

# Effect of UV curing conditions on polymerized tunable chiral nematic liquid crystals

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## ABSTRACT

Chiral nematic liquid crystals have attracted substantial interest. They spontaneously self-organize to form a helical structure with no complex fabrication procedure required and exhibit a reflection band for a certain wavelength interval. Since the photonic band gap can be tuned by applying external factors (heat, voltage, light, elasticity) chiral nematic liquid crystals are potentially interesting for large area optical filters and shutters, reflective displays and tunable lasers. In this work, a device which consists of a mixture of photo-polymerizable liquid crystal, non-reactive nematic liquid crystal and a chiral dopant is fabricated. By selecting the appropriate chiral dopant concentration, it is possible to make devices for different operation wavelengths. The influence of UV illumination on a partially polymerized chiral liquid crystal is investigated. A blue-wavelength shift of the photonic band gap is obtained as a function of power, duration time of UV illumination and the thickness of the cells. Interestingly the width and depth of the photonic band gap is unaffected by the change in UV curing conditions, which indicates that there is no degradation by the UV light.

**Keywords:** Liquid Crystal, UV curing, polymerization, tunable, optical filter

## 1. INTRODUCTION

Chiral nematic liquid crystals (CLC) have attracted considerable attention for their spontaneous arrangement into a helical periodic dielectric structure. The periodicity may be adapted such that a reflection band appears for visible wavelengths<sup>1</sup>. The periodicity of a CLC results in a 1D photonic band gap (PBG) with the band gap width of  $\Delta\lambda = \Delta n P$  where  $\Delta n = n_e - n_o$  is the LC birefringence and  $P$  is the pitch<sup>1,2</sup>. The band edges are defined by  $P n_o < \lambda < P n_e$ . CLCs are promising materials for electro-optic devices requiring low power, low cost and switchable diffracting elements such as lasers and displays<sup>3-8</sup>. In addition direct control and tuning of the PBG are of crucial importance for several emerging applications such as switchable optical devices, lab-on-a-chip devices as sensors<sup>9</sup>, modulators, reflectors and diffraction gratings. External stimuli can be used to tune the PBG such as heat<sup>10-13</sup>, light<sup>14-16</sup>, elasticity<sup>17</sup> and voltage<sup>18-29</sup>. In previous work<sup>30</sup> switchable devices with tuneable PBG with a fast response to electrical addressing and tuning over a broad range of wavelengths are demonstrated with a high reproducibility without deformation and degradation (Figure 1). The shift is performed by applying an electric field over a layer consisting of a mixture of photo-polymerizable LC and non-reactive nematic LC including a chiral dopant. In this work we investigate the effects of UV illumination on the same mixture. A blue wavelength shift of the PBG is obtained as a function of power, duration time of UV illumination and the thickness of the cells. There is no degradation and deformation by the change in UV curing conditions. It is well known that the use of photoresponsive chiral dopants results in a shift of the bandgap to longer wavelengths<sup>4,31</sup>. This is due to the fact that the chiral dopant loses its chiral twisting power after absorption of UV light. In this work we use a chiral dopant which does not react to UV light. Moreover, in this work the bandgap shifts to shorter wavelengths with increasing UV power, which is opposite to what would be expected from UV degradation of the chiral dopant.

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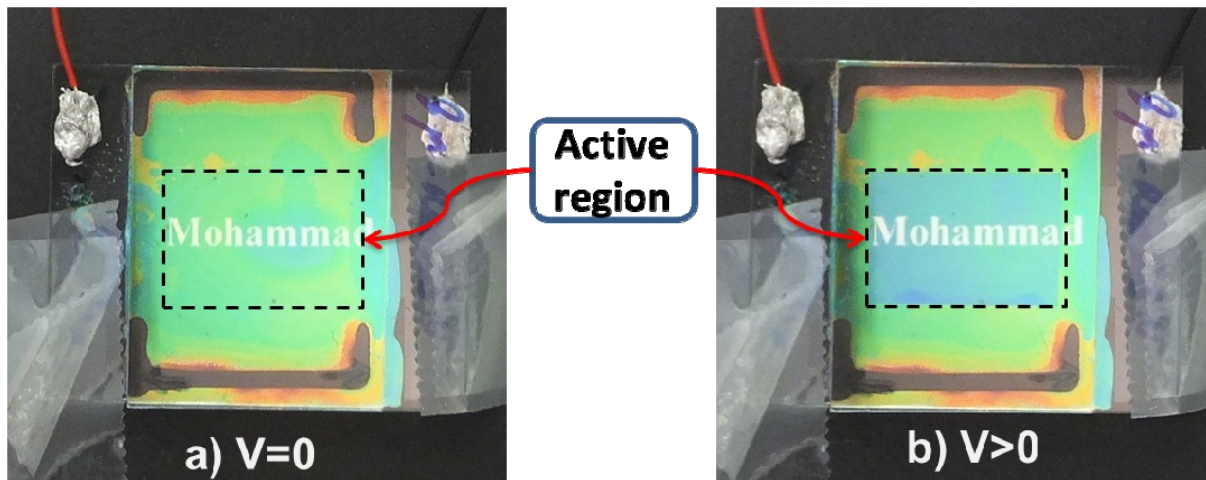


Figure 1. A photograph of a selective CLC reflector with a  $1 \times 1.4$  cm<sup>2</sup> active region placed on a black background on which the word Mohammad is printed in white, a) without and b) with applied electric field.

