University of Central Florida
STARS

Faculty Bibliography 2000s

Faculty Bibliography

1-1-2006

Photo-patterning micro-mirror devices using azo dye-doped cholesteric liquid crystals

Tsung-Hsien Lin
University of Central Florida

Yuhua Huang
University of Central Florida

Ying Zhou
University of Central Florida

Andy Y. G. Fuh

Shin-Tson Wu
University of Central Florida

Find similar works at: https://stars.library.ucf.edu/facultybib2000
University of Central Florida Libraries http://library.ucf.edu

This Article is brought to you for free and open access by the Faculty Bibliography at STARS. It has been accepted for inclusion in Faculty Bibliography 2000s by an authorized administrator of STARS. For more information, please contact STARS@ucf.edu.

Recommended Citation

Lin, Tsung-Hsien; Huang, Yuhua; Zhou, Ying; Fuh, Andy Y. G.; and Wu, Shin-Tson, "Photo-patterning micro-mirror devices using azo dye-doped cholesteric liquid crystals" (2006). *Faculty Bibliography 2000s*. 6360.
https://stars.library.ucf.edu/facultybib2000/6360

Photo-patterning micro-mirror devices using azo dye-doped cholesteric liquid crystals

Tsung-Hsien Lin,[1, 2] Yuhua Huang,[1] Ying Zhou,[1] Andy Y. G. Fuh,[2] and Shin-Tson Wu[1]

[1]*College of Optics and Photonics, University of Central Florida, Orlando, Florida 32816*
[2]*Institute of Electro-Optics, National Cheng Kung University, Tainan, Taiwan 701, ROC*
swu@mail.ucf.edu

http:/lcd.creol.ucf.edu

Abstract: A simple method for fabricating patternable micro-mirror devices by photo-induced alignment of dye-doped cholesteric liquid crystal (CLC) is demonstrated. The CLC texture can be changed from random distribution to nearly perfect planar by the photo-excited adsorbed dyes. This structure transformation leads to a substantial reflectivity increase. Using this photo-patterning technique, one- and two-dimensional micro-mirror arrays which function as gratings are also demonstrated.

©2006 Optical Society of America

OCIS codes: (230.3720) Liquid-crystal devices; (050.1970) Diffractive optics

---

References and links

1. S. Chandrasekhar, *Liquid Crystals* (Cambridge University Press, London, 1977).
2. L. M. Blinov and V. G. Chigrinov, *Electro-Optical Effects in Liquid Crystal Materials* (Springer-Verlag, New York, 1994).
3. D. K. Yang, J. L. West, L. C. Chien, J. W. Doane, “Control of the reflectivity and bistability in displays based on cholesteric liquid crystals,” J. Appl. Phys. **76**, 1331-1333 (1994).
4. M. H. Lu, “Bistable reflective cholesteric liquid crystal display,” J. Appl. Phys., **81**, 1063-1066 (1997).
5. S. T. Wu and D. K. Yang, *Reflective Liquid Crystal Displays* (Wiley, New York, 2001).
6. I. Shiyanovskaya, A. Khan, S. Green, G. Magyar, and J. W. Doane, “Single substrate encapsulated cholesteric LCDs: coatable, drapable and foldable,” SID Symposium Digest **36**, 1556-1559 (2005).
7. K. Chari, C. M. Rankin, D. M. Johnson, T. N. Blanton, and R. G. Capurso, “Single-substrate cholesteric liquid crystal displays by colloidal self-assembly,” Appl. Phys. Lett. **88**, 043502 (2006).
8. B. Taheri, A. F. Munoz, P. Palffy-Muhoray, and R. Twieg, **“**Low threshold lasing in cholesteric liquid crystals,” Mol. Cryst. Liq. Cryst. **358**, 73-81, (2001).
9. S. M. Morris, A. D. Ford, M. N. Pivnenko, and H. J. Coles, “Enhanced emission from liquid-crystal lasers,” J. Appl. Phys. **97**, 023103 (2005).
10. Y. Huang, Y. Zhou, and S. T. Wu, “Spatially tunable laser emission in dye-doped photonic liquid crystals,” Appl. Phys. Lett. **88**, 011107 (2006).
11. Y. Huang, Y. Zhou, C. Doyle, and S. T. Wu, “Tuning photonic band gap in cholesteric liquid crystals by temperature-dependent dopant solubility,” Opt. Express **14**, 1236-1242 (2006).
12. T. H. Lin, H. C. Jau, C. H. Chen, and A. Y. G. Fuh, “Electrically controllable laser based on cholesteric liquid crystal with negative dielectric anisotropy,” Appl. Phys. Lett. **88**, 061122 (2006).
13. T. H. Lin, Y. J. Chen, C. H. Wu, A. Y. G. Fuh, J. H. Liu, and P. C. Yang, “Cholesteric liquid crystal laser with wide tuning capability,” Appl. Phys. Lett. **86**, 161120 (2005).
14. C. R. Lee, T. S. Mo, K. T. Cheng, T. L. Fu, and A.Y. G. Fuh, “Electrically switchable and thermally erasable biphotonic holographic gratings in dye-doped liquid crystal films,” Appl. Phys. Lett. **83**, 24-26 (2003).
15. C. R. Lee, T. L. Fu, K. T. Cheng, T. S. Mo, and A. Y. G. Fuh, “Surface-assisted photo alignment in dye-doped liquid-crystal films,” Phys. Rev. E **69**, 031704 (2004).
16. S. Y. Huang, S. T. Wu and A. T. G. Fuh, “Optically switchable twist nematic grating based on a dye-doped liquid crystal film,” Appl. Phys. Lett. **88**, 041104 (2006).
17. L. Lucchetti, M. Gentili, F. Simoni, “Colossal optical nonlinearity induced by a low frequency external electric field in dye-doped liquid crystals,” Opt. Express **14**, 2236 (2006).
18. L. Lucchetti, M. Di Fabrizio , O. Francescangeli and F. Simoni, “Colossal optical nonlinearity in dye doped liquid crystals,” Opt. Commun. **233**, 417 (2004).

