
Midwest Chapter- The society for Information Display



POLICRYPS structures: Self-aligning liquid crystal electro-optic constructs

Luciano De Sio

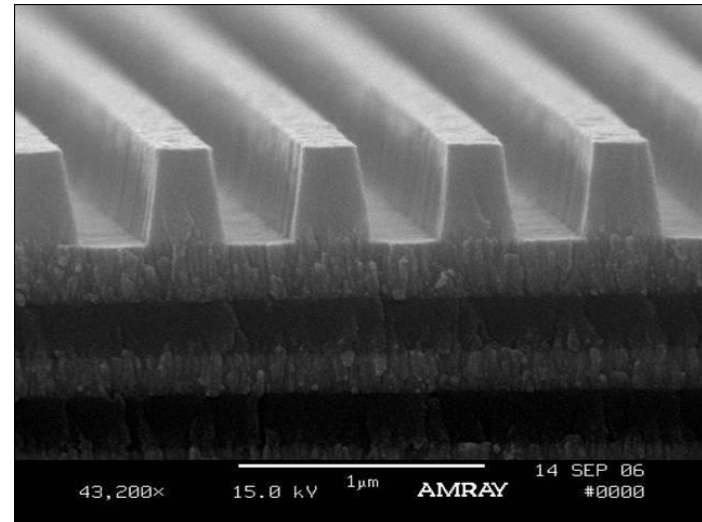
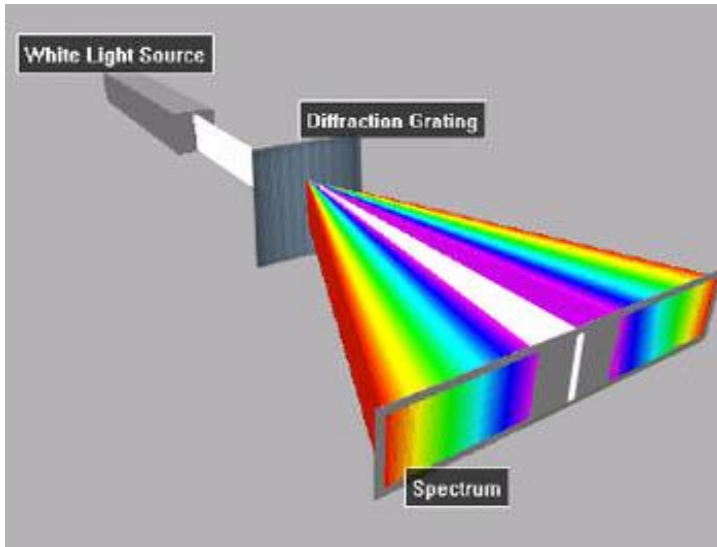
Beam Engineering for Advanced Measurements Company, 1300 Lee Road, Orlando, Florida 32789, USA.

Outline

- ✓ DIFFRACTION GRATINGS
- ✓ HOLOGRAPHIC SETUP: HIGH STABILITY LEVEL
- ✓ POLICRYPS: THE RECIPE
- ✓ POLICRYPS: OPTICAL AND ELECTRO - OPTICAL PROPERTIES
- ✓ POLICRYPS: SELF ALIGNING LIQUID CRYSTALS
- ✓ CONCLUSION

Diffraction Gratings

A diffraction grating is an optical component with a periodic structure, which splits and diffracts light into several beams travelling in different directions.



Fabrication processes

- Photolithography
- Electron-beam lithography
- Interference holography

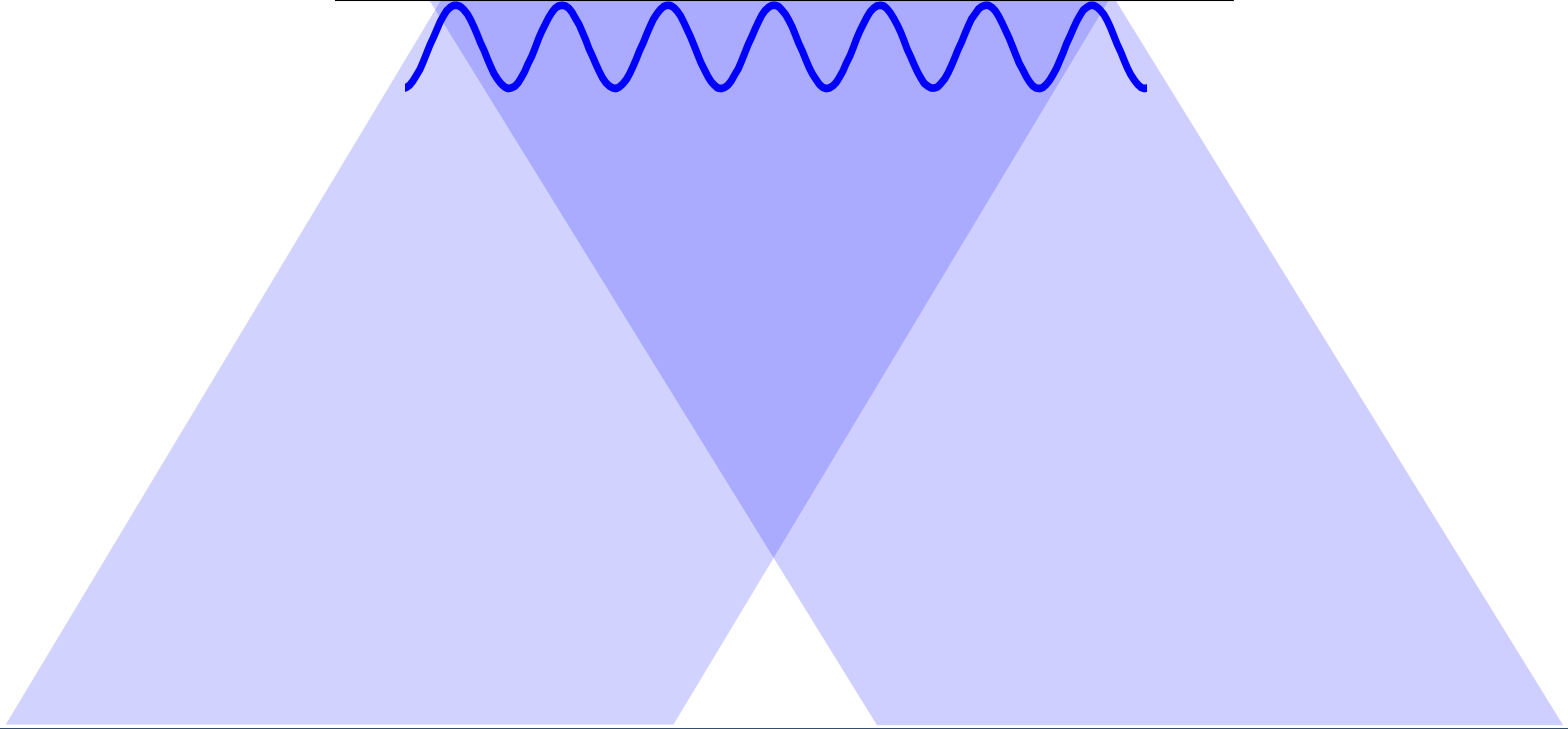
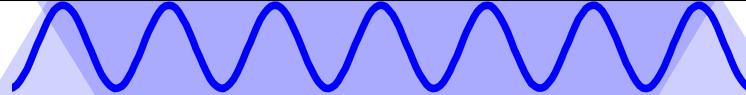
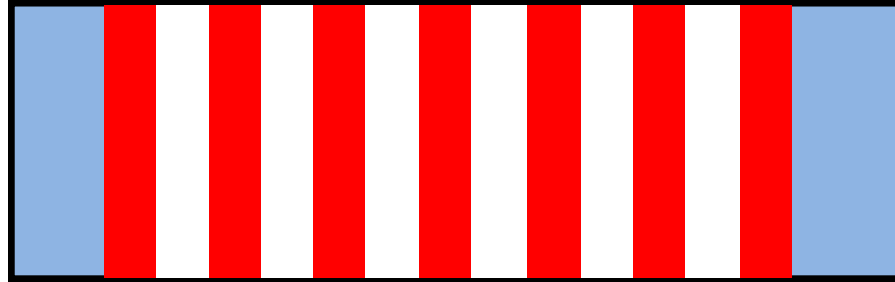
Pro and Cons

- Large area – low resolution
- High resolution – Expensive, small area
- Large area, easy method - Instability

Diffraction Gratings: lack of tunability/switching severely limits the applications

Holographic Polymerization

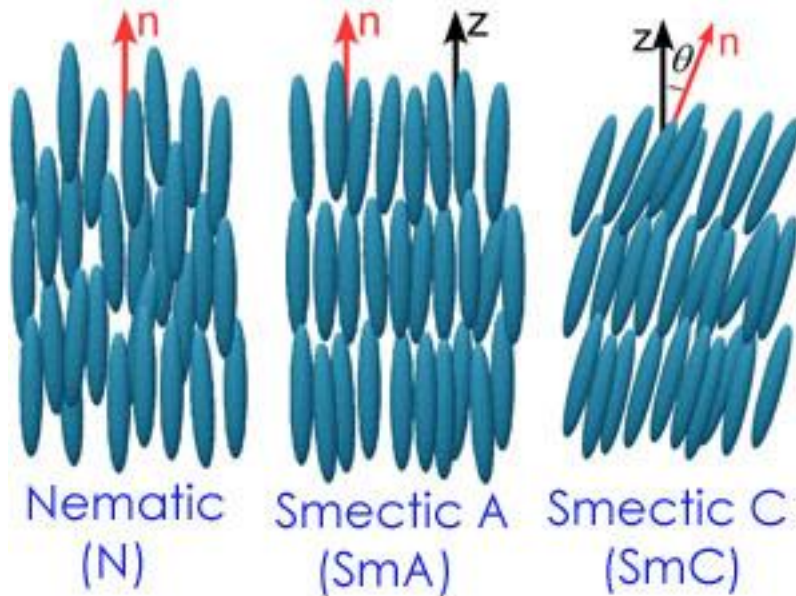
Multiple light beam interference + photosensitive materials



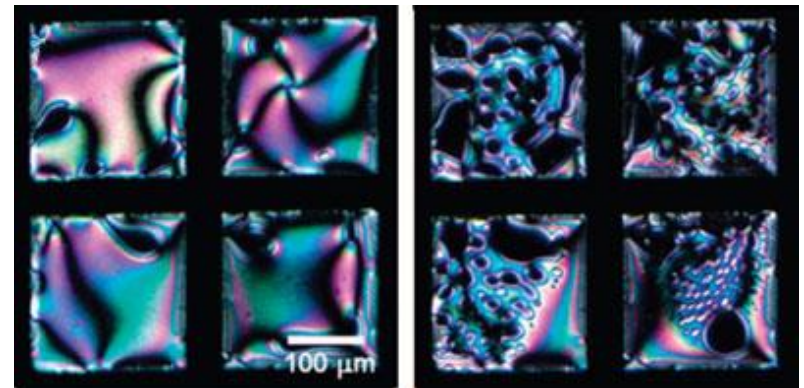
Liquid Crystals

Soft matter is a subfield of condensed matter comprising a variety of physical states that are easily deformed by thermal stresses or thermal fluctuations. They include liquids, colloids, biological materials and Liquid Crystals

The fourth state of matter



- Long range order
- Broad band range of birifringence
- High sensitivity to AC, DC and Optical field



Liquid Crystals Phases

Holographic Polymer Dispersed Liquid Crystals (H-PDLC)

Holographic photopolymerization

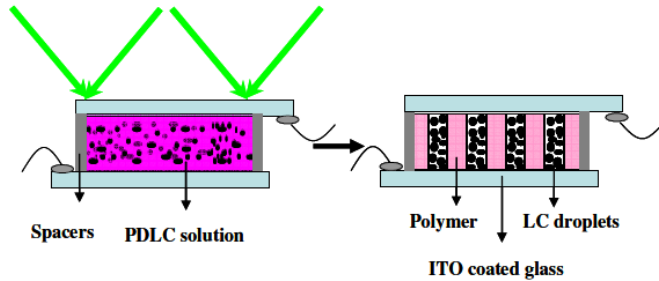
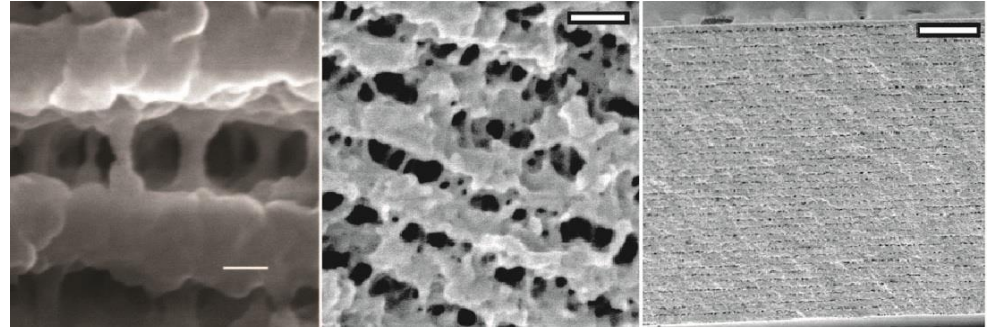
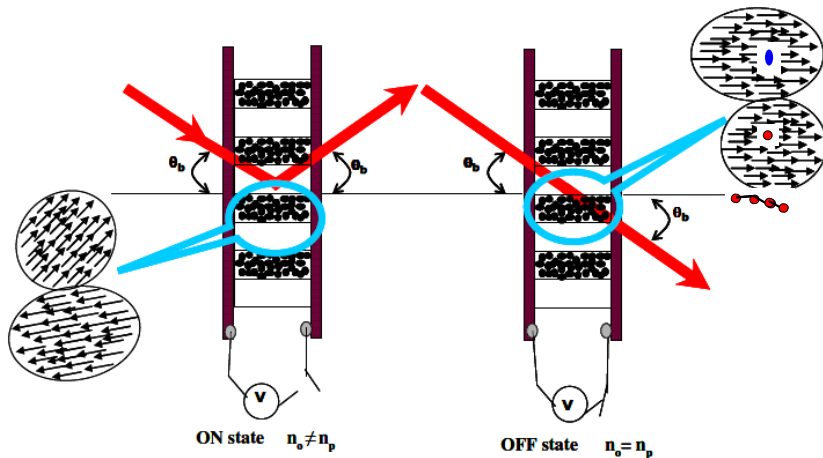


Figure 1 Creation of diffraction grating in PDLC layer.



