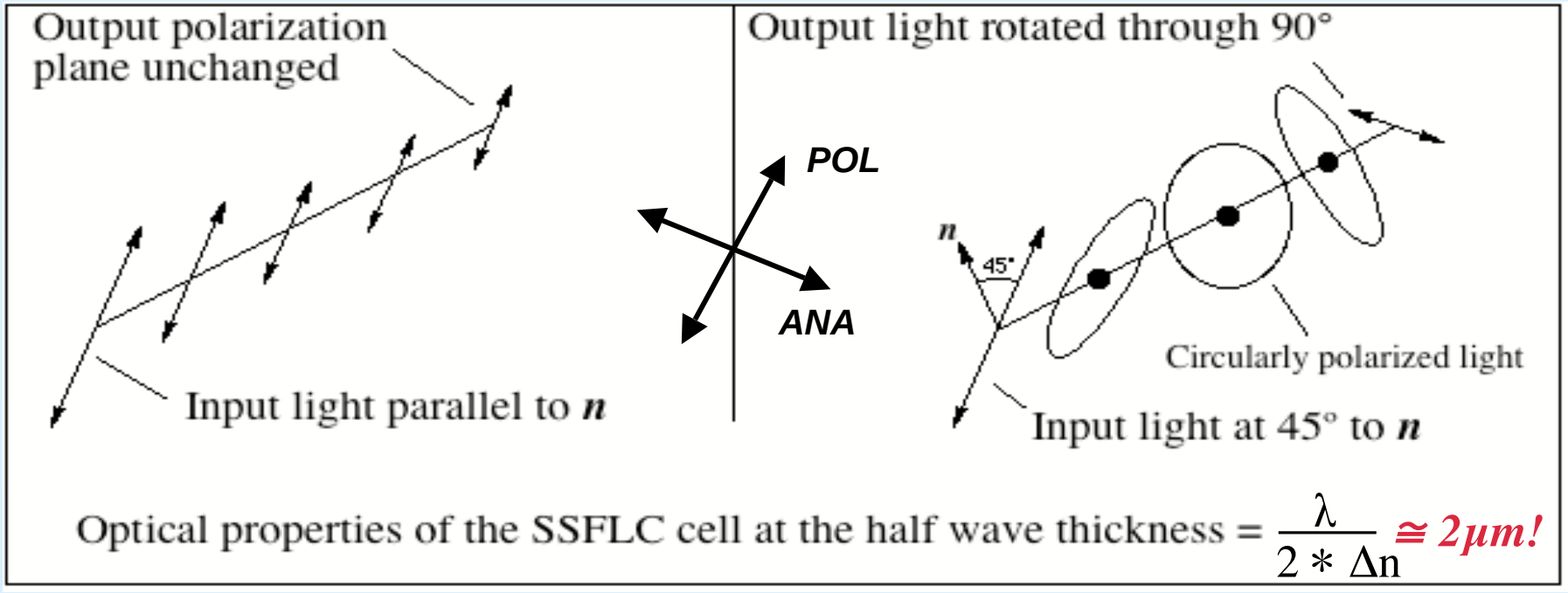
P > 0 ⇒ (R) configuration

SSFLC Electro-optics



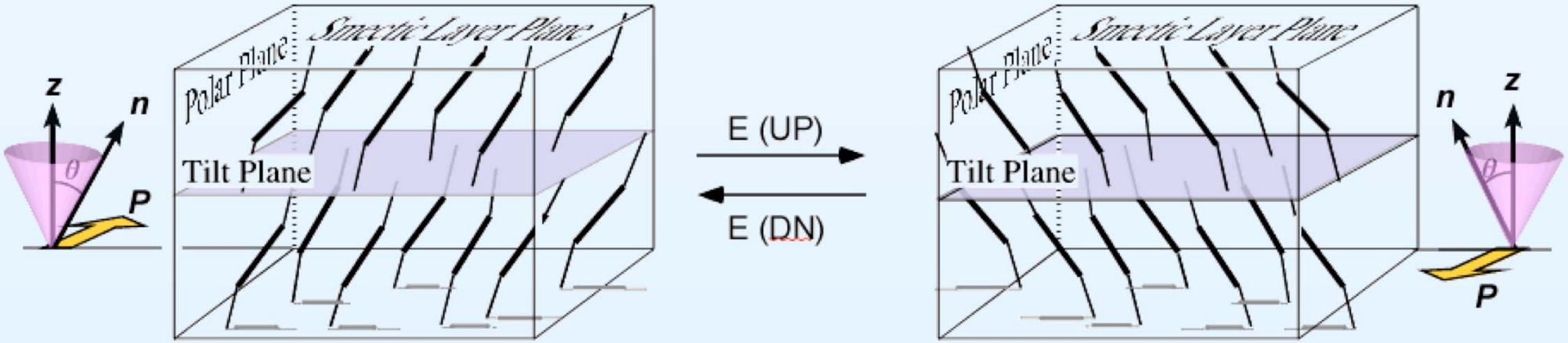
E = Electric field

