A Colloidal Approach to Liquid Crystal Transflective Displays: Making Your E-Reader Color

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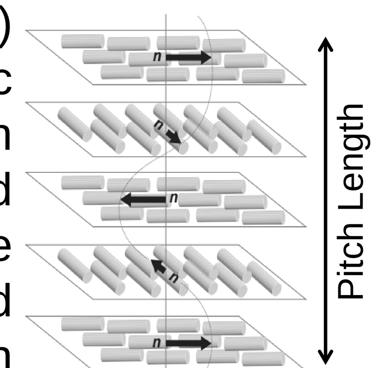
PURDUE MATERIALS ENGINEERING

Cholesteric liquid crystals (CLCs) structurally reflect light and have the potential to allow construction of transflective displays that can switch between transmitting light and selectively reflecting color. The Air Force Research Laboratory (AFRL) is interested in transflective displays as they work in reflected light and therefore have low power requirements. The goal of this project is to work towards creating a powder of CLCs where the flakes are monodisperse, have two aligned boundary conditions, have a thickness of 5 µm, and a length and width on the 10-50 µm size scale. This goal was addressed by attempting to create flakes either through a photopolymerization process or a replica molding method.

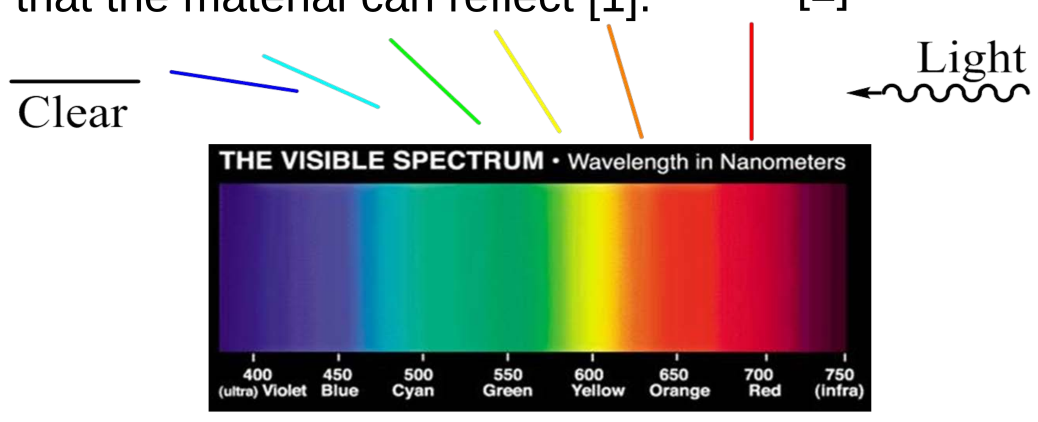
This work is sponsored by the Air Force Research Laboratory (AFRL) located in Dayton, OH

Project Background

Cholesteric Liquid Crystals (CLCs) self-assemble into a chiral nematic liquid crystal mesophase as shown on the right. Pitch length is defined as the length it takes to for the molecules to do a full rotation and represents the longest wavelength that the material can reflect [1].

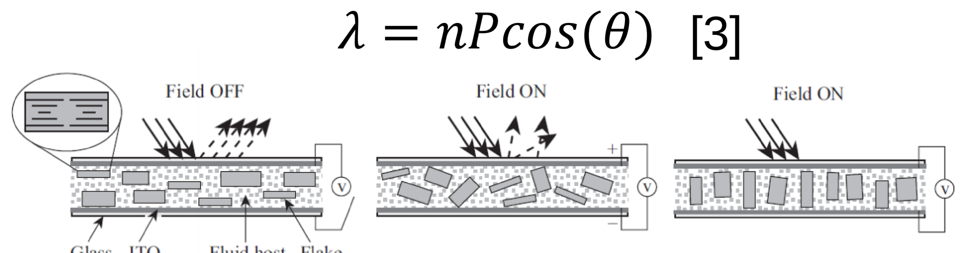


[2]



Bragg mirrors reflect different wavelengths depending on the angle of incident light as shown in the equation below where n is the average refractive index, θ is the incident light angle, P is the pitch, and λ is the wavelength reflected [3]. An illustration of this property is shown above.