#68925 - $15.00 USD
Received 13 March 2006; revised 2 May 2006; accepted 4 May 2006

19. Q. Hong, T. X. Wu and S. T. Wu, "Optical wave propagation in a cholesteric liquid crystal using the finite element method," Liq. Cryst. **30**, 367-375 (2003).
20. H. Ren, Y. H. Fan, S. Gauza, and S. T. Wu, "Tunable microlens arrays using polymer network liquid crystal," Opt. Commun. **230**, 267-271 (2004).

---

1. Introduction

Cholesteric liquid crystal (CLC) is regarded as a one-dimensional photonic crystal because of its self-organized chiral structure. A circularly polarized light with the same handedness as the CLC propagating along the helical axis is selectively reflected. The central wavelength λ_o and bandwidth $\Delta\lambda$ of the CLC reflection band are related to the pitch length p and the refractive indices of the CLC layer as: $\lambda_o = <n> \cdot p$ and $\Delta\lambda = \Delta n \cdot p$, where $<n>$ denotes the average refractive index ($(n_e + n_o)/2$) and $\Delta n (= n_e - n_o)$ is the birefringence of the LC. Many applications of CLC devices for strong optical rotatory powers and selective reflection of circularly polarized light [1, 2], reflective liquid crystal displays [3-7], and photonic crystal lasers [8-13] have been proposed.

In this paper, we develop a simple photo-patterning method for controlling the reflectivity of the dye-doped CLC micro-photonic devices. Initially, the dye-doped CLC sample is not aligned so that it functions as a diffusive reflector. Upon laser exposure, the azo dye molecules go through trans-cis transition and the photo-induced LC alignment takes place. As a result, the CLC layer is reconfigured to a planar structure and its reflectivity increases dramatically. By exposing the dye-doped CLC device with a green laser through a photomask, both one- and two-dimensional gratings are fabricated. The device resolution is ~50 μm.

2. Device fabrication

A right-handed CLC sample was prepared by mixing 39 wt% CB15 chiral agent to a nematic BL006 LC (from Merck). The herein employed azo dye is methyl red (MR, purchased from Aldrich); its trans-state has an absorption spectrum spanning from ~400 to 540 nm. The mixing ratio of MR dye to CLC is 1:99 wt%. Two indium-tin-oxide (ITO)-coated glass slides, separated by 8 μm plastic spacers, were used to fabricate an empty cell without any surface alignment treatment. The CLC and dye mixture was stirred thoroughly before being injected to the empty cell. As depicted in Fig. 1(a), the helical axis of the dye-doped CLC is almost randomly distributed. As a result, it acts as a diffusive reflector, i.e., the incident circularly polarized light is diffused to a large cone.