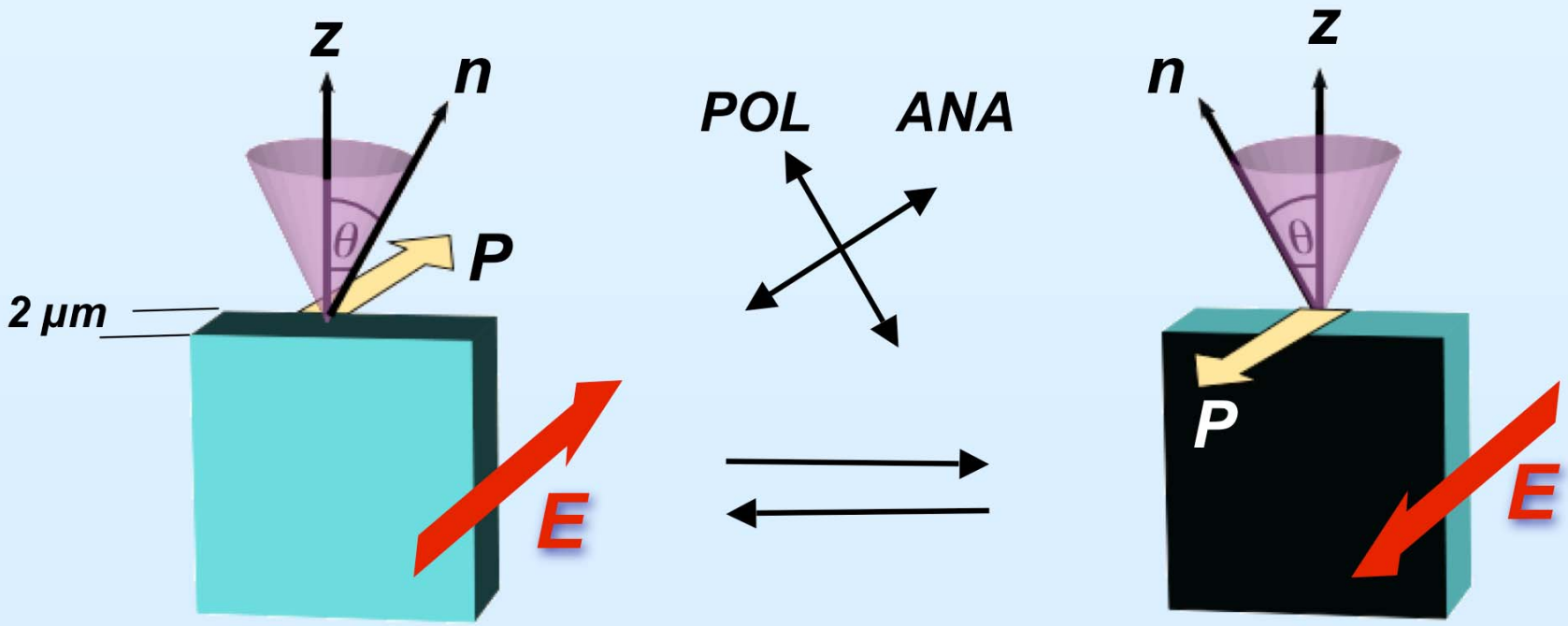
Dark State ***Bright State***



Optical properties of the SSFLC cell at the half wave thickness = $\frac{\lambda}{2 * \Delta n}$ ≅ *2μm!*