$$\lambda = nPcos(\theta) \quad [3]$$

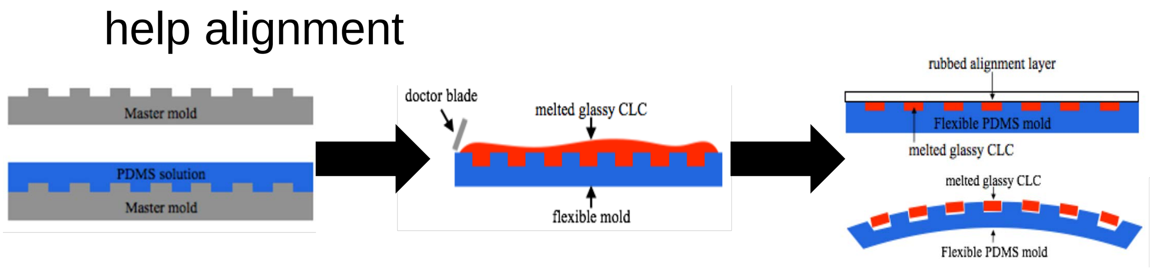


[4]

As illustrated above, CLC flakes can be used to create a device that either reflects color or transmits light based on the angle of rotation [4]. Cutting the backlight in these devices reduces the power consumption for a screen with this technology.

Replica Molding Procedure

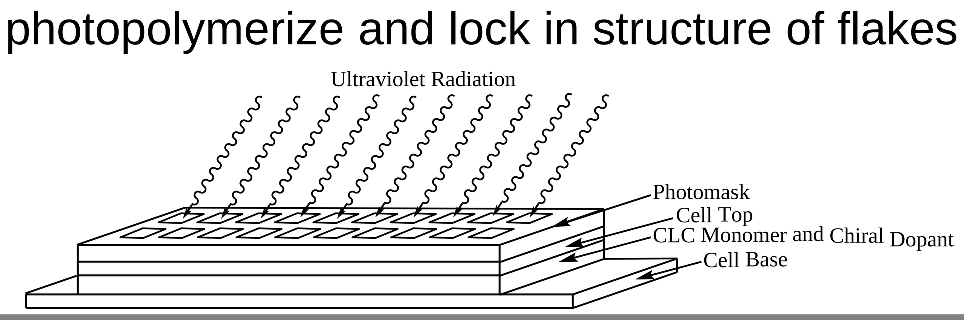
- Create master mold with positive imprint on top
- Cast PDMS onto top of mold to create a negative with wells to form the flakes
- Remove PDMS from master mold
- Fill PDMS mold with a solution of glassy CLC dissolved in toluene. Doctor blade of the excess so that the wells are filled
- Evaporate off the solvent and heat to the isotropic point
- Cover with glass slide and shear as it cools to help alignment



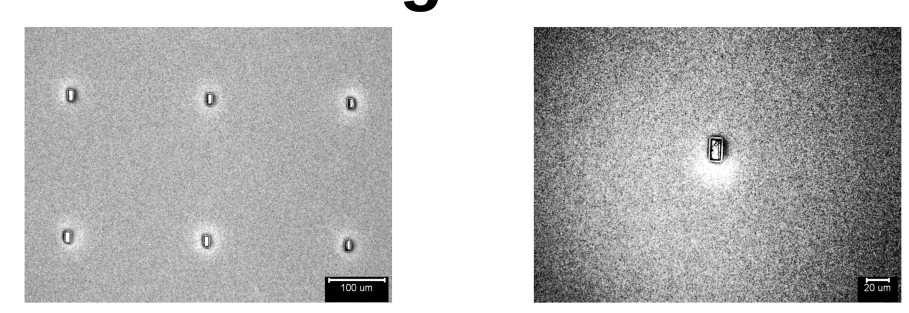
Alignment can be encouraged by either directly rubbing the PDMS mold or adding a felt rubbed polyimide alignment layer.