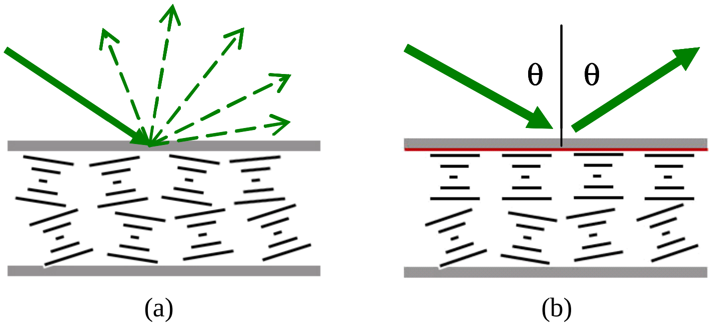


Fig. 1. Schematic representation of the (a) imperfect CLC planar texture with nearly randomly distributed helical directions, (b) photo-aligned planar CLC texture.

To reorient the CLC directors on the untreated surface to a desired direction, in principle, we can illuminate the dye-doped CLC with a linearly polarized, continuous wave (CW) laser whose wavelength is around the azo dye's absorption peak. Under such a circumstance, the azo dyes in the CLC sample undergo trans–cis isomerization, followed by molecular reorientation, diffusion and finally adsorption onto the ITO surface. As a result, the long axes

Received 13 March 2006; revised 2 May 2006; accepted 4 May 2006

of the azo dyes are aligned along the untreated substrate of the CLC cell but perpendicular to the polarization of the pumping beam. The adsorbed dyes then force the LC molecules on the untreated surface to reorient along the direction of the azo dyes' long axes [14-18]. The CLC molecules on the untreated surface can be aligned along the direction of the azo dyes' director only when the adsorbed azo dyes establish sufficient surface anchoring force. This can be achieved by irradiating the dye-doped CLC sample with a linearly polarized light for a long enough time and sufficiently high intensity because the high laser dosage would induce the adsorbed dyes to aggregate and then generate adequate anchoring force. When the front LC molecules are forced to align parallel to the substrate, as shown by the red line in Fig. 1(b), the CLC helical axes would be perpendicular to the substrate. However, to achieve a complete Bragg reflection, at least 10 CLC layers need to be established [19]. A fewer planar CLC layers would lead to a lower reflectivity.

3. Experimental

In our experiment, a linearly polarized CW laser from a diode-pumped solid state laser was used to irradiate the dye-doped CLC sample because the laser wavelength (λ=532 nm) is within the absorption band of the Methyl Red. The laser beam was expanded and collimated to 2 cm diameter. After laser illumination, we used an experimental setup as depicted in Fig. 2 to measure the reflection properties of the photo-aligned dye-doped CLC sample. In Fig. 2, a broadband white light was used as a light source. A pair of crossed polarizer and analyzer was used to filter the surface reflections from the glass substrates. Reflection spectrum and intensity of the CLC were measured using a spectrum meter and a photo diode, respectively.

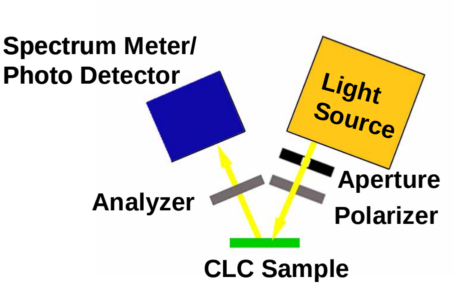


Fig. 2. Experimental setup for measuring the reflection spectrum and intensity of the dye-doped CLC.

4. Results and discussions

Figure 3 shows a picture of the photo-aligned CLC taken by a digital camera. The green circle (8 mm diameter) represents the region illuminated by a linearly polarized CW laser at intensity I~50 mW/cm^2 for 60 min. The surrounding is not exposed. Due to the photo-alignment effect of the azo dyes, the excited azo dyes are adsorbed to the inner surface of the front substrate to form a homogeneous alignment. The texture of the illuminated region is transformed from random to nearly perfect planar, as Fig. 1 depicts. Therefore, a strong Bragg reflection from the exposed region is observed.