SSFLC EO is Unichiral

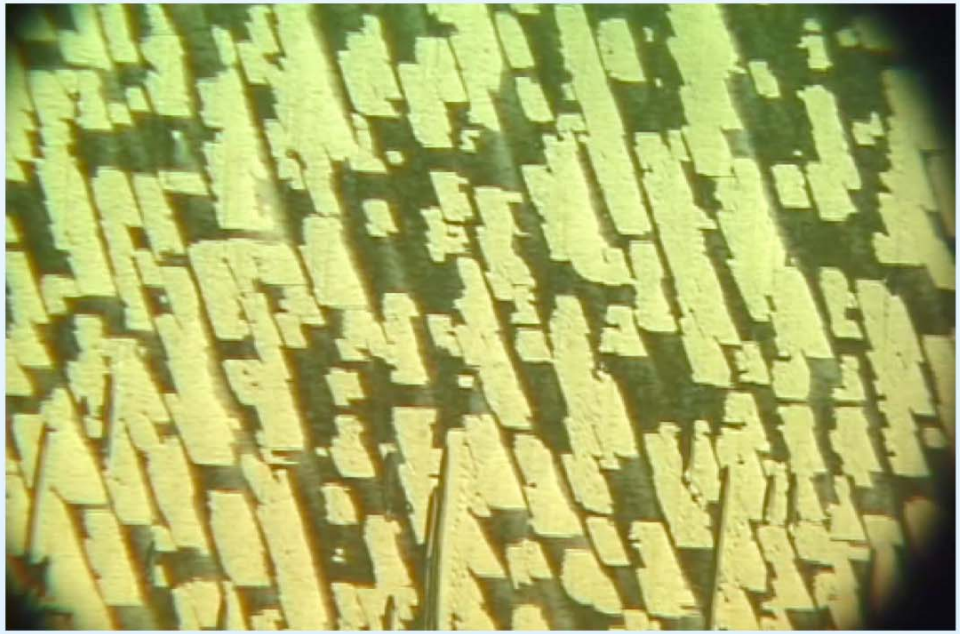


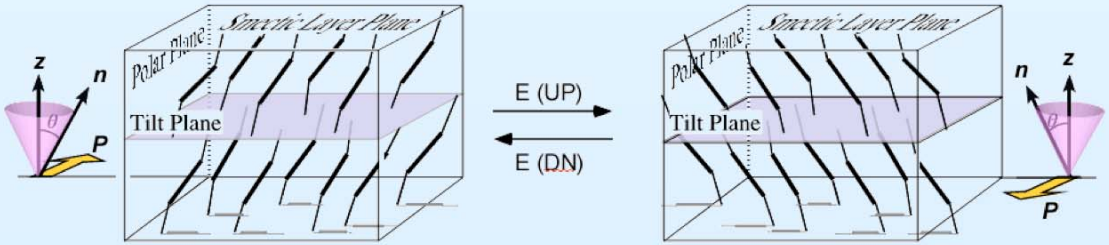


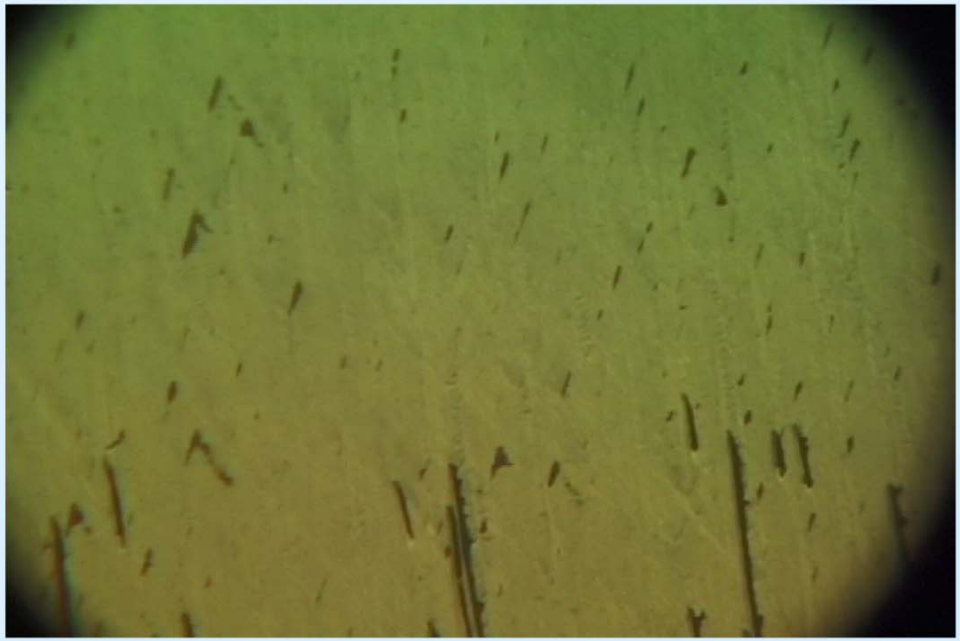
P > 0 (right-handed)