Bunning et al. (2000), Annual Review of Material Science 30, 83

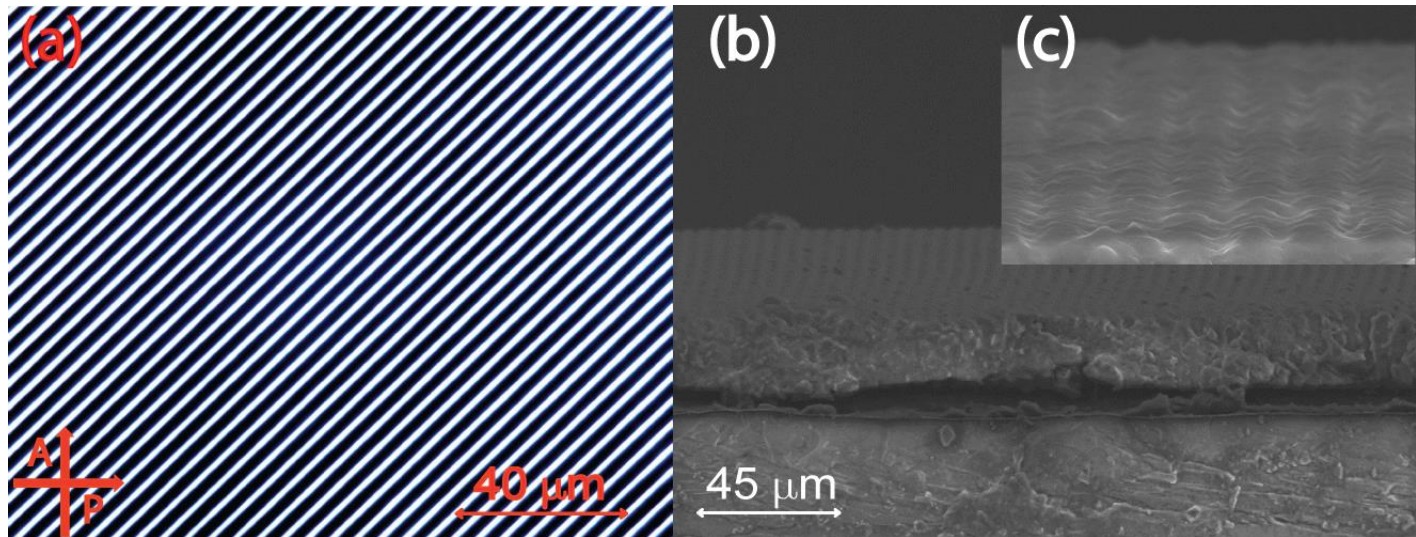


Drawbacks

- Scattering
- High switching voltage

Pavani, K. et al. (2009). Journal of Optics A: Pure and Applied Optics

POlymer LIquid CRYstal P Polymer S Slides



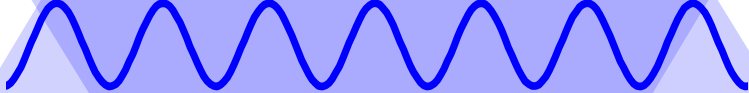
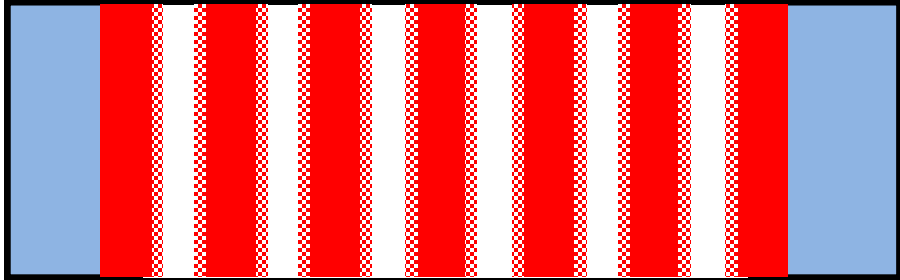
R. Caputo, L. De Sio, A. Sukhov, A. Veltri, C. Umeton

Development of a new kind of holographic grating made of liquid crystal films separated by slices of polymeric material

Optics letters 2004, 29,1261

Stability problems during curing

Stable setup



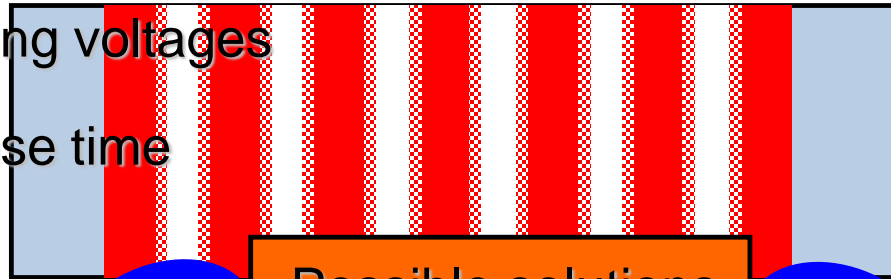
Stability problems during curing

Unstable setup

Irregular morphology

High switching voltages

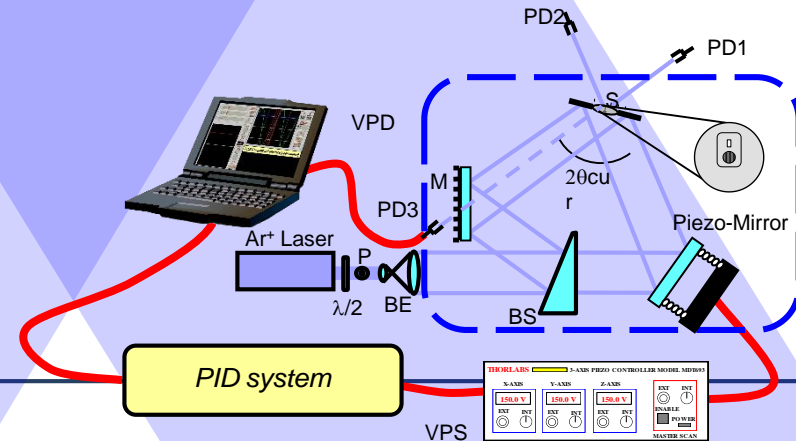
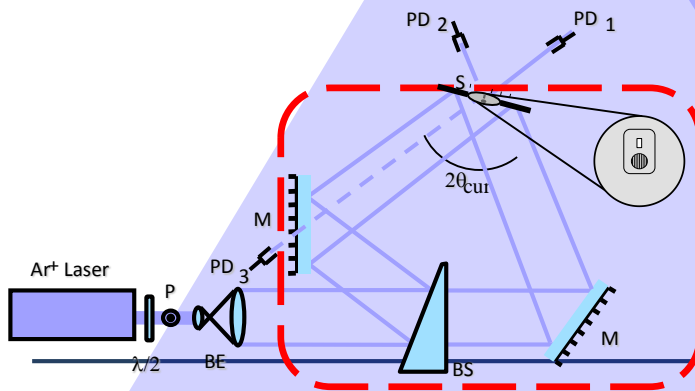
High response time