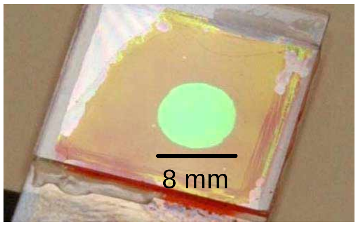


Fig. 3. A photo of dye-doped CLC cell with (green circle) and without laser illumination.

We also compared the texture of dye-doped CLC with different irradiation time. Figure 4

#68925 - $15.00 USD
Received 13 March 2006; revised 2 May 2006; accepted 4 May 2006
(C) 2006 OSA

presents the microscopic textures of the photo-aligned CLC which were observed under a reflection-type polarizing optical microscope. Figure 4(a) shows the texture of unexposed dye-doped CLC. Random structure is observed and its reflectance is fairly low. Figures 4(b), 4(c) and 4(d) represent the dye-doped CLC with 20 min, 40 min, and 60 min exposure time, respectively. Initially, the azo dye molecules are distributed randomly in the cell. Those dichroic dyes whose principal molecular axis parallel to the pumping laser's polarization would be excited more easily than the rest dyes. Thus, different molecular domains would have different optical thresholds for the CLC reorientation to occur. As the exposure time increases, more planar domains would appear. After 60 min of laser illumination, almost all the exposed regions are converted to planar texture as shown in Fig. 4(d).

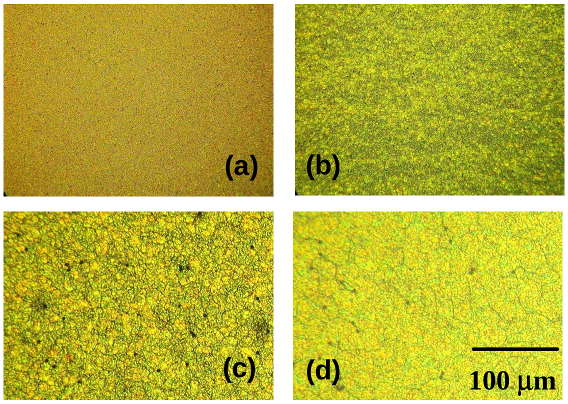


Fig. 4. The microscopic textures of a photo-aligned CLC observed under a reflection optical microscope with (a) 0 min, (b) 20 min, (c) 40 min and (d) 60 min illumination time.

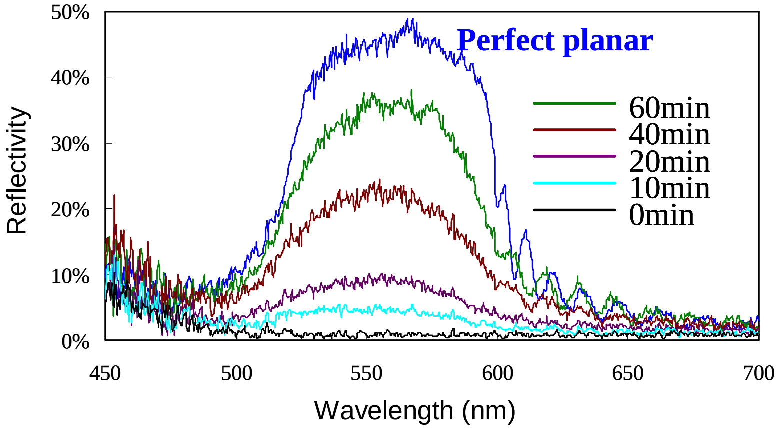


Fig. 5. Reflection spectrum of the photo-aligned dye-doped CLC at different laser exposure time.

