Exploring Motion Reversal in Polymer Cholesteric Liquid Crystal Devices

University of Rochester
Laboratory for Laser Energetics

SPIE Optics and Photonics 2006
San Diego, CA
13–17 August 2006
Outline

- Introduction
  - polymer cholesteric-liquid-crystal flakes
  - devices

- Flake relaxation
  - accelerating with a designer waveform
  - preventing with a holding voltage

- Future work and applications

- Summary
Summary

New driving techniques are allowing better control of PCLC-flake motion and device characteristics.

- Environmentally and physically robust particles with unique wavelength- and polarization-specific optical properties.

- Current reorientation times are of the order of several hundred milliseconds with drive voltages as low as tens of millivolts/μm.

- Motion reversal can be achieved with specifically designed waveforms.

- A holding voltage can be applied to minimize power consumption.

- Improved motion control will expand the potential applications for PCLC-flake technology.
Selective reflection in PCLC flakes is a Bragg-like effect.

\[
\lambda_0 = n_{\text{avg}} p \left\{ \cos \frac{1}{2} \left[ \sin^{-1} \left( \frac{1}{n_{\text{avg}}} \sin \varphi_i \right) + \sin^{-1} \left( \frac{1}{n_{\text{avg}}} \sin \varphi_s \right) \right] \right\}
\]

- Reflected light is inherently \textit{circularly polarized}.
- Broadband selective reflection is possible in systems with a pitch gradient.
When suspended in an appropriate fluid host, PCLC flakes can be readily reoriented with an electric field.

- Interfacial polarization induces a dipole moment, causing flakes to rotate 90°.
- Bright selective reflection is shifted and diminished when flakes rotate.
- Optimal flake dimensions
  - length: 40 to 60 μm
  - aspect ratio: 3:1
  - thickness: 3 to 5 μm

Removal of the driving field allows PCLC flakes to relax to their original highly reflective orientation.

- PCLC-flake relaxation rate depends on
  - flake size and shape
  - host-fluid viscosity
  - difference between specific gravity of flake and host fluid
Optical system for quantifying flake motion by reflected signal magnitude

- Occasionally a CCD camera replaced the PMT and the total image intensity quantified the test-device brightness.

Viewing: normal to cell plane

*Polarizing white-light microscope in reflection, typically at 100×.
Waveforms with various pulse shapes and lengths were applied to accelerated PCLC-flake relaxation.

- The polarity of the pulse did not influence results.
- The square pulse returned the device to maximum brightness most quickly.
- The short response times for pulse lengths <1.5 s are deceiving because most flakes do not have time to respond and device reflectivity is low.
The trailing edge of square pulses causes PCLC flakes to jolt back into motion, decreasing device brightness.

- A sharp leading edge causes flakes to respond more quickly.
- A gradual trailing edge prevents flakes from adversely responding to the end of the pulse.
A combination of a sharp leading edge and a gradual trailing edge produced optimal results.

- Sawtooth pulses caused flakes to respond the most quickly and returned the device to the highest brightness.

<table>
<thead>
<tr>
<th>Pulse Shape</th>
<th>Time to Fully Respond*</th>
<th>% Return to Reflectivity*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Square</td>
<td>0.64 s</td>
<td>56%</td>
</tr>
<tr>
<td>Triangle</td>
<td>1.22 s</td>
<td>65%</td>
</tr>
<tr>
<td>Sine</td>
<td>1.26 s</td>
<td>77%</td>
</tr>
<tr>
<td>Sawtooth</td>
<td>0.62 s</td>
<td>77%</td>
</tr>
</tbody>
</table>

*Average of 1.5-s and 2-s pulses
The driving voltage affected how well the devices returned to their reflective state.

- The highest drive voltage caused flakes to reorient most quickly and return to the highest level of brightness.

- The 3-V pulse amplitude produced the best results.

- Perhaps higher drive voltages act on or dislodge more ions, making more charge available to throw flakes back into motion and, therefore, return the flakes to a more-reflective position.
An optimized 3-V, 1.5-s sawtooth pulse was used to compare natural and accelerated relaxation.

- Accelerated relaxation occurs within 4 s.
- Natural relaxation requires ~70 s to reach the same brightness level.
- Waiting 8 min to gain the additional brightness would not be useful for most applications.
A holding voltage lower than the drive voltage can prevent flake relaxation while consuming less power.

- <0.2 V: little difference and device regains reflectivity
- 0.25 V–0.35 V: reflectivity returns slowly, but does not reach previous levels
- 0.4 V–0.5 V: few flakes relax so cell remains dark

- The initial intensity starts to decrease due to aging effects, and some flakes do not return to their original position within a reasonable amount of time.
The effectiveness of the holding-voltage is influenced by the frequency

- <80 Hz: many flakes relax and a significant amount of reflectivity is regained.
- >80 Hz: the magnitude of the brightness barely changes from its minimum level.

- 3-Vpp drive voltage
- 0.4-V holding voltage

- Free ions cannot move far at high frequencies; therefore, the induced dipole remains.
Low-aspect-ratio (square) flakes require higher holding voltages to prevent relaxation.

- The area of the flake does not impact flake behavior as much as its shape.

- Aspect ratio = \( \frac{\text{length}}{\text{width}} \)

- Filled marker denotes holding voltage at which point the flake stops relaxing.

- Uniformly shaped flakes with an aspect ratio of 3:1 would allow the use of a lower holding voltage.
The unique properties of PCLC flakes open a host of possible device applications.

- **Information display**
  - Reflective, multicolor-particle displays, flexible displays, 3-D displays, and “electronic paper”

- **Electro-optics and photonics**
  - Switchable/tunable color filters, micropolarizers, modulators with unique polarizing, reflection, and transmission properties

- **Military/Security**
  - Anticounterfeiting, signature reduction, camouflage, “patterned” particles for encoded- and encrypted-information storage.

- **Coatings technology**
  - Switchable “paints” and conformal coatings, switchable “smart windows” for energy or privacy control
Summary/Conclusions

New driving techniques are allowing better control of PCLC-flake motion and device characteristics

- Motion reversal is best achieved with a sawtooth pulse to return devices to a more reflective state by a factor of 15 to 20 times faster.
- A specific pulse amplitude (3 V) is most effective for the entire 2 to 5-V driving-voltage range.
- Holding-voltages less than a third of the driving voltage prevent flakes from relaxing.
- Operating holding voltages at frequencies higher than the drive-voltage frequency produces the best results.
- Lower holding voltages can be used for devices with high-aspect-ratio flakes.

- On-going research topics
  - materials properties and response time; bistability mechanisms
  - layered PCLC flakes (alter dielectric properties and enhance reflectivity)
  - microcapsule size/shape control
Acknowledgment

Laboratory for Laser Energetics
University of Rochester

U.S. Department of Energy
Office of Inertial Confinement Fusion
Cooperative Agreement No. DE-FC52-92SF19460