Photopolymerization Procedure

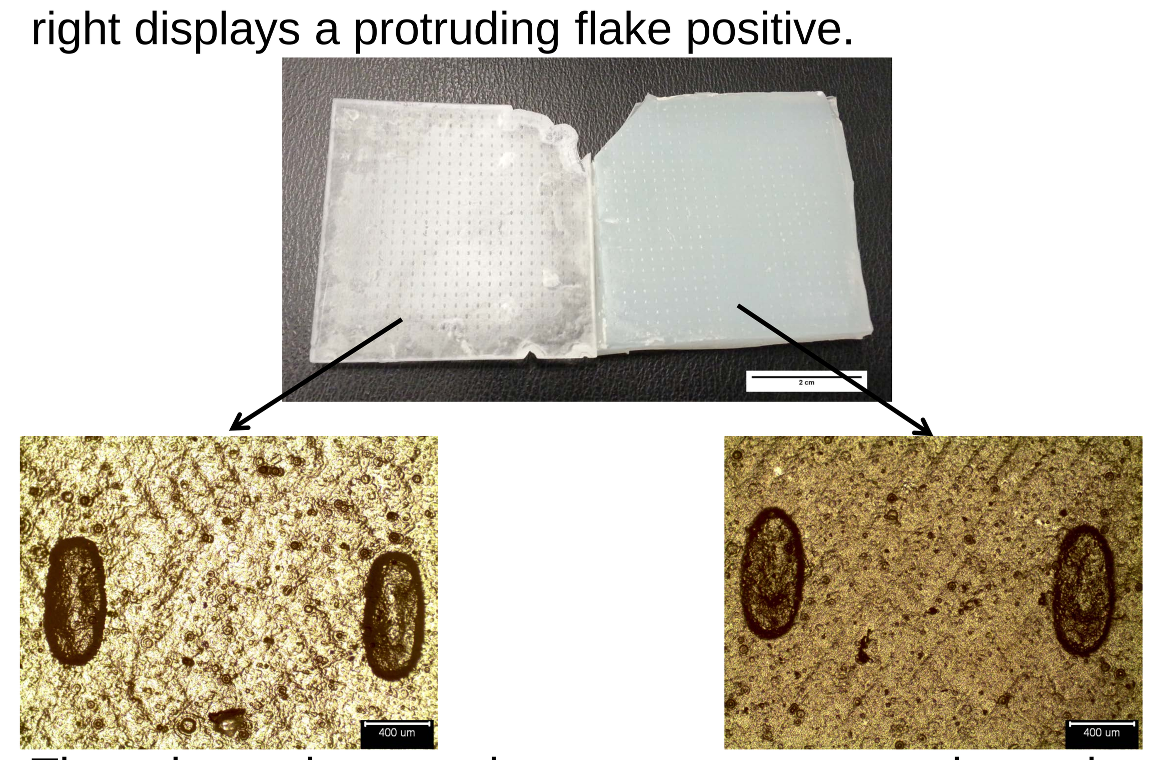
- Batch out monomeric CLC with solvent to dilute the chiral dopant and control pitch (color)
- Heat CLC to isotropic point and infiltrate cells shearing the fluid as it cools down to increase alignment
- Irradiate Sample with UV light to photopolymerize and lock in structure of flakes



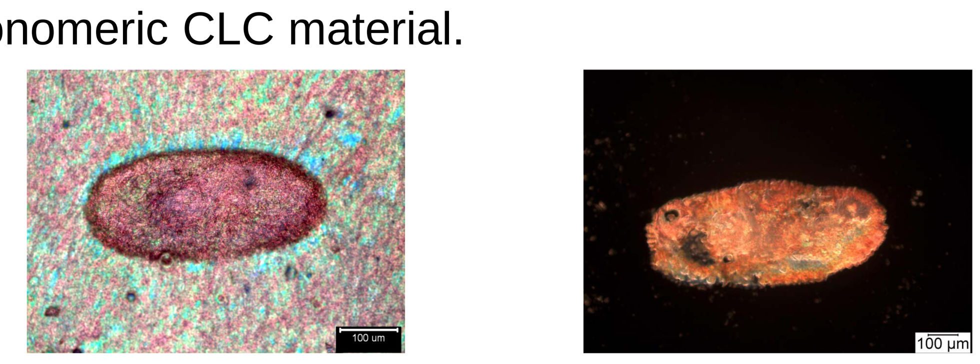
Replica Molding Results



The above images show optical micrographs of a silicon master mold fabricated at Birck Nanotechnology Center. The image on the left shows the array of features and the image on the right displays a protruding flake positive.



The above image shows a macroscopic and microscopic view of the 3D printed master mold on the left and the PDMS daughter mold on the right. The optical images show how well the pattern transfers. Below are some preliminary flakes produced by using the PDMS mold and some monomeric CLC material.