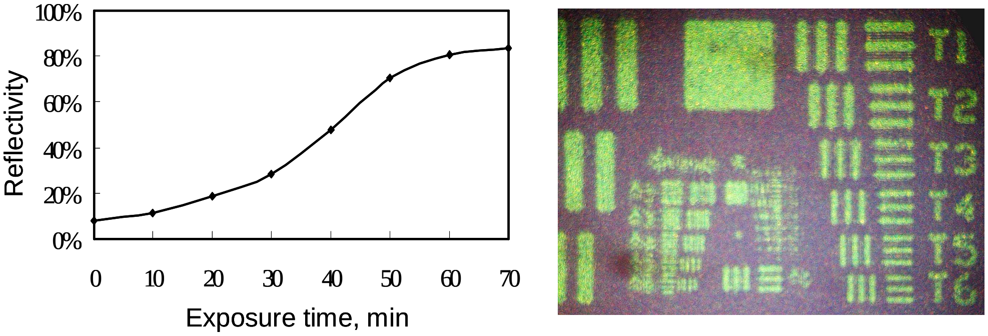
Figure 5 shows the measured reflection spectra of the photo-aligned dye-doped CLC with different exposure time. The blue line represents the reflection spectrum of a perfect planar CLC using a homogeneous cell. The peak reflectivity reaches the theoretical value, which is ~50% for a right-handed circularly polarized incident light. The bottom black line represents the unexposed dye-doped CLC sample. Because the CLC directors are randomly distributed, the reflectivity of the cell is nearly vanished at the reflection angle ($\theta \sim 30^o$ in this experiment). As explained above, as the illumination time increases more planar domains are generated and the reflectivity increases. The reflectivity of the dye-doped CLC sample (with 60 min exposure) reaches ~80% level of a perfect planar structure. During such a long exposure time,

Received 13 March 2006; revised 2 May 2006; accepted 4 May 2006
(C) 2006 OSA

the LC and dye molecules could diffuse away so that the resolution is degraded. The exposure time could be reduced to ~5 min. if the ITO-glass is coated with a polymer layer [16].

We also measured the reflected light intensity of the photo-aligned dye-doped CLC. Figure 6(a) plots the exposure time dependent reflectivity of the CLC sample. The reflected light is collected at the reflection angle and its intensity normalized to that of a perfect planar CLC. As the laser exposure time increases, more planar CLC domains appear which, in turn, enhance the reflectivity. When the exposure time gets longer than 60 min, the reflectivity reaches above 80% and gradually saturates. It indicates that the exposed region in the sample has been converted to multi-domain planar structure. However, some defects between the boundaries of multiple domains are still present, as Fig. 4(d) shows. As a result, the reflectivity does not reach 100%.

In order to determine how fine the photo-alignment process is, we exposed the sample through a commercially available resolution target. It has several scale groups as Fig. 6(b) shows. We can determine the resolution of an optical storage film by illuminating a uniform intensity beam through the resolution target which is in proximity contact with the storage film. The smallest but distinguishable spacing between two adjacent lines of the group image defines the resolution. The collimated CW green laser beam with ~50 mW/cm^2 intensity was incident normal to the sample through the resolution target. Figure 6(b) shows the image observed from a reflection polarizing optical microscope. The resolution of the photo-aligned dye-doped CLC sample is better than 50 μm. In this experiment, the resolution target was put on top of the CLC cell. That means, the resolution target and the CLC film are separated by a glass substrate, which is ~0.5 mm. Thus, the beam passing the resolution target will be diffracted before reaching the CLC film [20]. To improve resolution, a thinner top glass substrate or a more collimated exposure system can be considered.



(a) (b)

Fig. 6. (a) Reflectivity of the photo-aligned dye-doped CLC with different illumination time. 100% stands for the reflectivity of a perfect planar CLC. (b) Resolution of this sample observed under a reflective polarizing optical microscope.

Based on the above-mentioned mechanism, we demonstrated two kinds of micro mirror arrays using photo-aligned dye-doped CLC. The first type is a 1D reflection grating. To fabricate such a grating, we irradiated the CLC sample using a green CW laser (I~50 mW/cm^2) through a grating photomask. The grating spacing is about 100 μm. After laser exposure, a photo-aligned planar grating was formed. Figure 7(a) shows the image of the photo-aligned CLC under a reflective polarizing optical microscope. The bright lines (high reflectance) are the exposed regions where the nearly perfect planar textures are established. On the other hand, the darker regions originate from the random CLC textures, as described in Fig. 1(a). Figure 7(b) shows the diffraction patterns of this photo-aligned CLC reflective grating. Four diffraction orders are observed clearly and the 1st order diffraction efficiency is ~10%.