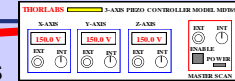
Possible solutions

Passive setup

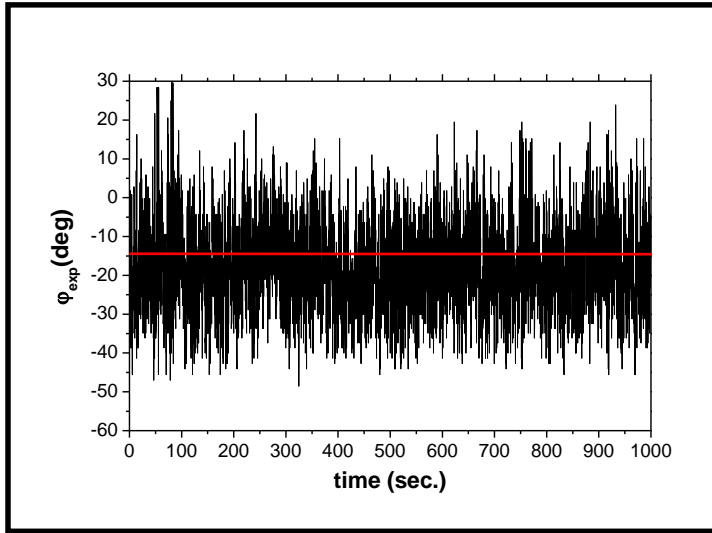
Active setup



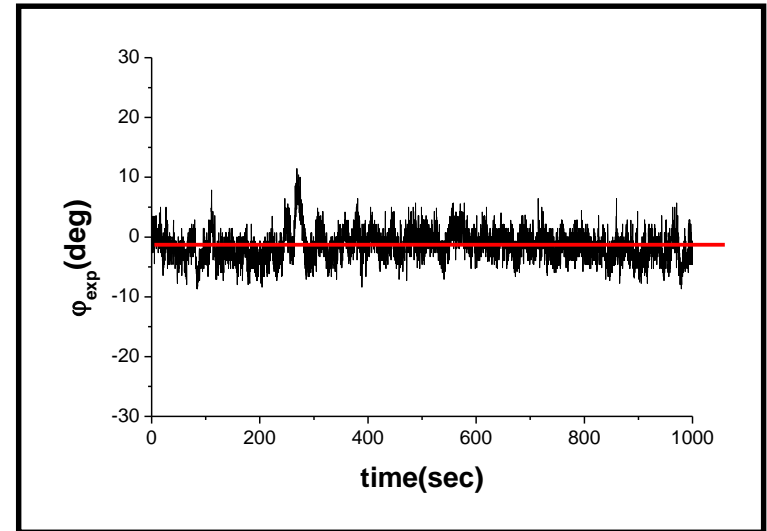
PID system



Passive setup



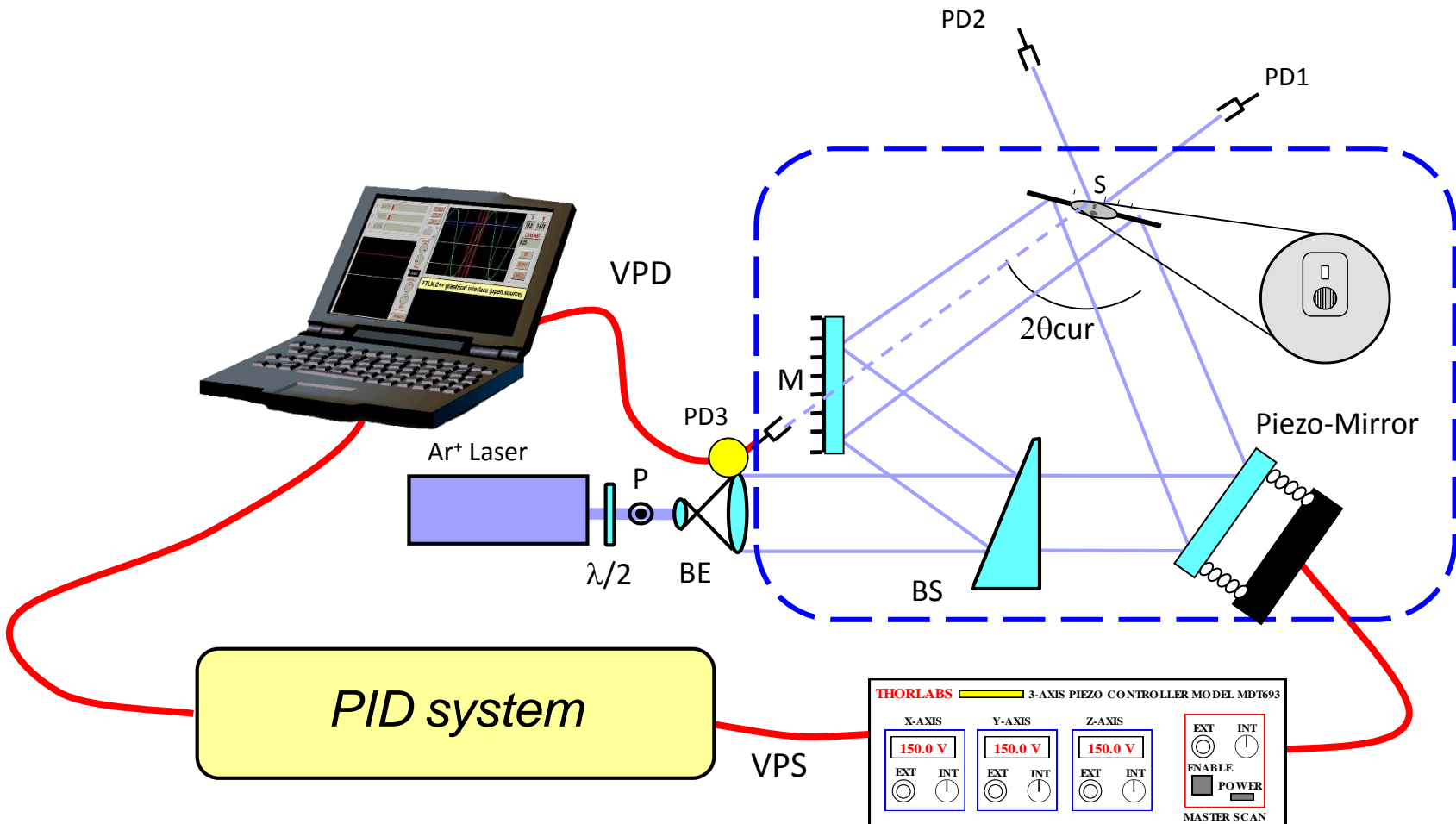
without stabilization



with stabilization



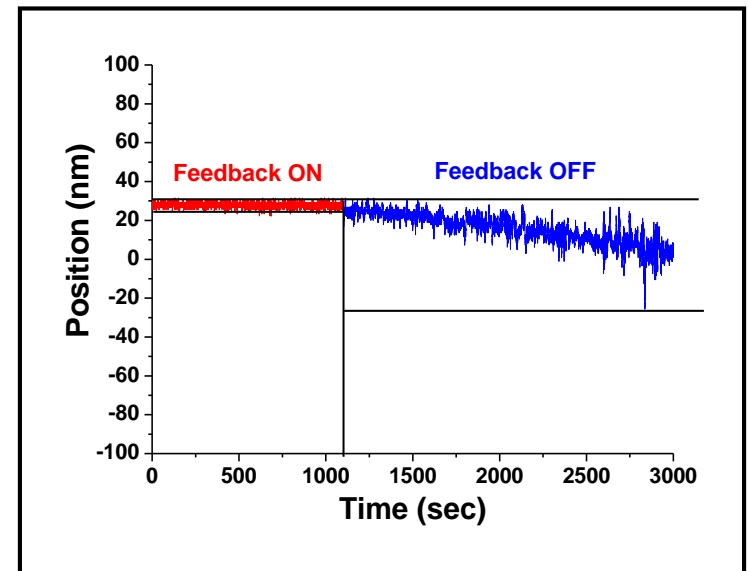
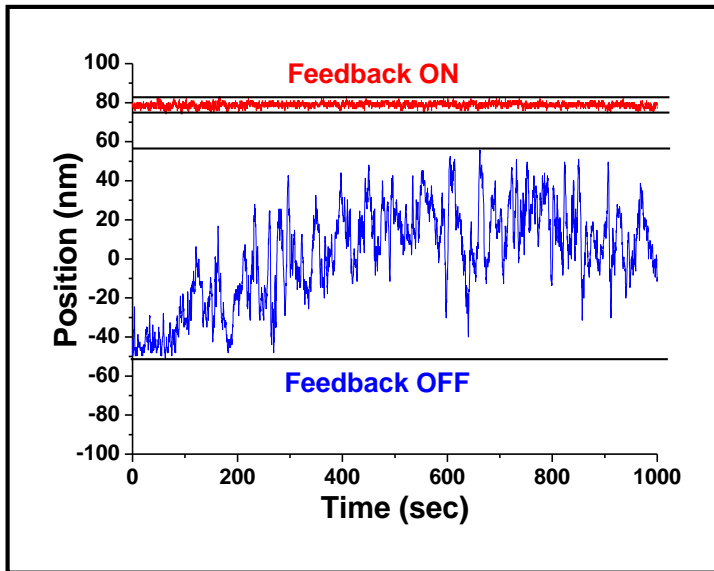
Active setup



L. De Sio et al. Appl. Opt. 45, 3721-3727 (2006)

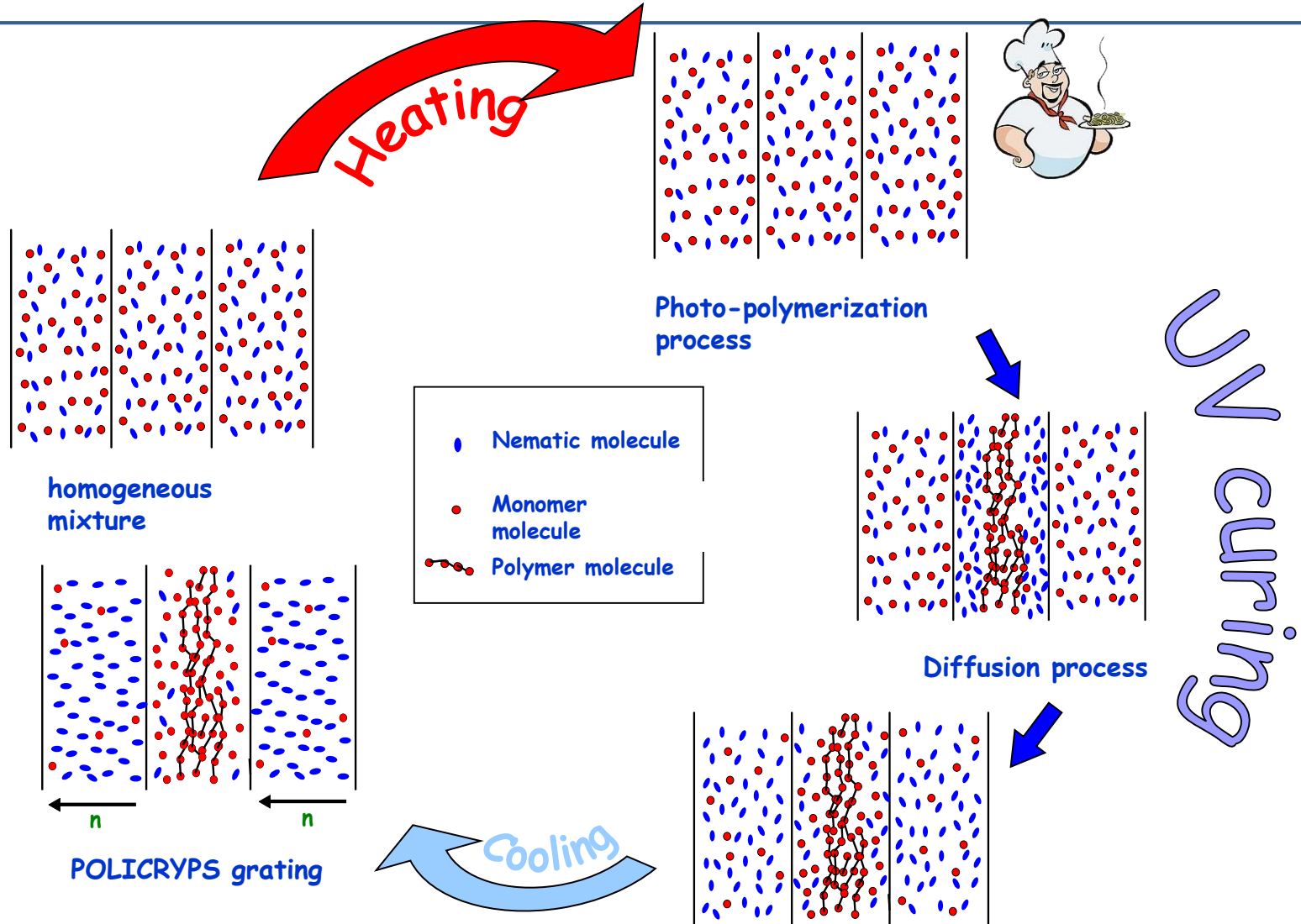
Experimentals Results

Without thermo-acoustic isolation



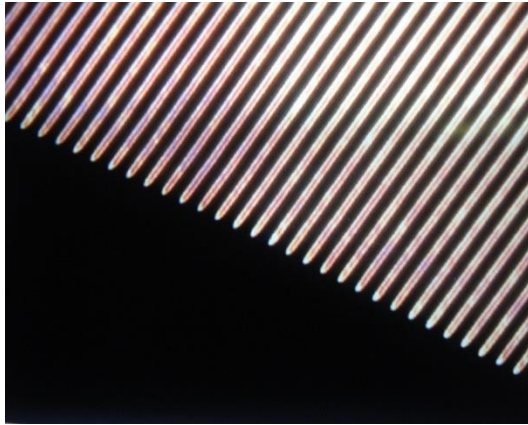
L. De Sio et al. Appl. Opt. 47, 1363-1367 (2008)

POLICRYPS: the recipe

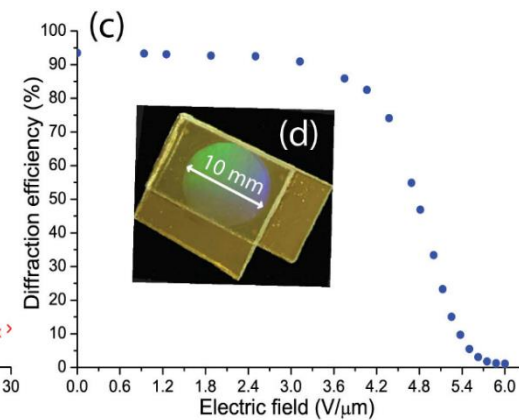
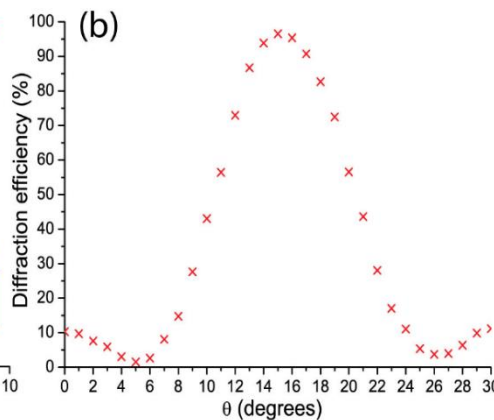
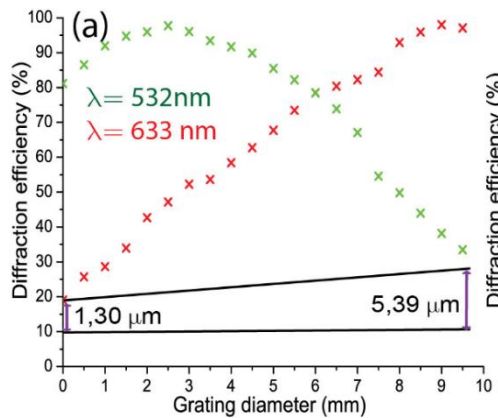
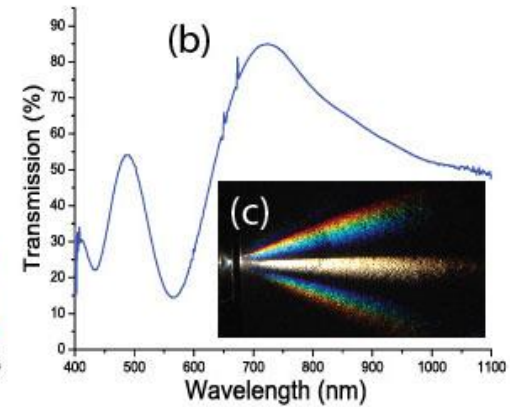
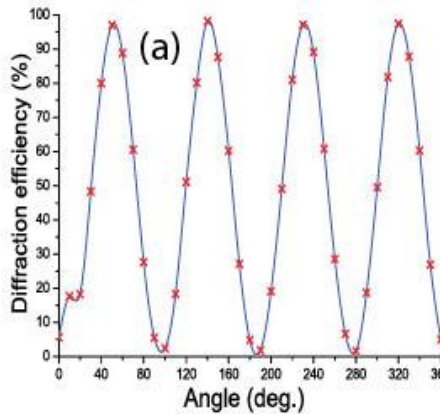