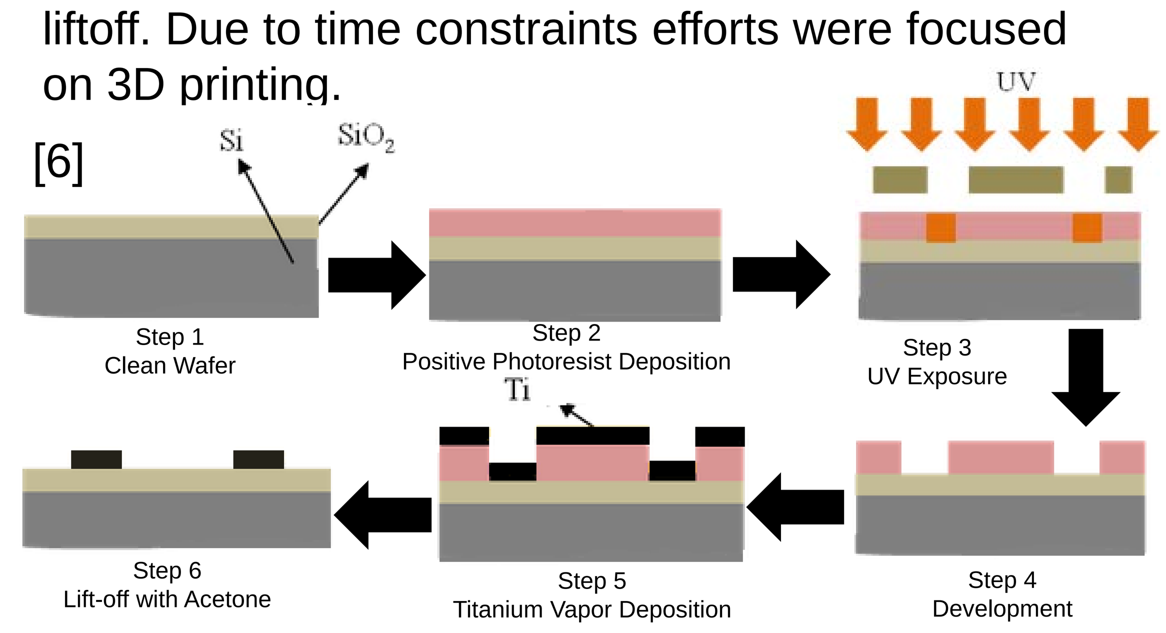


Replica Molding Discussion

Birck Silicon Master Mold

The photolithography procedure detailed below was performed by Birck Nanotechnology Center. Birck however incorrectly spun-coat 1.7 µm of positive photoresist with 5 µm of titanium vapor deposition. This means that the photoresist was completely encapsulated by the titanium preventing proper liftoff. Due to time constraints efforts were focused on 3D printing.

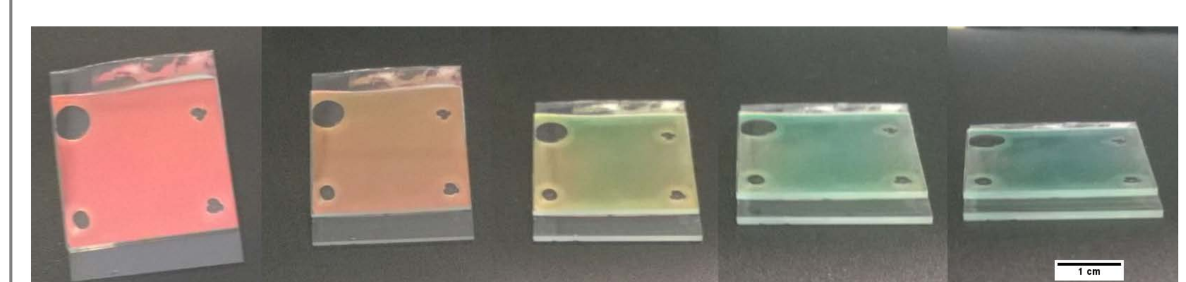
[6]