SSFLC Switching

Bright and Dark ferroelectric domains



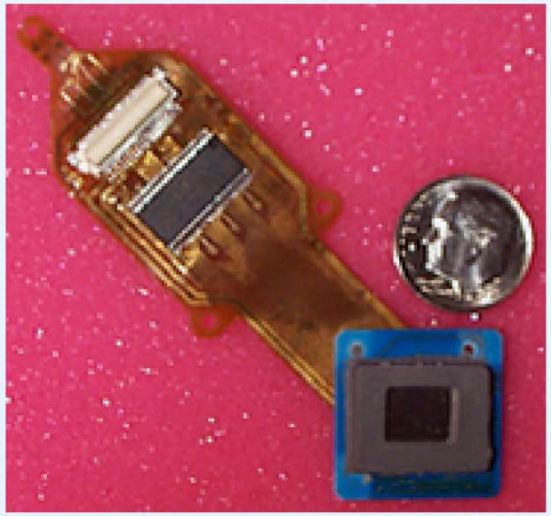




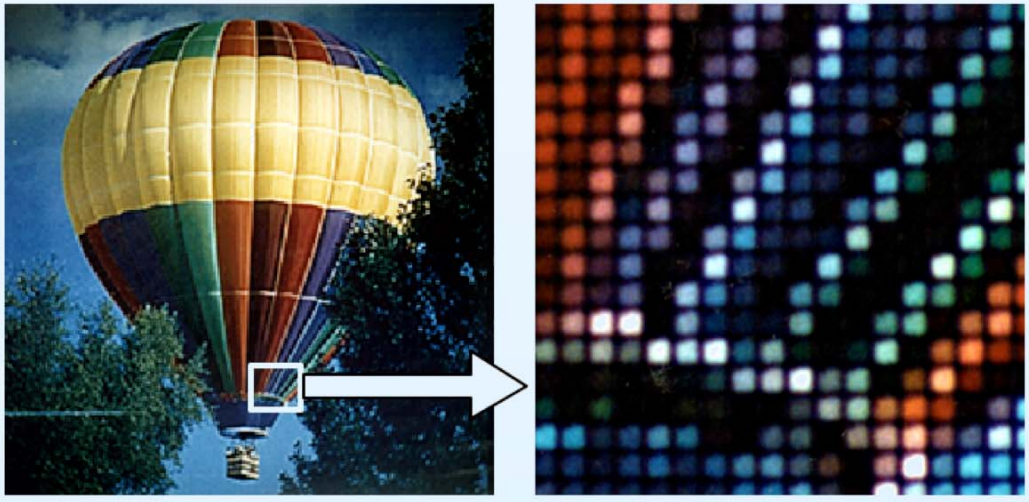
Chiral EO response to an applied triangular driving waveform (the material has a very small P)