POLICRYPS Gratings

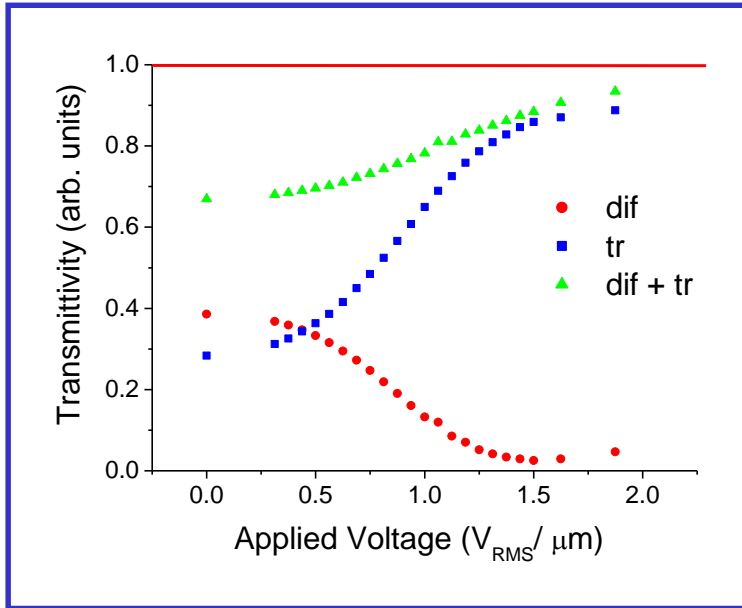
Kogelnik theory



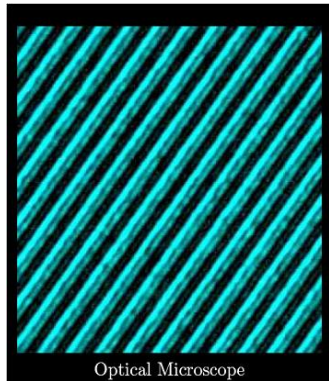
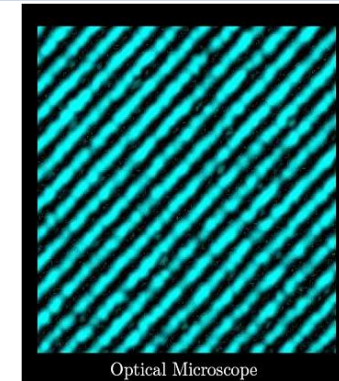
$$\eta = \sin^2 \left[\frac{\pi \cdot \Delta n_g \cdot L}{n_0 \cdot \lambda \cdot \cos \vartheta} \right] = \sin^2 [\phi(L, \vartheta, \Delta n_g(E, T), \lambda)]$$



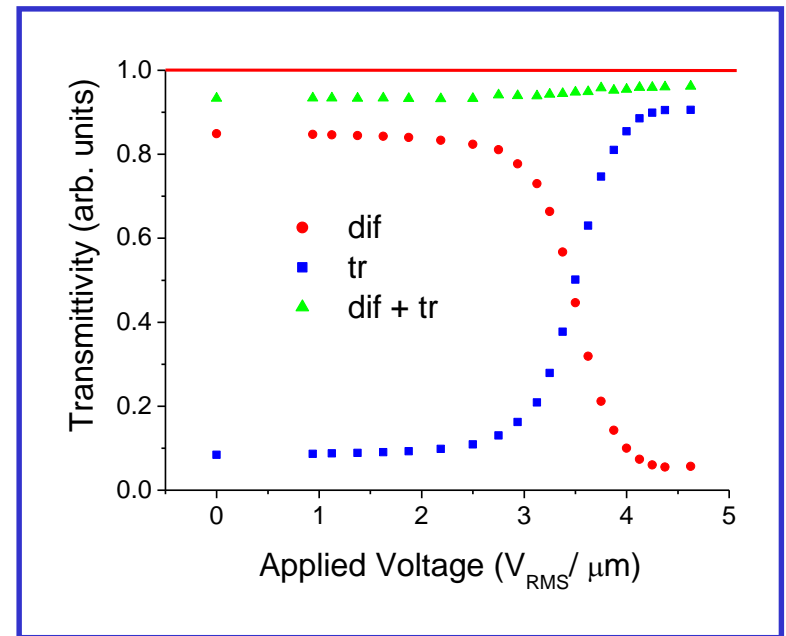
Electro-optical comparison



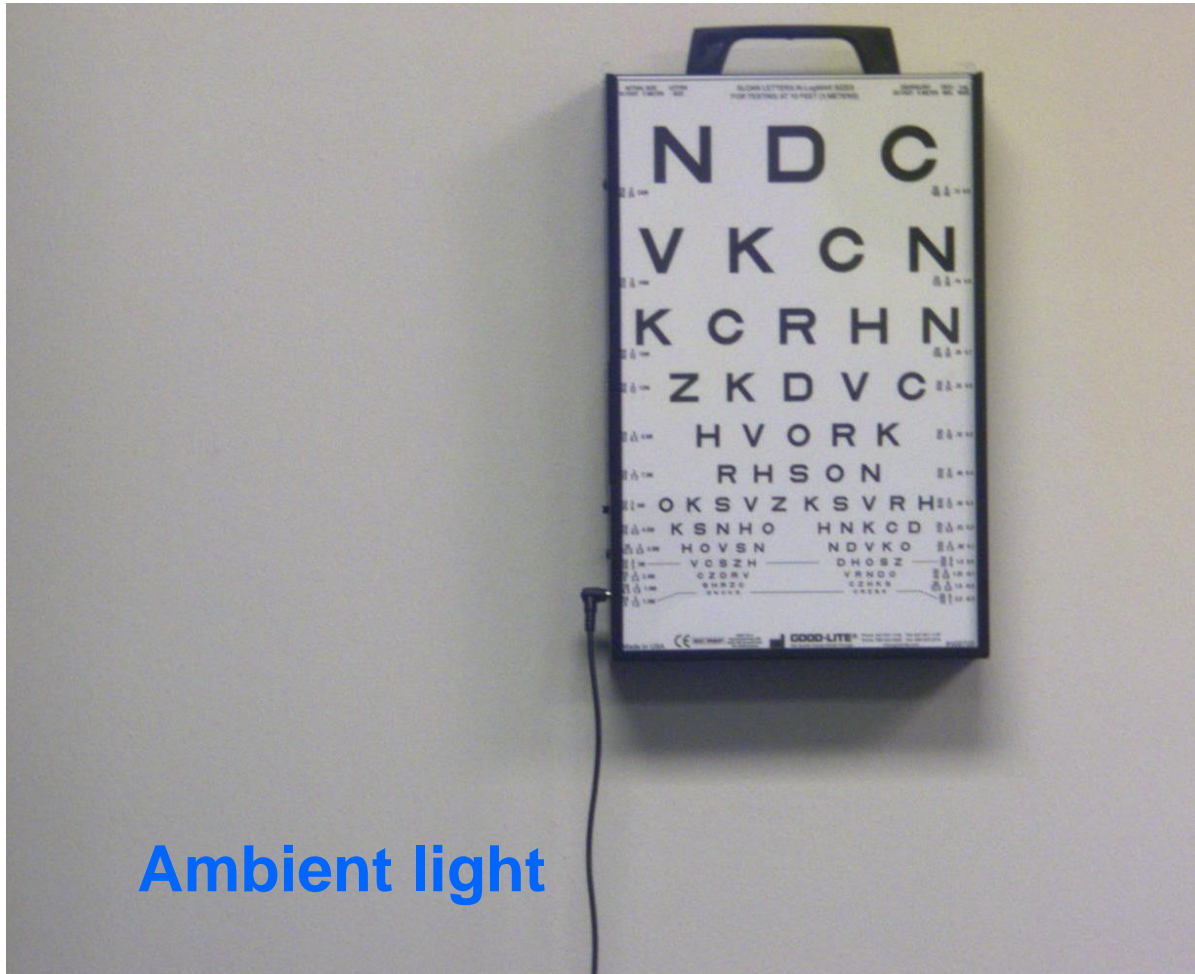
← Irregular polymeric walls



Homogeneous LC Film in nematic phase
Sharp morphology

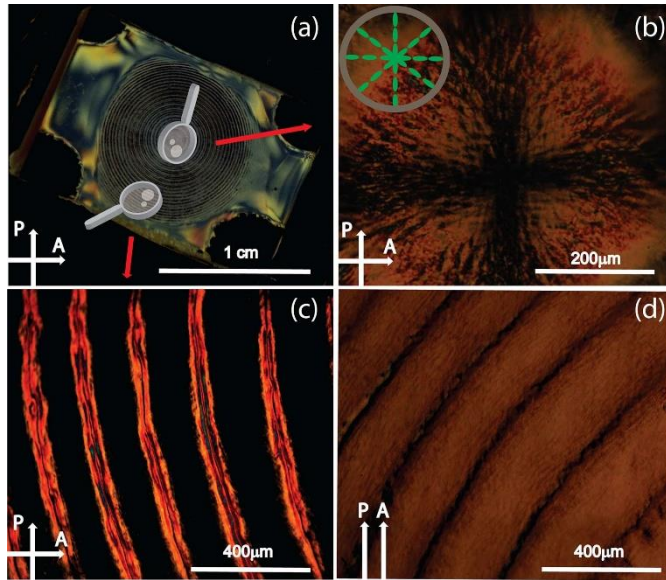


Looking through a POLICRYPS

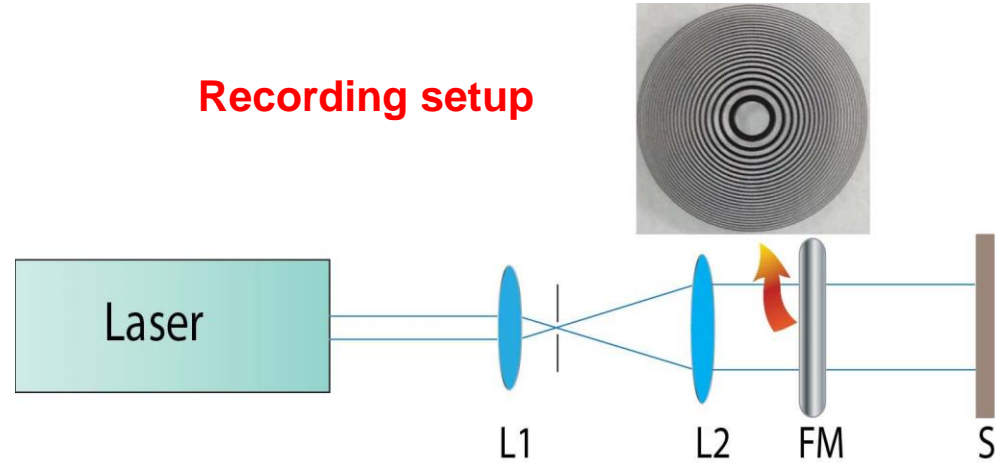


Ambient light

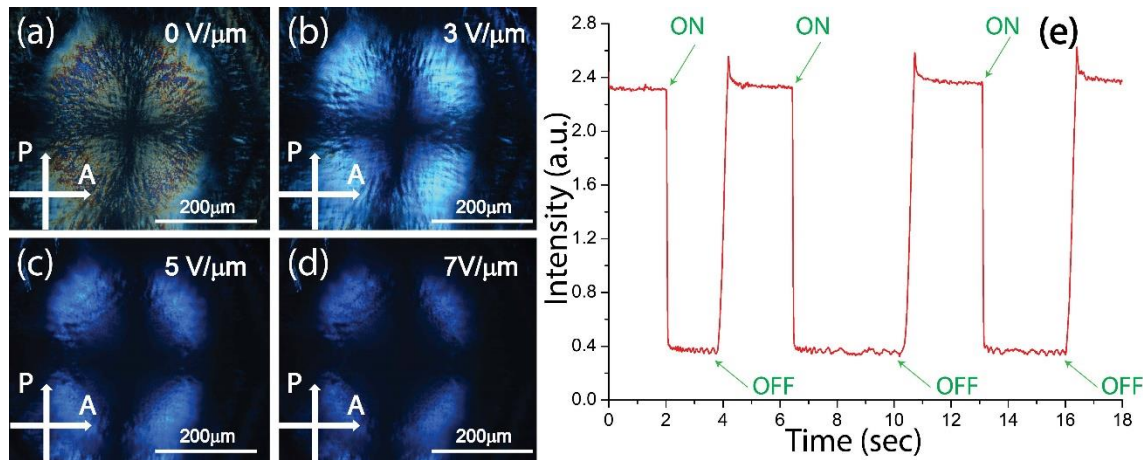
Radial liquid crystals alignment on curved polymeric surfaces



Recording setup



Electro-optical response



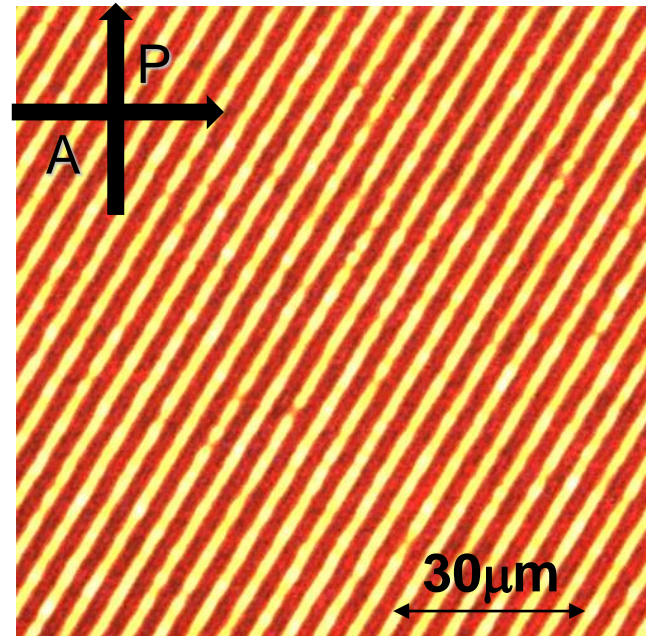
L. De Sio, N. Tabiryan, T. Bunning *Applied Physics Letters* **2014**, 104 (22), 221112.

