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

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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

Drawbacks
- Scattering
- High switching voltage


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

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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

POlymer LIquid CRYstal Polymer Slides
Stability problems during curing
Stability problems during curing

Unstable setup

Irregular morphology
High switching voltages
High response time

Possible solutions

Passive setup
Active setup

PID system

Ar+ Laser
M
BE
BS
2\lambda_c\text{ur}
PD 2
PD 1

THORLABS 3-AXIS PIZZO CONTROLLER MODEL
MDT 693
EXT
EXT
EXT
INT
INT
INT
ENABLE
POWER
X-AXIS Y-AXIS Z-AXIS
MASTER SCAN

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Passive setup

- **without stabilization**
  - Graph showing fluctuations in $\phi_{\exp}(\text{deg})$ over time (sec.)
  - Stabilization required to reduce variability

- **with stabilization**
  - Graph showing reduced fluctuations in $\phi_{\exp}(\text{deg})$ over time (sec.)
  - Stabilization yields more consistent readings

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Active setup

Experimentals Results

Without thermo-acoustic isolation

POLICRYPS: the recipe

Heating

Photo-polymerization process

Diffusion process

UV curing

homogeneous mixture

Nematic molecule
Monomer molecule
Polymer molecule

POLICRYPS grating

Cooling

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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**

- **Homogeneous LC Film in nematic phase**
  - Sharp morphology

- **Irregular polymeric walls**

### Transmittivity vs. Applied Voltage

**Graph 1:**
- **Y-axis:** Transmittivity (arb. units)
- **X-axis:** Applied Voltage (V_{RMS}/\mu m)
- **Markers:**
  - Red: dif
  - Blue: tr
  - Green: dif + tr

**Graph 2:**
- **Y-axis:** Transmittivity (arb. units)
- **X-axis:** Applied Voltage (V_{RMS}/\mu m)
- **Markers:**
  - Red: dif
  - Blue: tr
  - Green: dif + tr
Looking through a POLICRYPS

Ambient light
Radial liquid crystals alignment on curved polymeric surfaces

Recording setup

Different Materials

- Cholesteric LC
- Ferroelectric LC
- Azo LC

Best Result

Single-Step POLICRYPS (azo-LC)

30μm

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Selective Etching Process

After 1 Hour

After 2 Hours

After 3 Hours
Universal template

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

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)

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

Photoisomerization process

$hv \rightarrow hv' KT$

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)

ULH TEXTURE

Helical Flexoelectro-Optic Effect

CONIC TEXTURES

G. Carbone et al., APL, 95, 011102 (2009)
POLYMER WALLS INDUCED SSFLC

Clark and Lagerwall, 1980
SSFLC (surface-stabilized ferroelectric liquid crystals), CS1024

\[ \Lambda = 3 \mu m \]
\[ L = 10 \mu m \]

Memory Capability

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

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

Dielectric function of the medium surrounding the metallic nanoparticles

Liquid Crystal as active dielectric medium


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### Mixture

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

<table>
<thead>
<tr>
<th>Room temperature</th>
<th>High temperature (~ 90 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLC</td>
<td>CLC + NPG-J</td>
</tr>
</tbody>
</table>

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

(a) Conic textures

(b) $n_S$ $n_L$

50$\mu$m

(c) Transmittance (a.u.)

Wavelength (nm)

(d) 10$\mu$m

(e) 500 nm

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Spectral response of the sample to external electric field

\[ \Delta n \text{ (grating index contrast)} \]

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

![Graph showing transmittance vs wavelength for different temperatures (T=25°C, T=47°C, T=57°C, T=75°C). The wavelength range is 320-1040 nm with a λ change of 50 nm.]
Conclusion

✓ POLICRYPS: OPTICAL AND ELECTRO - OPTICAL PROPERTIES

✓ POLICRYPS: UNIVERSAL POLYMERIC TEMPLATE
Coworkers

AFRL
- Dr. Timothy Bunning

UNICAL
- Prof. Roberto Bartolino
- Prof. Cesare Umeton
- Dr. Roberto Caputo

BEAM Co.
- Dr. Nelson Tabiryan

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