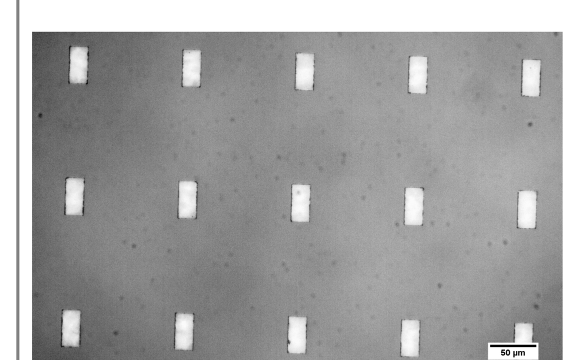
3D Printed Molds

A Formlabs Form 1+ 3D printer was used in conjunction with SolidWorks CAD files of the 3D molds at 400µm x 800µm , 200µm x 400µm, 100µm x 200 µm oval sized microflakes. Oval shaped flakes were used to optimize lateral printing resolution. Flakes were produced using monomeric and glassy CLCs. Difficulties included proper wettability of the CLC on the PDMS negative mold resulting in inadequate filling of the wells. Corona surface treatments and the addition of toluene were used to improve wettability.

Photopolymerization Results

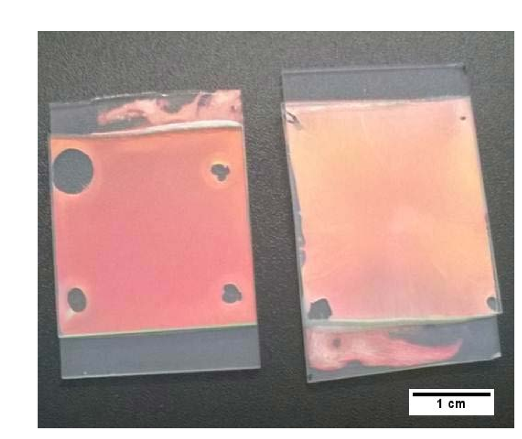


The images of the sample shown above were taken at different angles. Taking a photograph from different angles changes the incidence angle of light and shortens the wavelength of light reflected. These images confirm that our samples are in fact Bragg mirrors.



Shown on the left is an optical micrograph of the photomask used to create 20x40 µm flakes. The windows in the mask are spaced 100 µm apart to avoid light interference during polymerization.

Shown on the right above is an example of two CLC films created from the same batch of monomer where the film on the left has an alignment layer and the film on the right does not. The uniformity and strength reflection in these samples depends on the degree of molecular alignment.



Photopolymerization Discussion

Creating flakes with the photopolymerization method turned out to be much more difficult than originally anticipated. The recurring issues with this method are shown below.

- Overheating the monomeric CLC causing thermopolymerization when infiltrating the cell
- Judging the purity of CLC when boiling off acetone
- Batching CLC and solvent at the proper levels to redshift the color without turning infrared
- Finding the correct dosing time with the UV cure system

The first three issues were resolved, but finding the final dosing time was abandoned for focusing the group's efforts on the more interesting (novel) developments on the replica molding portion of this project.

Recommendations

- Use a higher resolution 3D printer for master mold
- Get a more elegant UV source
- Look into ink jet printing for directly printing flakes

References

[1] N. Tamaoki, "Cholesteric Liquid Crystals for Color Information Technology," *Advanced Materials,* vol. 13, no. 15, pp. 1135-1147, 2001.

[2] R. H. Chen, Liquid Crystal Displays, John Wiley & Sons, Inc., 2011.

[3] T. Kosc, K. Marshall, A. Trajkovska-Petkoska, C. Coon, K. Hasman, G. Babcock, R. Howe, M. Leitch and S. Jacobs, "Development of Polymer Cholesteric Liquid Crystal Flake Technology For Electro-Optic Devices and Particle Displays," in *Emerging Liquid Crystal Technologies II*, Rochester, 2007.

[4] A. Tajkovska-Petkoska, R. Varshneya, T. Z. Kosc, K. L. Marshall and S. Jacobs, "Enhanced Electro-Optic Behavior For Shaped Polymer Cholesteric Liquid-Crystal Flakes Made Using Soft Lithography," *Advanced Functional Materials,* vol. 15, no. 2, pp. 217-222, 2005.

[5] C. Heinen, A. Natekar, T. Schroeder and H. Zhou, "A Colloidal Approach to Liquid Crystal Transflective Displays: Making your E-Reader Color," Purdue University Materials Engineering Senior Design Group, 2014.

[6] "Microelectronics: Fabrication of micro/nano structures on silicon surface" DNANOTECH. (2012).