Different Materials

- Cholesteric LC
- Ferroelectric LC
- Azo LC
-
-

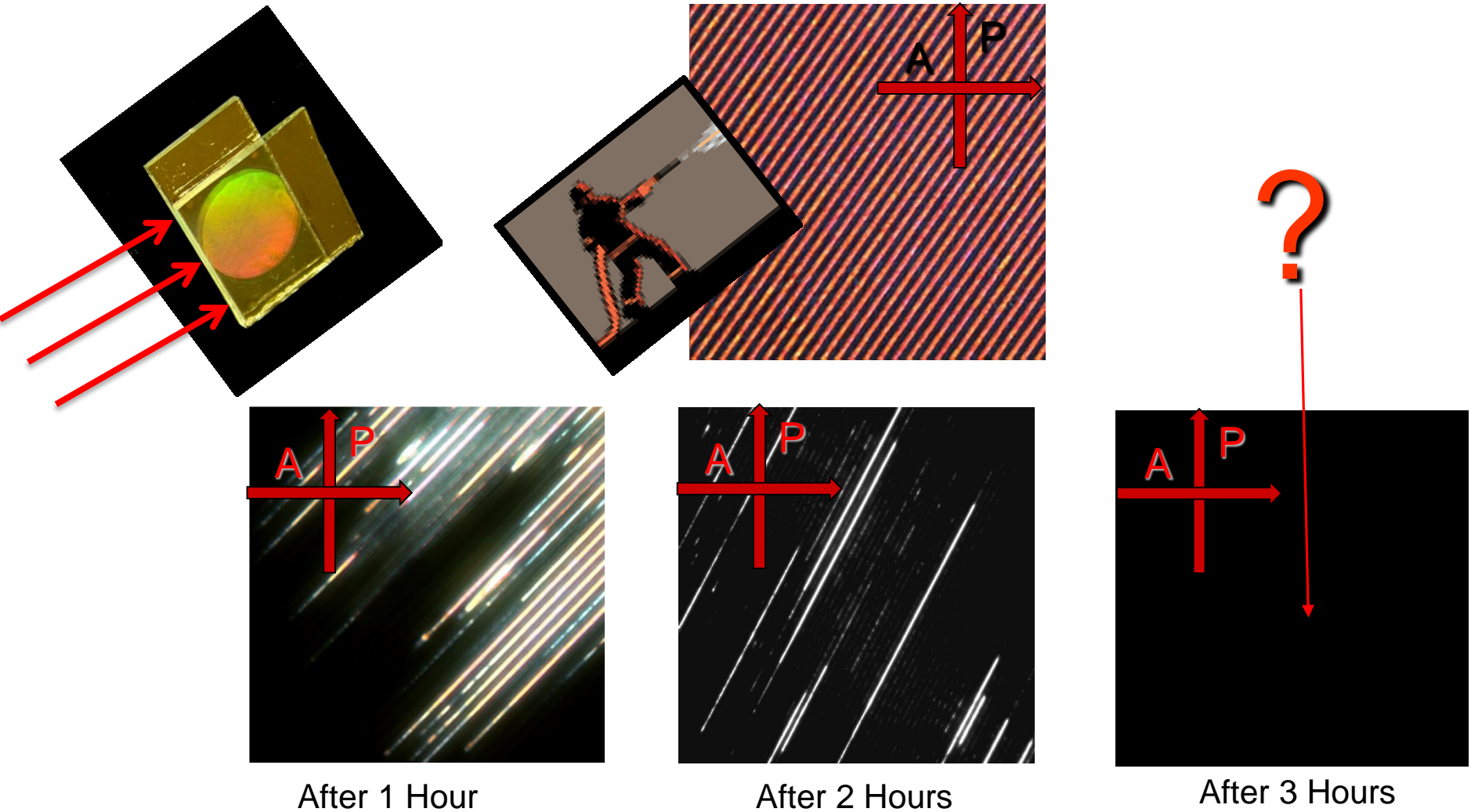


Best Result

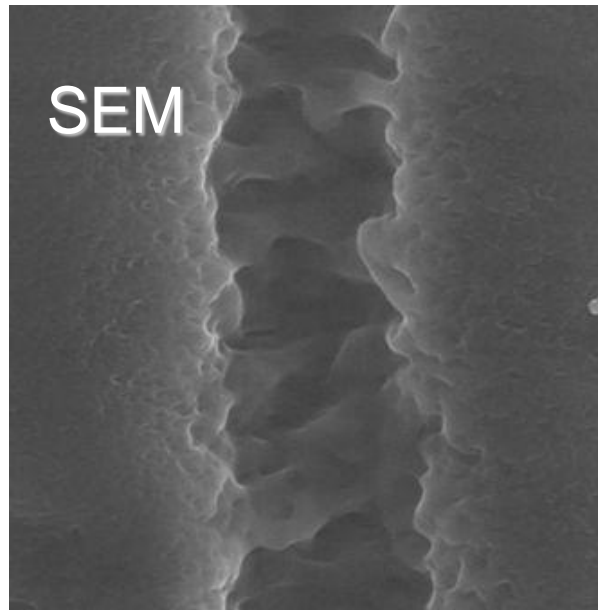
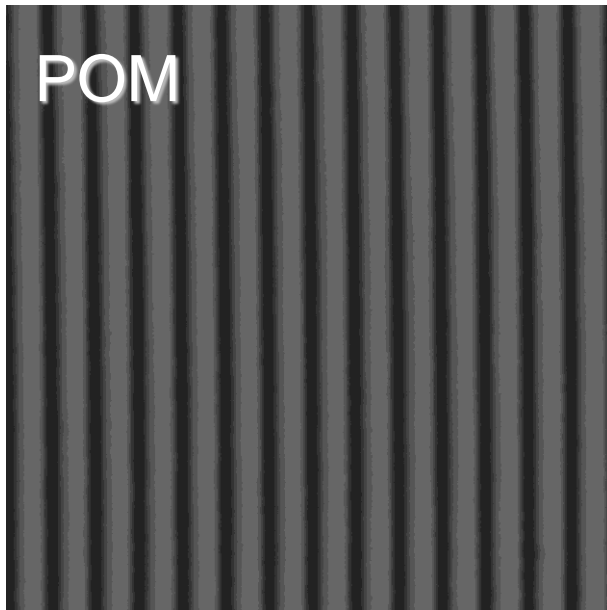


**Single-Step POLICRYPS
(azo-LC)**

Selective Etching Process



Universal template



- LIQUID CRYSTALS
- METAMATERIALS
- PHOTONIC SENSORS
- MAGNETIC DIFFRACTION
- DYE LASERS
- OPTICAL MICROCHANNELS
- WAVEGUIDE ARRAYS
-

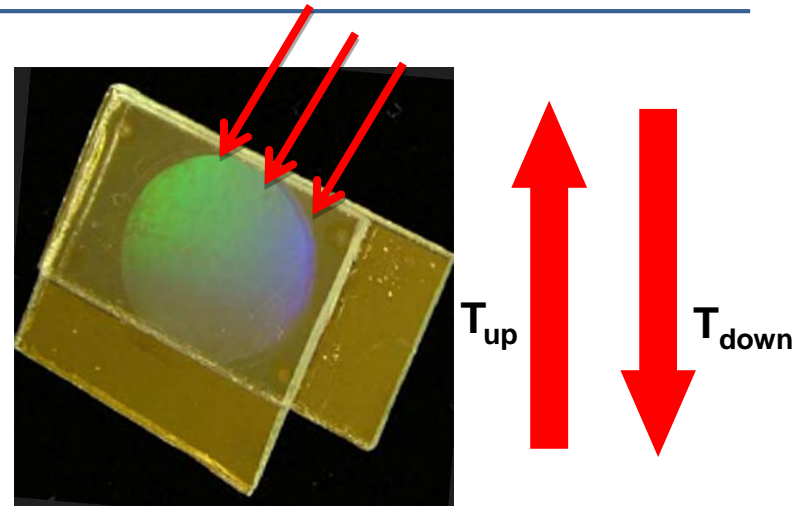
L. De Sio , S. Ferjani, G. Strangi, C. Umeton, R. Bartolino

“Universal Soft Matter Template For Photonic Applications” Soft Matter 7, 3739-3743 (2011)

paper selected in the top five hot-articles

Template Assisted Method

1. The periodic structure is filled by capillary force in isotropic phase
2. After the filling process the system is cooled down at room temperature by using a rate of 0.5 deg/min

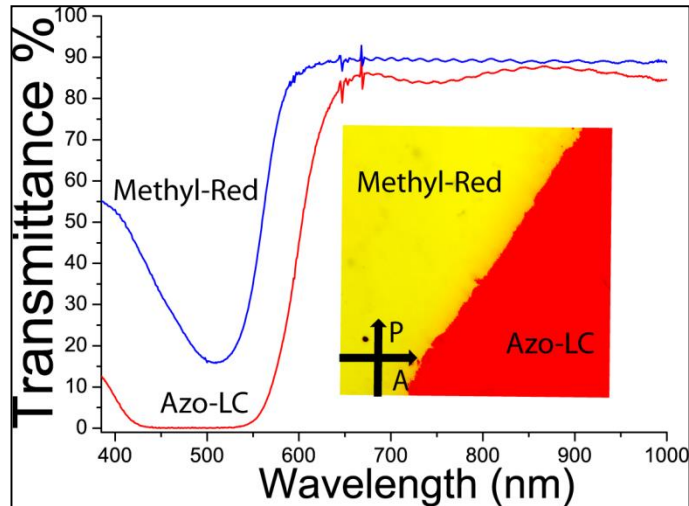


LC PHASES

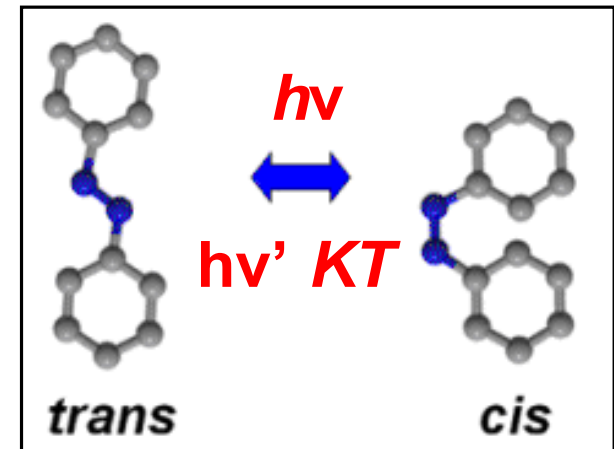
- 1) Nematics for grating purposes
- 2) Cholesterics for optical activity features
- 3) Chiral smectics for ferroelectric fast switching
- 4) 2-D composite matrices for photonics

All-Optical diffraction gratings

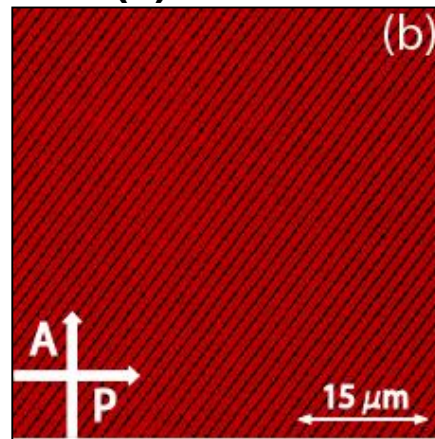
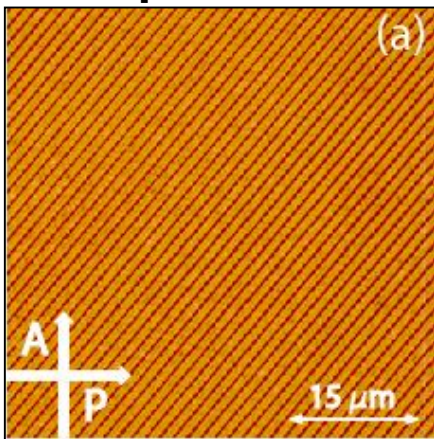
Visible spectrum of CPND-57 azo-LC (red curve) and Methyl-Red (blue curve)