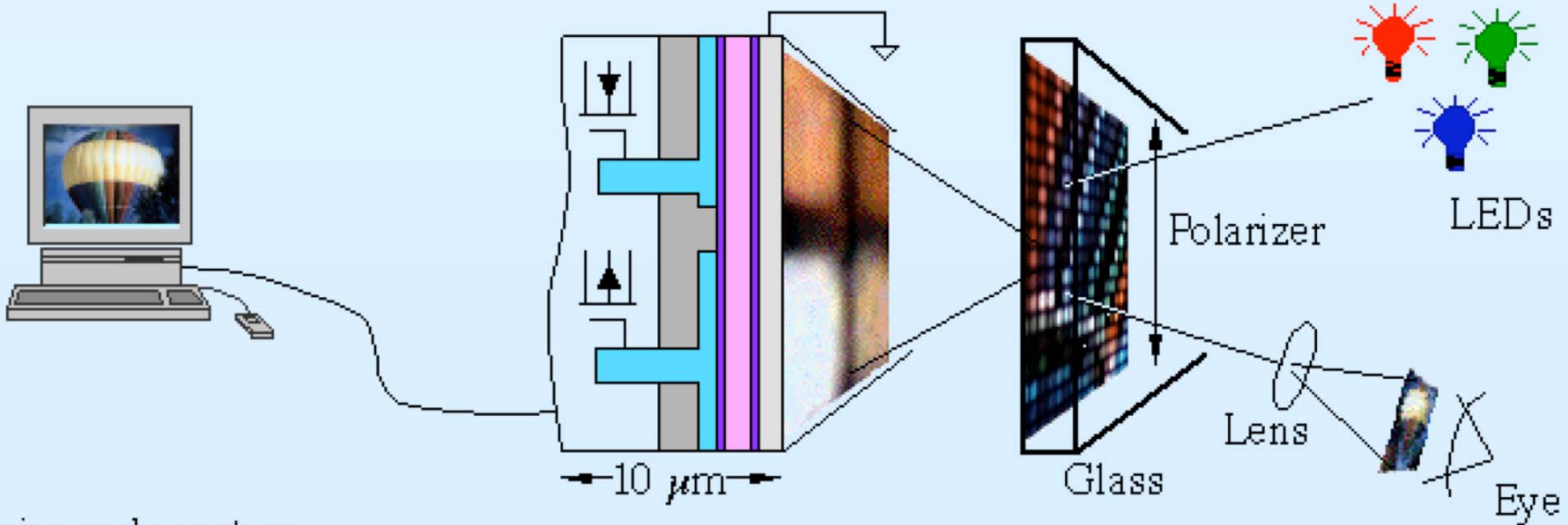
FLC on Silicon (FLCOS) Microdisplays

SSFLC on Silicon Integrated Optical Chip



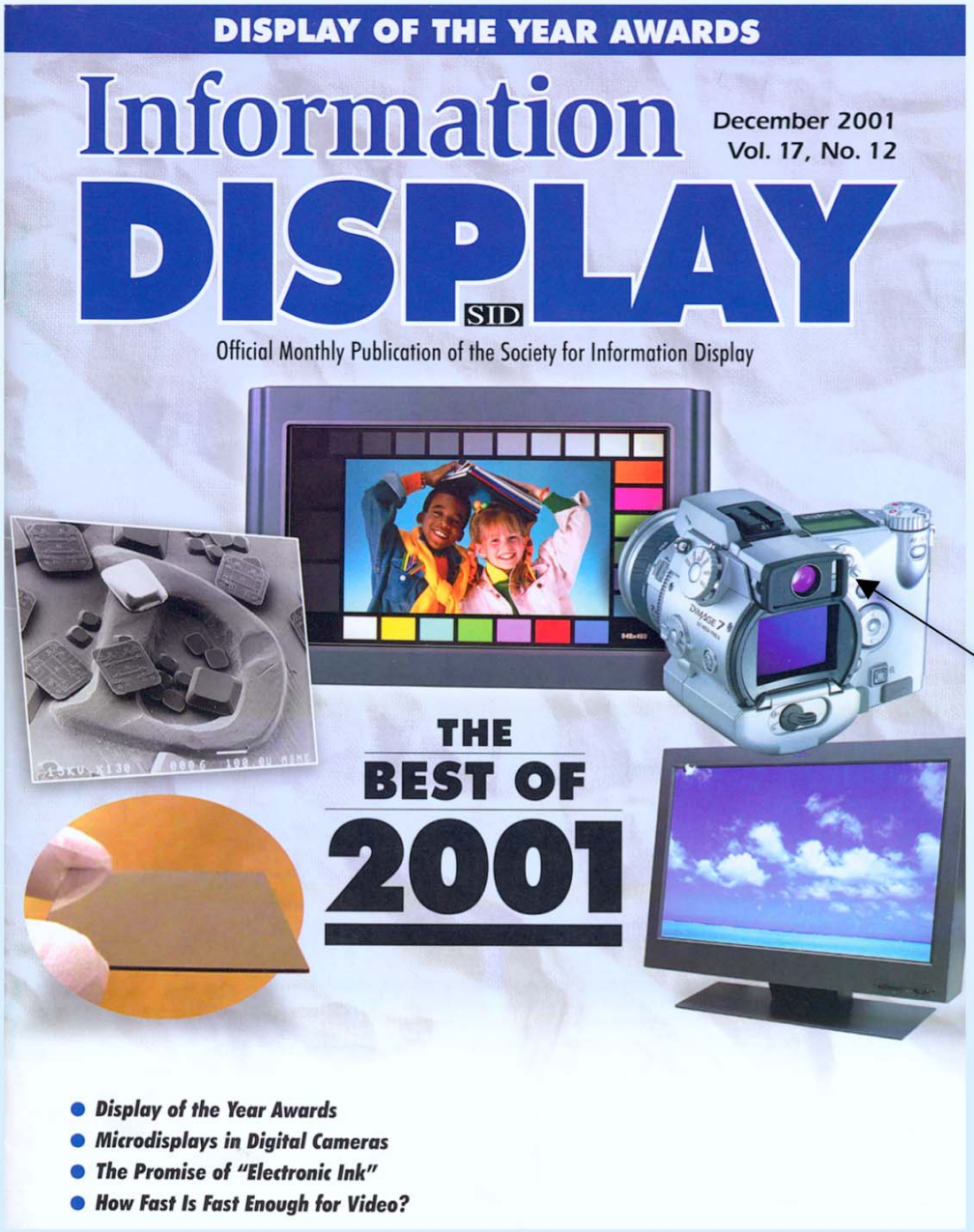
300K Channels