Received 13 March 2006; revised 2 May 2006; accepted 4 May 2006

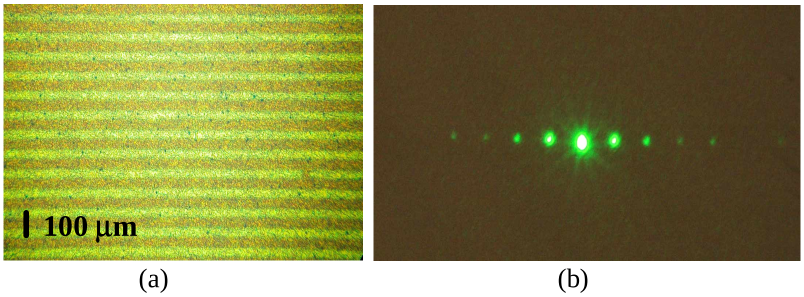


Fig. 7. (a) The recorded image of the photo-aligned CLC under a reflective polarizing optical microscope. The grating spacing is ~100 μm. (b) The diffraction patterns of the photo-aligned CLC reflective grating.

The second device we fabricated is a two-dimensional (2D) micro mirror array. The fabrication procedure is similar to the 1D grating except that a different photomask is employed. The mask has circular spots. Figure 8(a) shows the image of the photo-aligned 2D CLC micro-mirror array under a reflective polarizing optical microscope. The bright dots are the exposed regions which represent the planar textures while the dark regions result from the random CLC distribution. From Fig. 8(a), the pitch length is about 50 μm. Figure 8(b) shows the diffraction patterns of this 2D photo-aligned CLC reflective grating.

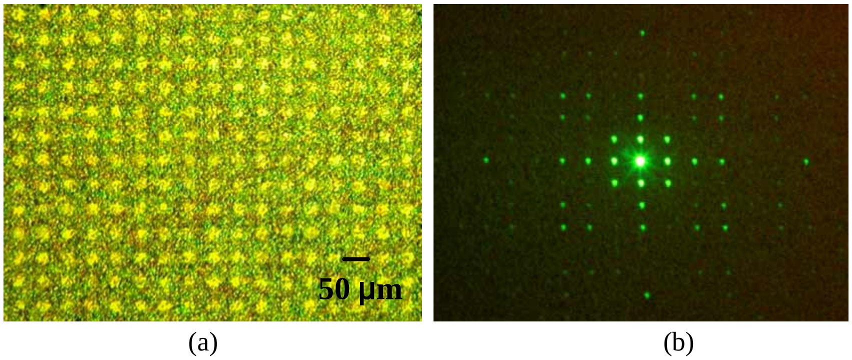


Fig. 8. (a) The reflection image of the 2D photo-aligned CLC under a reflective polarizing optical microscope. The grating spacing is ~50 μm. (b) The diffraction patterns of this photo-aligned CLC reflective grating.

The described photo-patterning technique possesses several attractive features. The configuration of micro mirrors can be constructed through photomask design or by scanning a laser beam. For applications like barcode reading, scanning image projection, and optical data transfer deflectable micro mirrors could be important for future product development. Also, due to the electrically tunable characteristics of CLC, the micro-mirror made by CLC can be switched by an electric field. Moreover, CLC exhibits bistability [3]. Bistable, yet electrically switchable micro photonic devices made of dye-doped CLC can be realized.

5. Conclusion

A photo-patternable micro-mirror device made by photo-aligned dye-doped cholesteric liquid crystal is demonstrated. By illuminating the dye-doped CLC sample with a linearly polarized laser beam, the adsorbed azo dyes establish a homogeneous alignment near the front surface. The CLC texture can be changed from random distribution to nearly perfect planar. The reflectivity of photo-aligned dye-doped CLC can reach 80% level of a perfect planar structure. The device resolution is better than 50 μm. Both 1D and 2D micro-mirror devices can be made by illuminating the sample through a photomask. The fabrication process is fairly easy.

Received 13 March 2006; revised 2 May 2006; accepted 4 May 2006
(C) 2006 OSA

The authors would like to thank the National Science Council of the Republic of China (Taiwan) for the financial support under Contract No. NSC 93-2112-M-06-016.

#68925 - $15.00 USD
Received 13 March 2006; revised 2 May 2006; accepted 4 May 2006

(C) 2006 OSA

132.170.27.255 {ts '2019-08-29 08:56:45'}