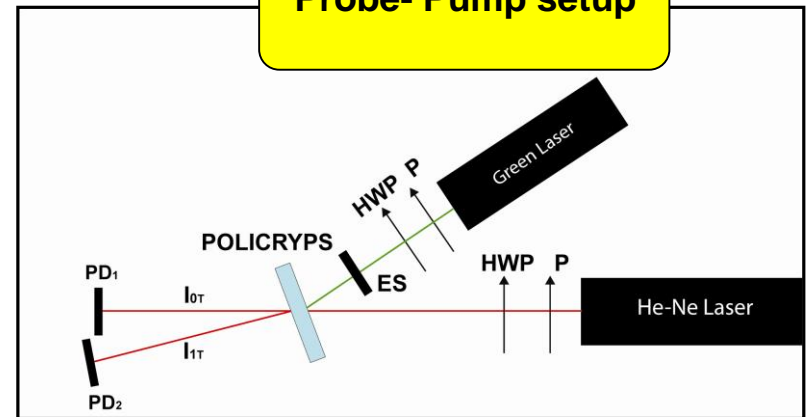
Photoisomerization process



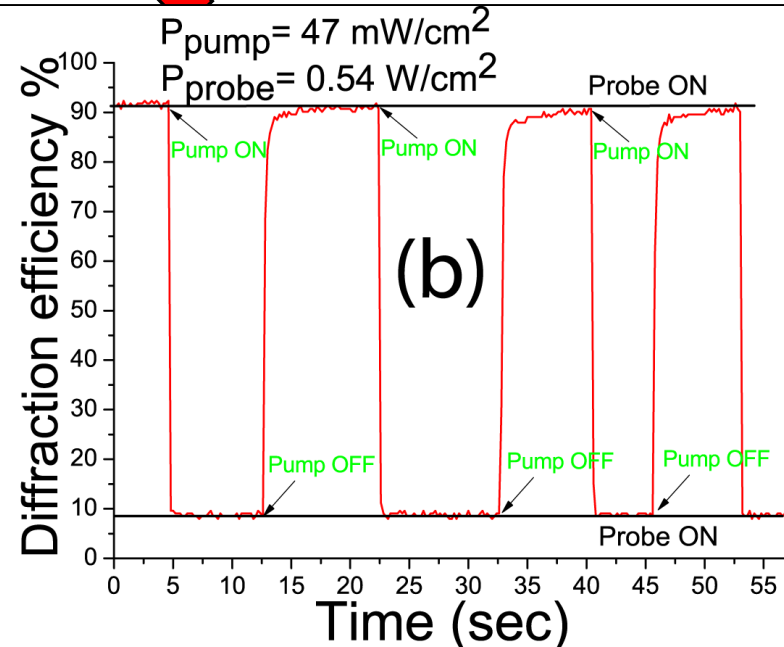
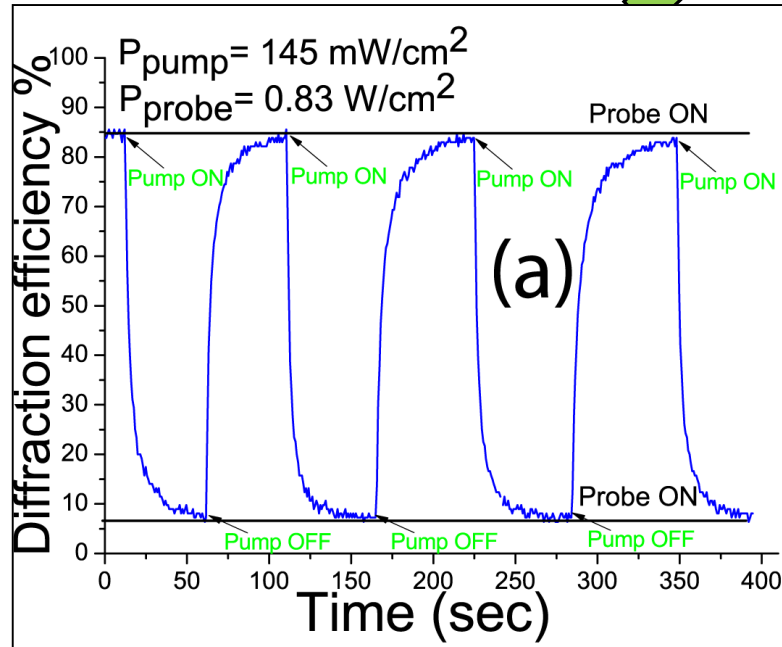
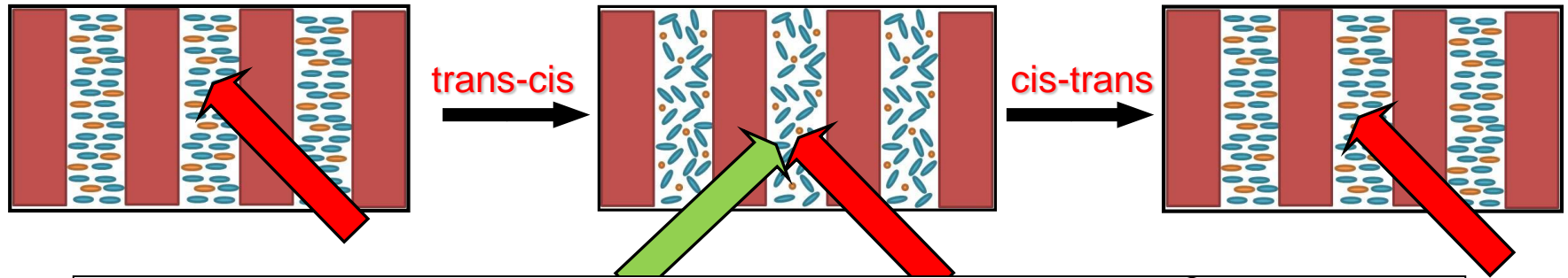
Templates filled with MR (a) and azo-LC (b)



Probe- Pump setup



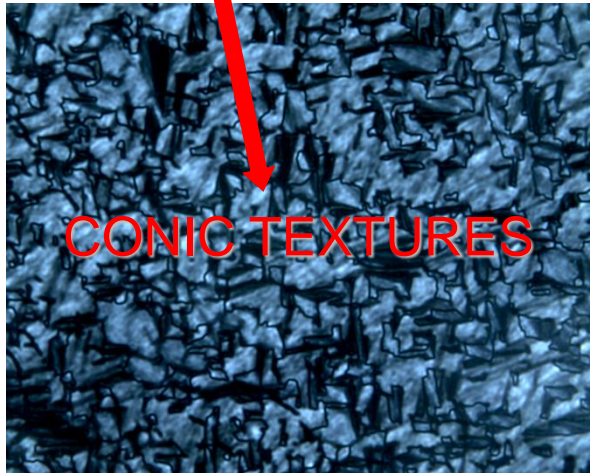
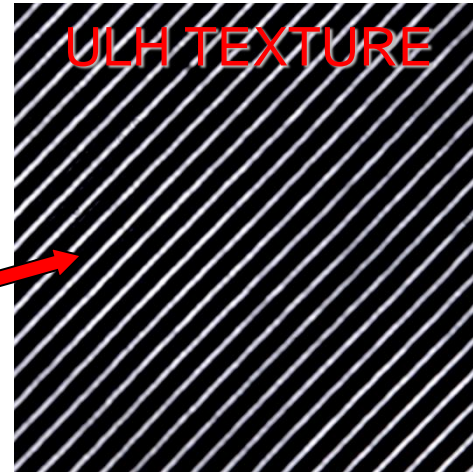
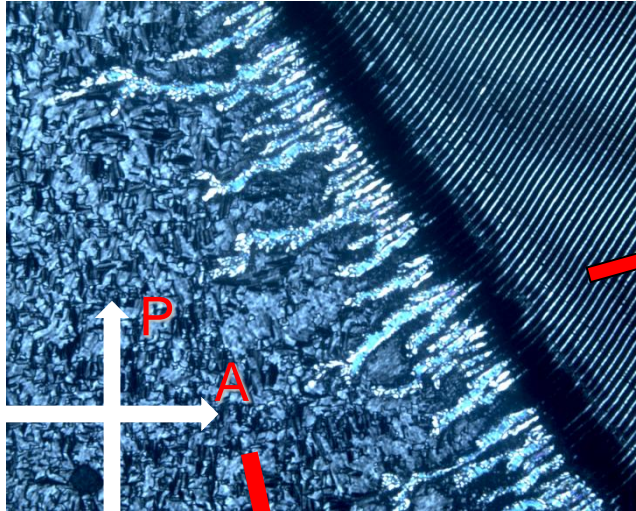
Control of diffracted light by using light



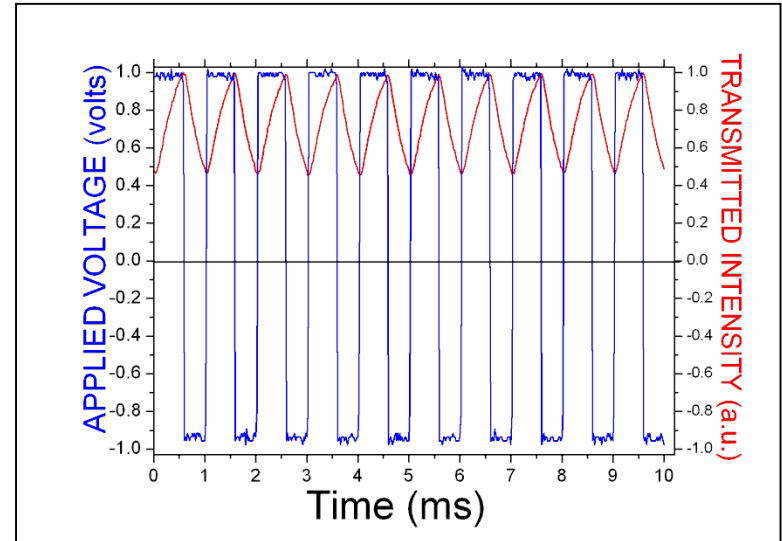
Comparison between the reversible and repeatable changes of the diffraction efficiency of the MR based sample (a) and azo-LC based sample (b)

Uniform Lying Helix (ULH) Alignment

SHORT PITCH CLC (BLO94)



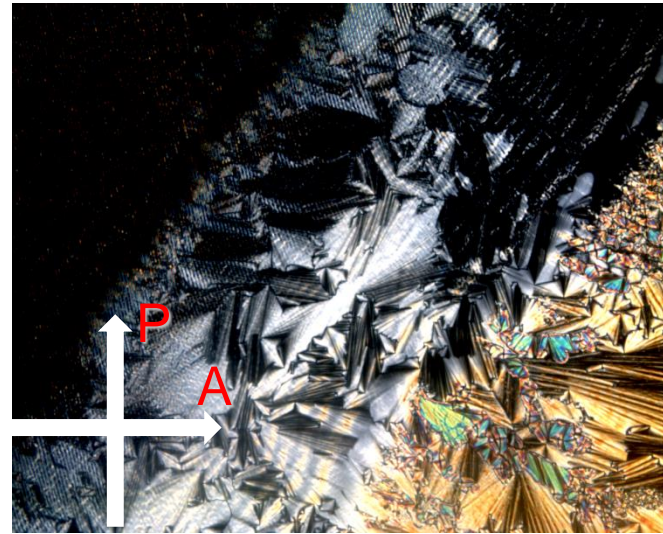
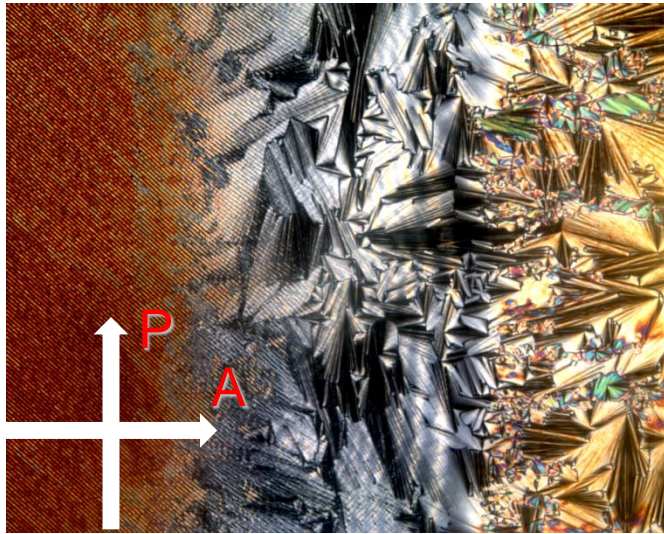
Helical Flexoelectro-Optic Effect