@ 10 KHz ~ 3 Gbits/sec





Photomicrographs courtesy
Displaytech, Inc.

Unichiral Electro-optics can be Useful

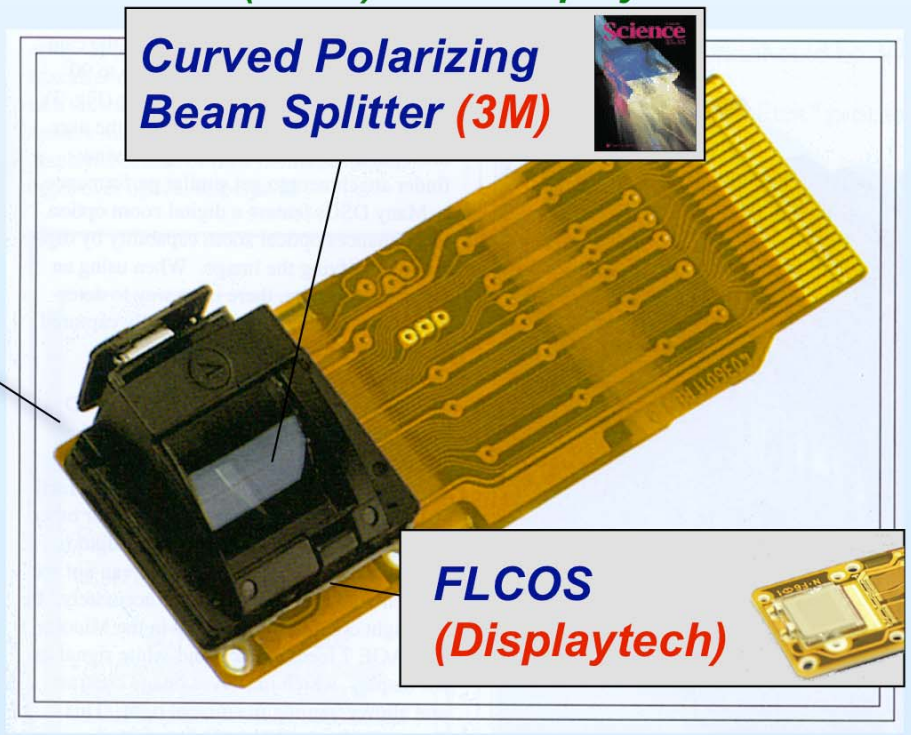


"Display Product of the Year

Gold Award:

Minolta's DiMAGE 7 Digital Still Camera

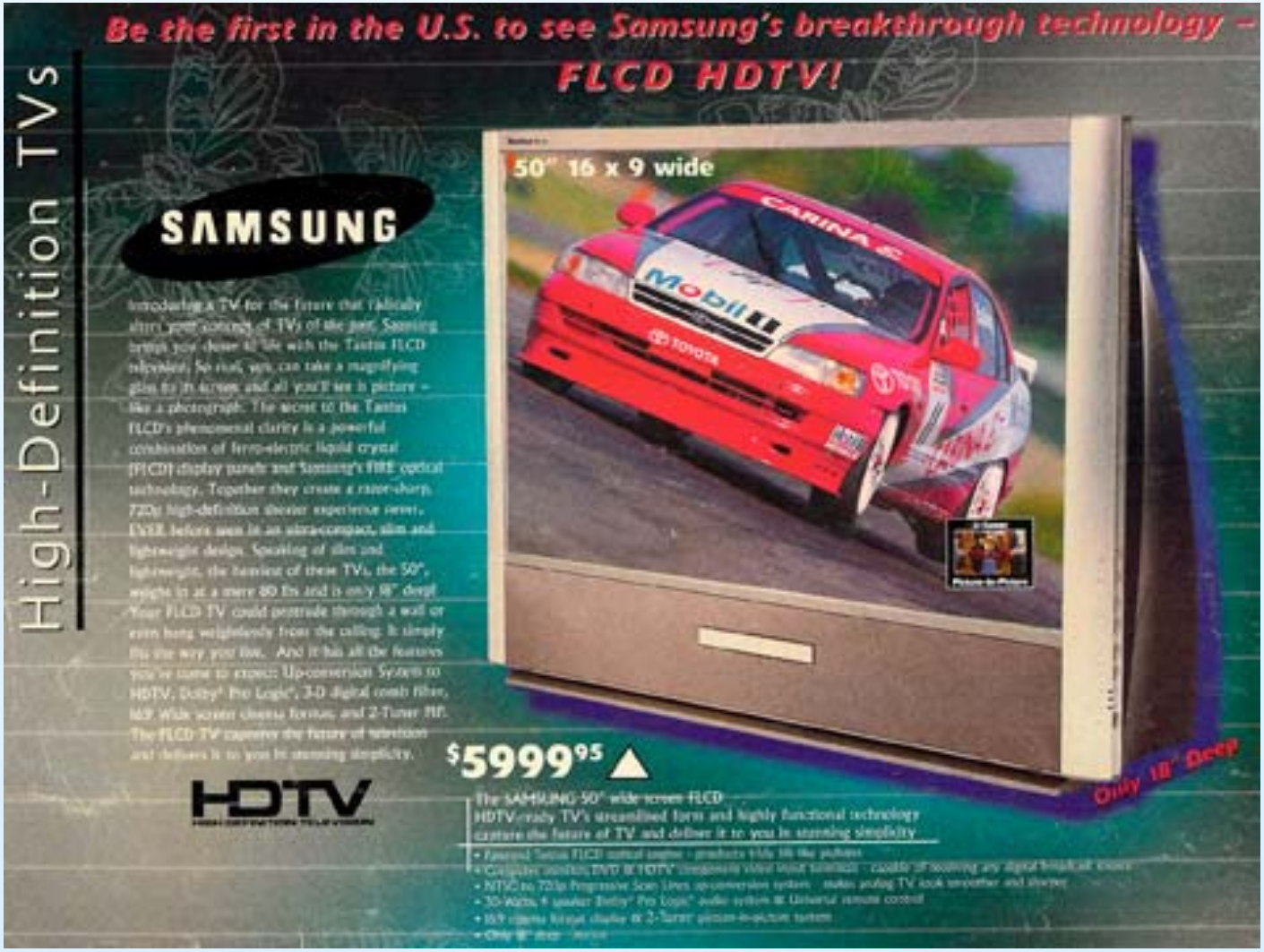
In its 5-Mpixel DiMAGE 7, Minolta Corp. has pioneered the use of a liquid-crystal-on-silicon (LCoS) microdisplay…"