POLYMER WALLS INDUCED SSFLC

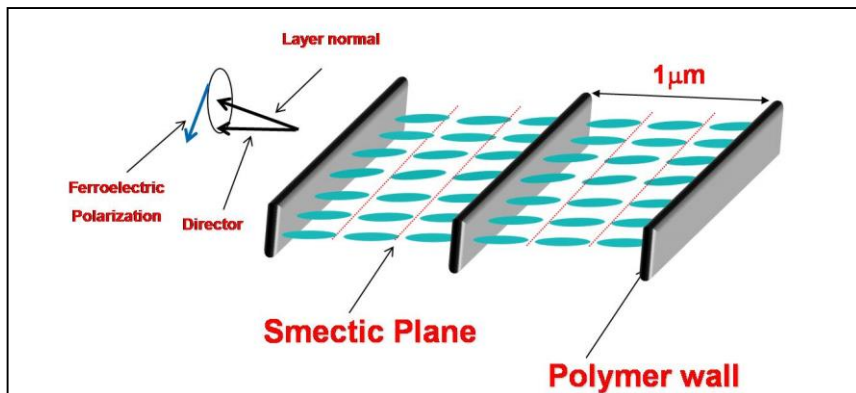
Clark and Lagerwall, 1980

SSFLC (surface-stabilized ferroelectric liquid crystals), CS1024

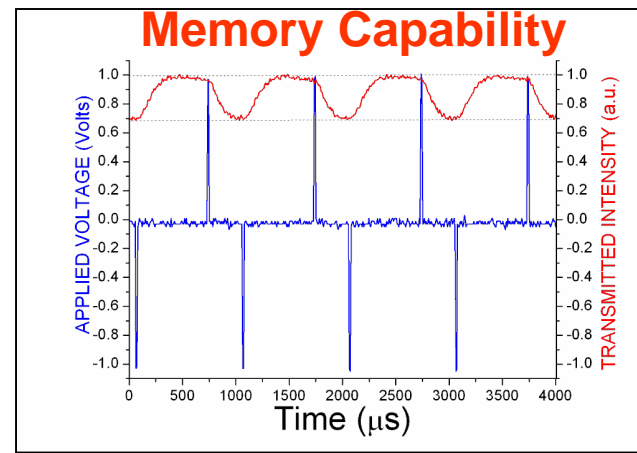


$\Lambda = 3 \mu\text{m}$

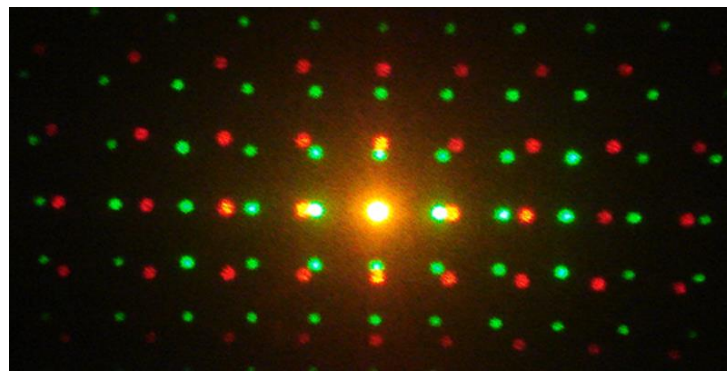
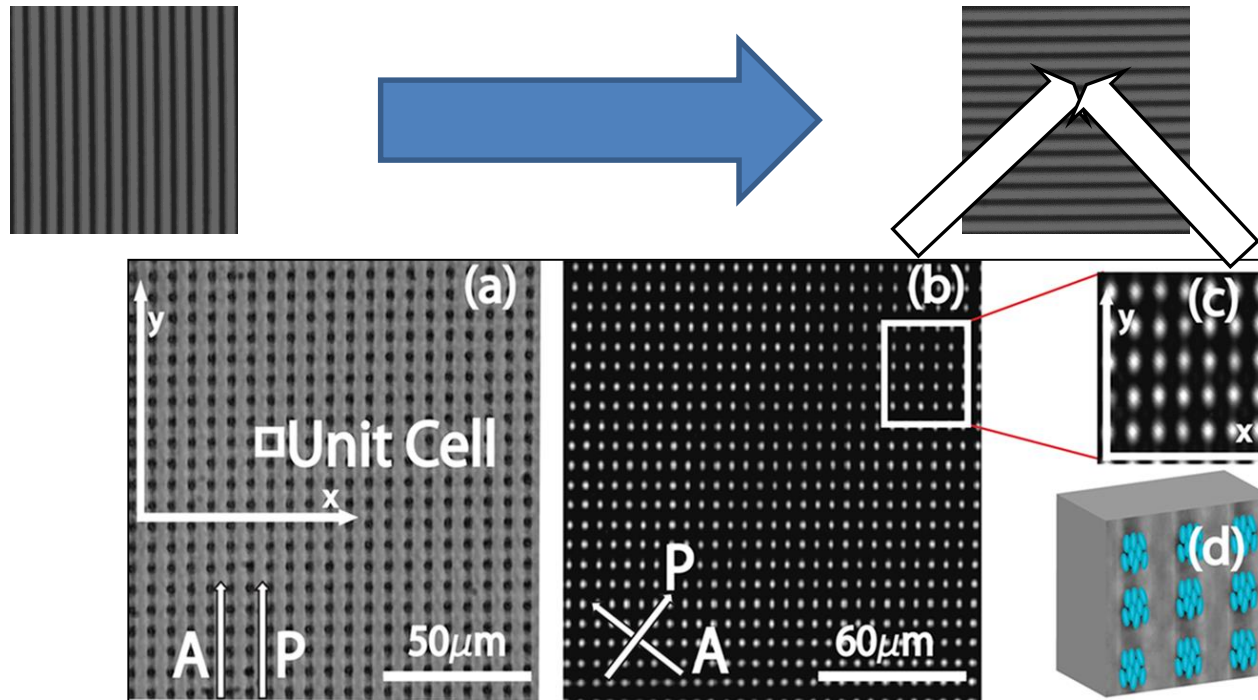
$L = 10 \mu\text{m}$



SSFLC Geometry inside the template



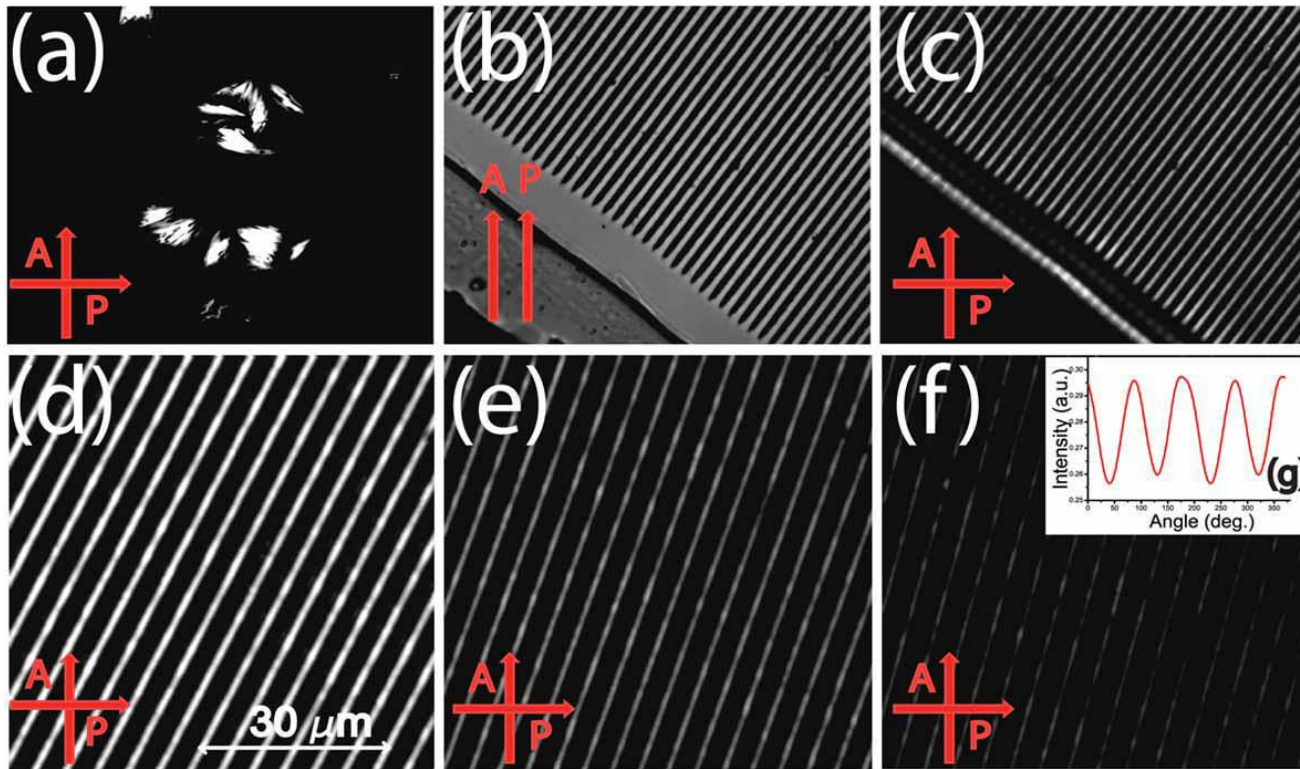
2D PERIODIC STRUCTURES



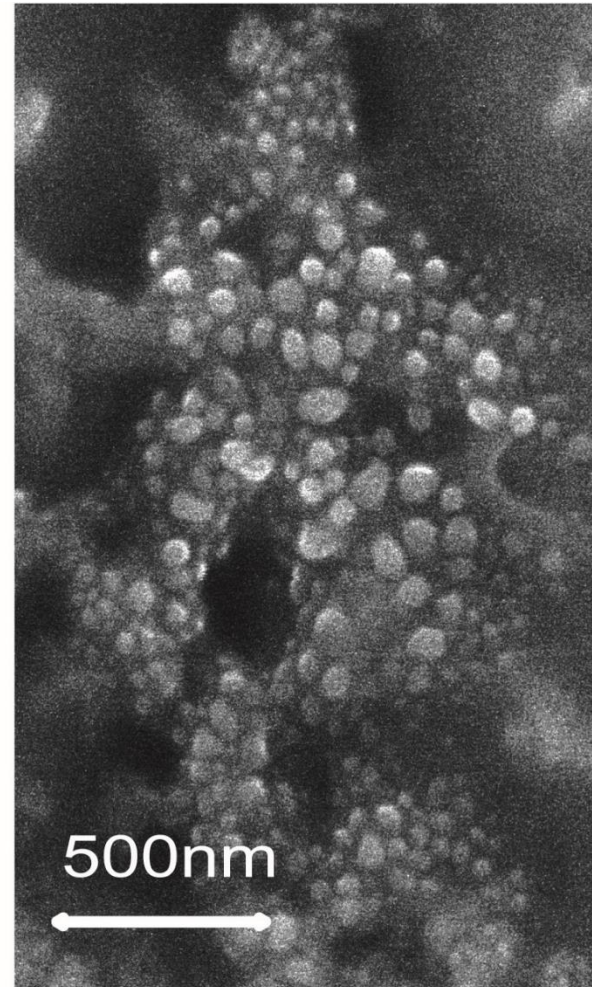
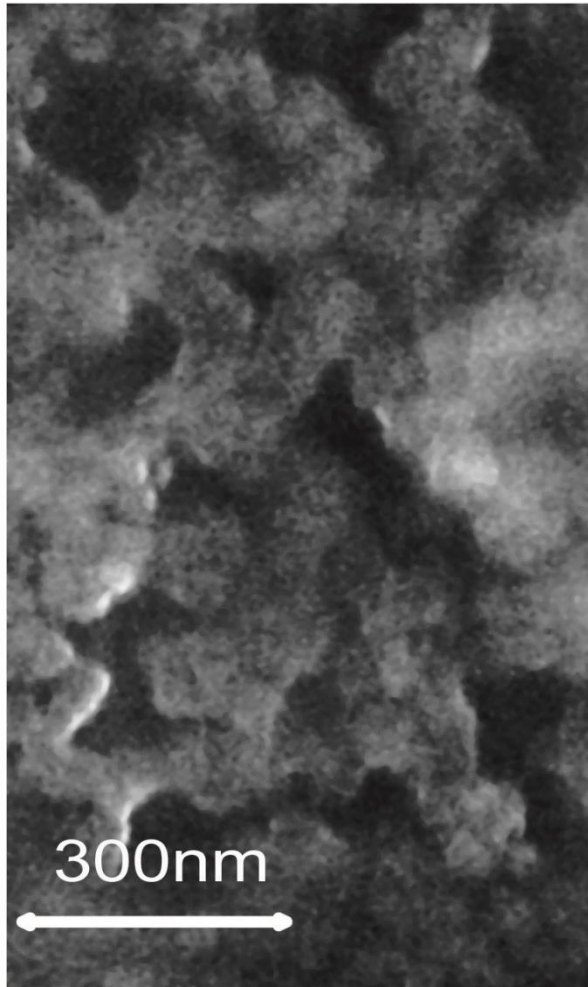
Far field diffraction pattern

Human Genomic DNA

By capillary flow, we have injected a genomic DNA solution into the micro-channels of the polymeric template



Human Genomic DNA



Plasmonic nanomaterials

Metallic (Au, Ag, etc) nanoparticles (NPs) are used as building blocks for realizing new generation of nanomaterials

Localized Surface Polariton Resonance

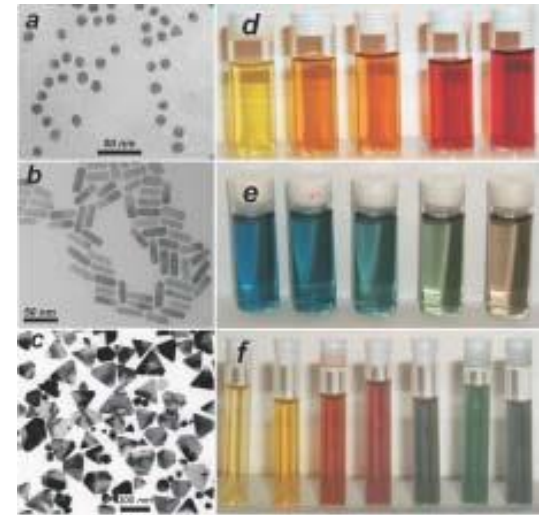
Color variations arising from changes in the composition, size, and shape of nanoparticles →

Mie Theory:

Extinction coefficient

$$\sigma_{ext}(\omega) = 9 \frac{\omega}{c} \varepsilon_m^{3/2} V_0 \frac{\varepsilon_2(\omega)}{\left[\varepsilon_1(\omega) + 2\varepsilon_m \right]^2 + \varepsilon_2(\omega)^2}$$

Dielectric function of the medium surrounding the metallic nanoparticles



L.M. Liz-Marzan, Mater. Today 2004, 7, 26-31.

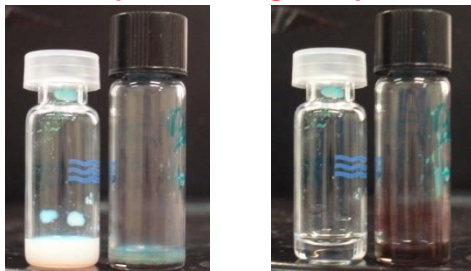
Liquid Crystal as active dielectric medium

Universal Soft Matter Template

Mixture

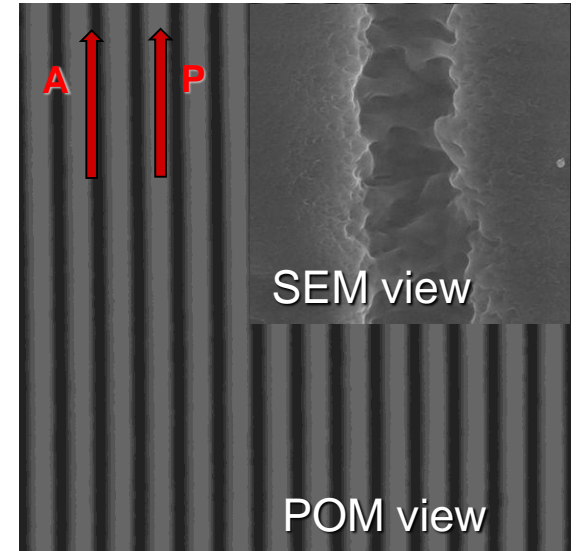
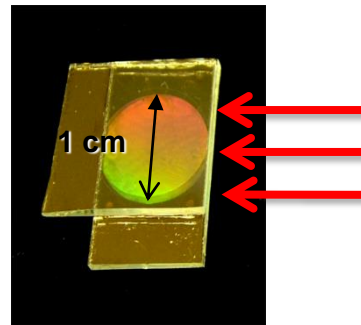
Harima Gold nanopaste NPG-J (20 %)
BL098 CLC by Merck (helix pitch ~ 400 nm)

Room temperature High temperature ($\sim 90^\circ \text{C}$)



CLC

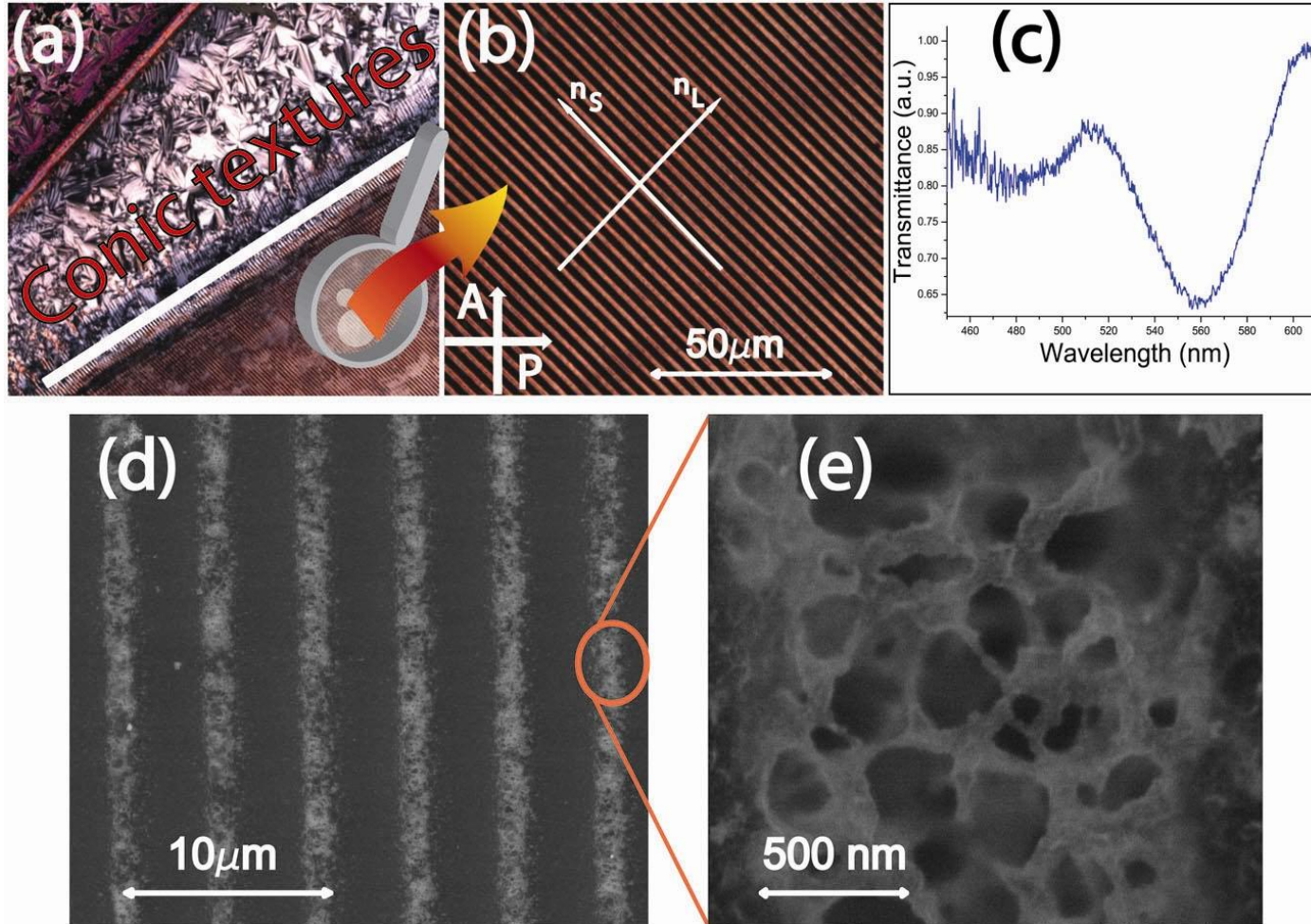
CLC + NPG- J



1. The empty periodic structure is filled by capillary force in isotropic phase (90°C)
2. After the filling process the system is cooled down at room temperature by using a rate of 0.5 deg/min

TOWARDS METAMATERIALS

Top-Down Helps / Meets Bottom-Up

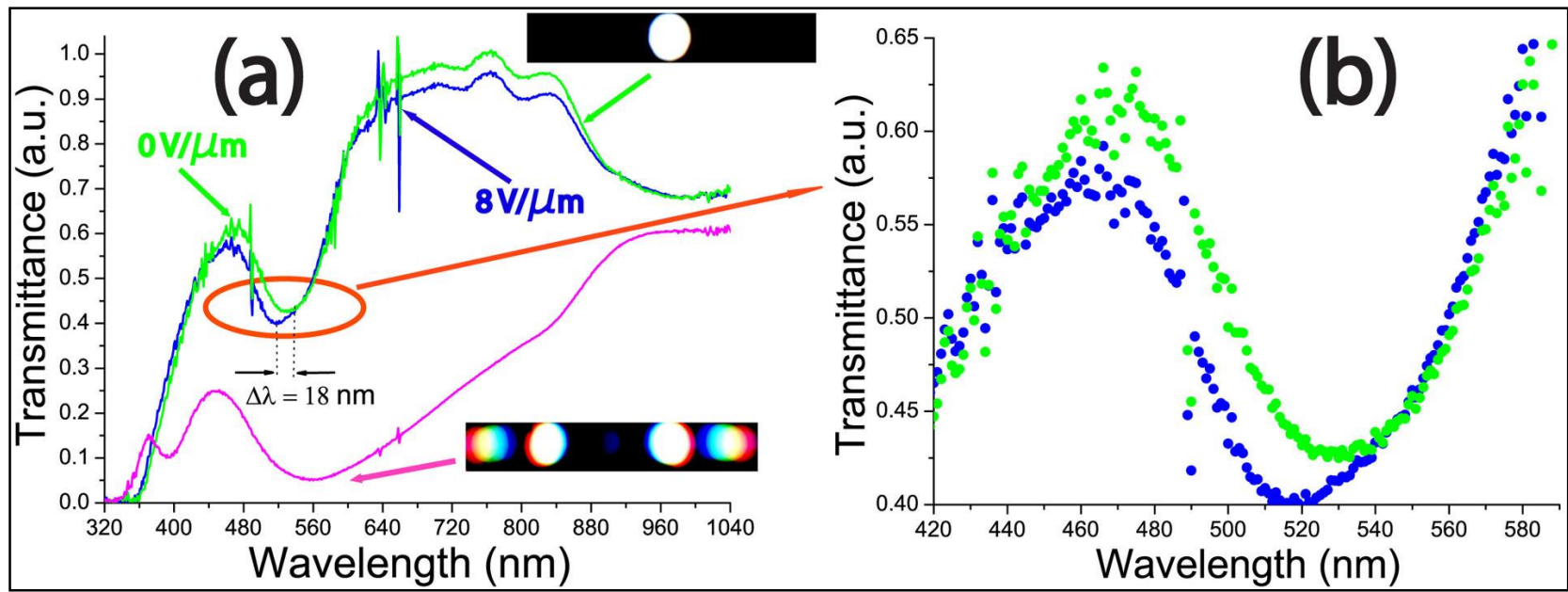
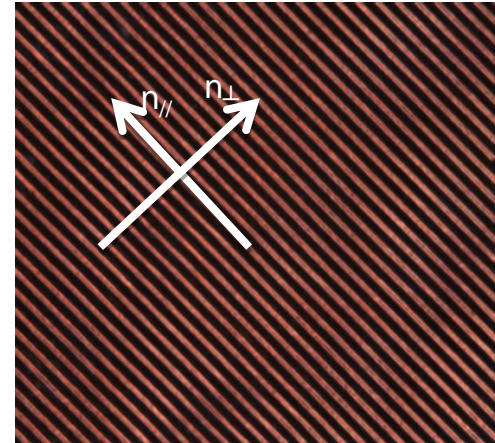


Spectral response of the sample to external electric field

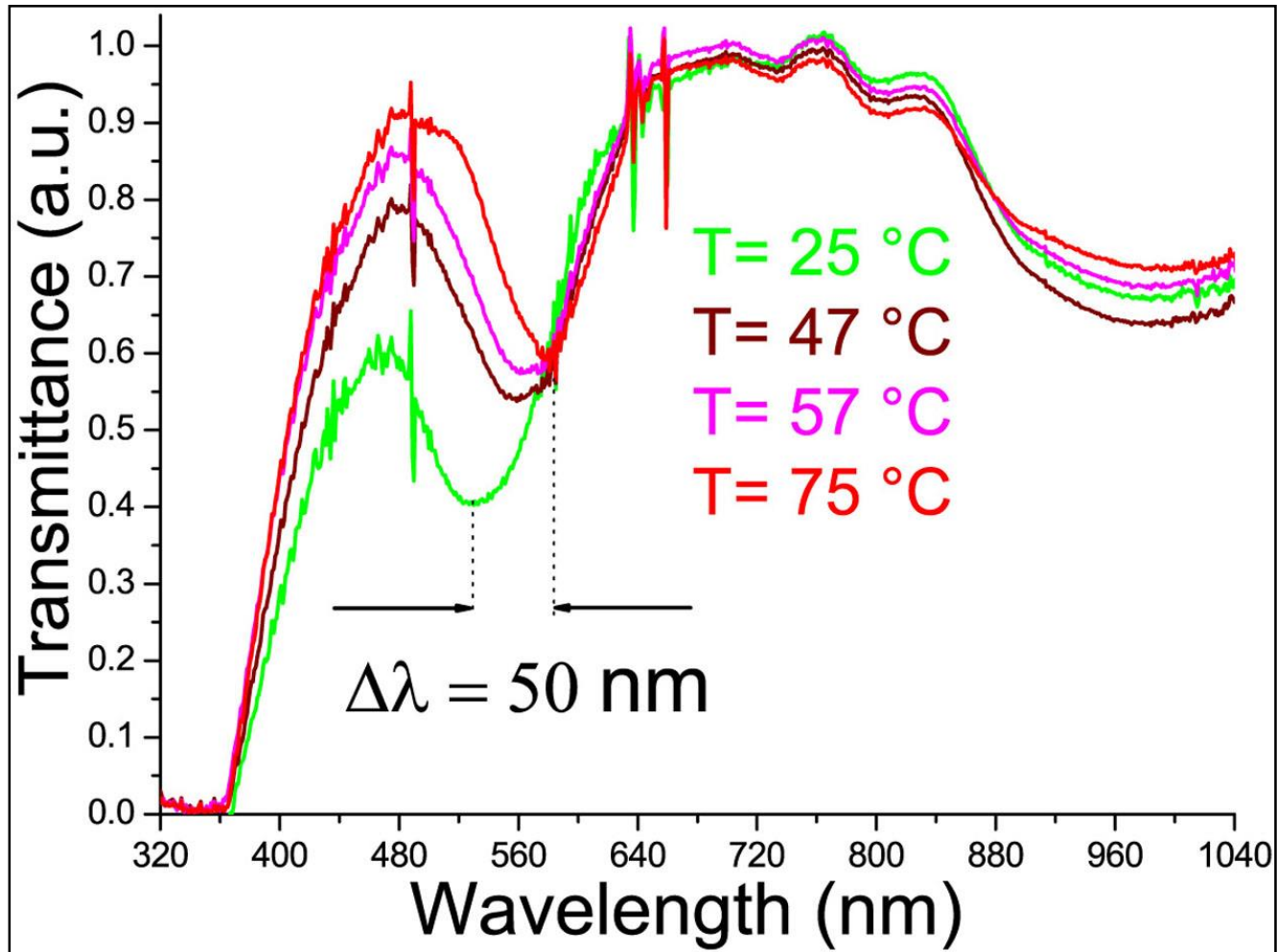
Δn (grating index contrast)

P-polarization: $\Delta n = n_{\perp} - n_p \approx 1.64 - 1.54 = 0.1$

S-polarization: $\Delta n = n_{\parallel} - n_p \approx 1.56 - 1.54 = 0.02$



Spectral response of the sample to temperature variation



Conclusion

- ✓ POLICRYPS: OPTICAL AND ELECTRO - OPTICAL PROPERTIES
- ✓ POLICRYPS: UNIVERSAL POLYMERIC TEMPLATE

Coworkers

AFRL

➤ Dr. Timothy Bunning

BEAM Co.

➤ Dr. Nelson Tabiryan

UNICAL

➤ Prof. Roberto Bartolino

➤ Prof. Cesare Umeton

➤ Dr. Roberto Caputo



WE SOLVE EXTRAORDINARY PROBLEMS IN OPTICS