8 Millionth shipped (Feb, 2005)

Displaytech/Samsung FLCOS HDTV

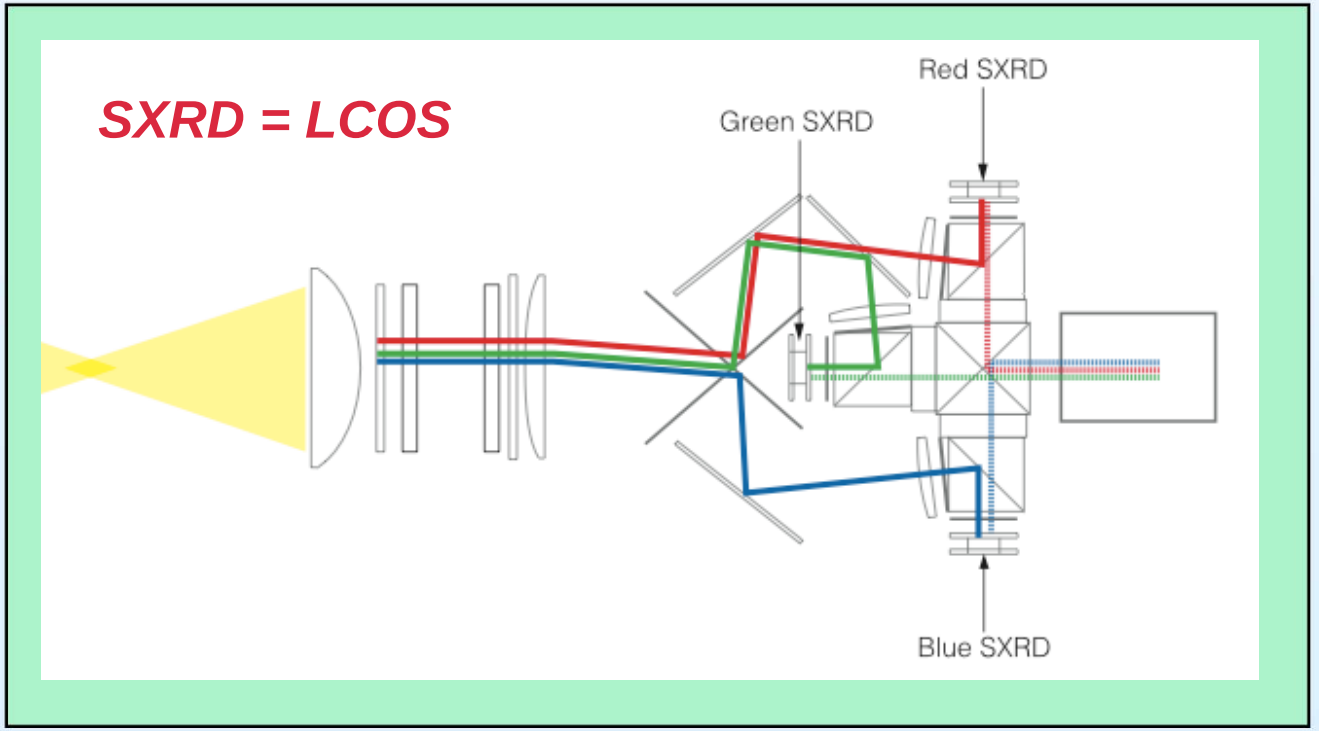
One 0.78” Displaytech FLCOS Chip for each color channel



Boulder SoundTrack brochure, Fall 2000

Failed due to manufacturing problems

Sony VAN-LCOS HDTV - 2005



70” Rear-Projection 1080 p (!) HDTV @ ~$10K
Vertically-Aligned Nematic LCOS
Apparently shipping in US as of June 2005

A Liquid Crystal Conglomerate?

- *Next time - the liquid crystal version of the most famous experiment in organic stereochemistry!*