## 2. FABRICATION

The CLC mixture is prepared by mixing 50 wt% non-reactive nematic LC (MDA-00-3536, Merck), 3.47 wt% right handed chiral dopant (BDH1305, Merck), 0.03 wt% photo initiator (Irgacure 819, BASF) and 46.5 wt% reactive LC in chloroform after stirring it for 20 minutes. The reactive LC is a blend of different reactive mono- and di-acrylate mesogens from Merck. It is possible to make devices for different operation wavelengths by selecting the appropriate chiral dopant concentration. A cell is made by two glass substrates with 30 nm thick conductive Indium-Tin-Oxide (ITO) electrodes. The substrates are coated with a nylon layer and rubbed anti-parallel in order to stabilize the CLC in the planar texture with the helical axis perpendicular to the glass substrates. The gap in the empty cell is determined by spacers balls mixed inside the glue. In this work different spacers of 4, 8 or 10  $\mu\text{m}$  are used. The composite mixture is injected into the empty cell using the capillary effect in vacuum on a hot stage in the isotropic phase (102°C) of the polymerizable LC mixture. The cell is cooled down such that the liquid crystal can orient itself into a helical structure as a uniform film without domains. Then the cell is exposed to UV light from a mercury lamp (with the main power at 365 nm and a blocking filter for short and long wavelengths) to polymerize the CLC mixture. A CLC polymer film is formed exhibiting selective reflection of right handed circularly polarized light. The CLC film is otherwise transparent without observable scattering. This indicates that droplets of nonreactive LC formed in the cross-linked network are much smaller than the wavelength of visible light (Figure 2). To control the behaviour of the CLC films, the UV power, curing time and the thickness of the cell are investigated.

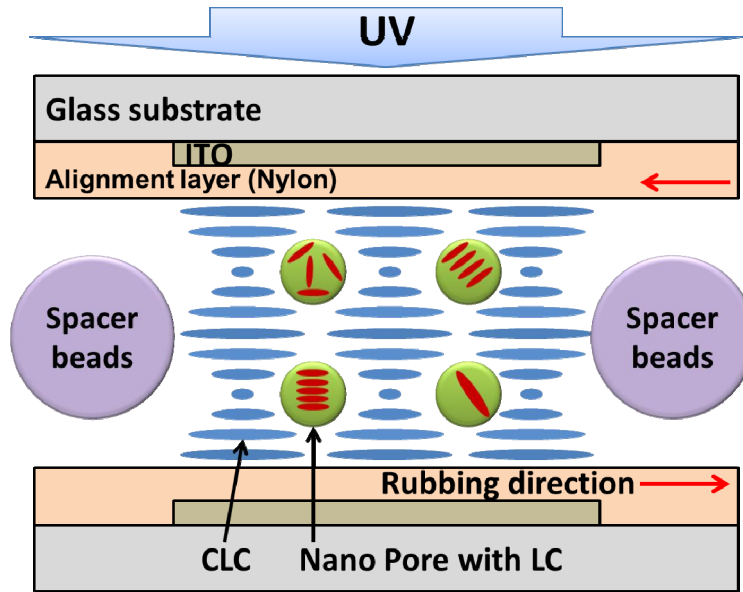


Figure 2. Scheme of the structure of a polymerized CLC network with dispersed nematic LC droplets.

### 3. RESULTS AND DISCUSSION

To investigate the influence of the UV power on the network structure and the photonic band gap, the mixture is infiltrated in cells with  $8\ \mu\text{m}$  thickness. Then the cells are exposed to various powers of UV light (1.75, 3.5, 7, 10.5 mW) for 1 minute to polymerize the CLC mixture. After fabrication, the transmission spectra of the cells are measured by a spectrometer (Perkin Elmer). In order to rule out the polarization dependencies of the spectrometer, the transmission measurements have been performed for right-handed circularly-polarized light produced with a linear polarizer and a zeroth-order quarter-wave plate at 850 nm. The fabricated CLC films exhibit a broad PBG with a total bandwidth of approximately 100 nm. The PBG of the devices shift to the blue by increasing the UV power as shown in figure 3(a). Various powers of UV light (1.75, 3.5, 7, 11, 40 mW) are used to illuminate the cells from both sides for a duration of 1 minute. The blue shift of the PBG of the devices is shown in figure 3(b) with increasing UV power. The strongest blue shift is 110 nm and the film features high stability and reflectivity without any noticeable degradation or disruption.

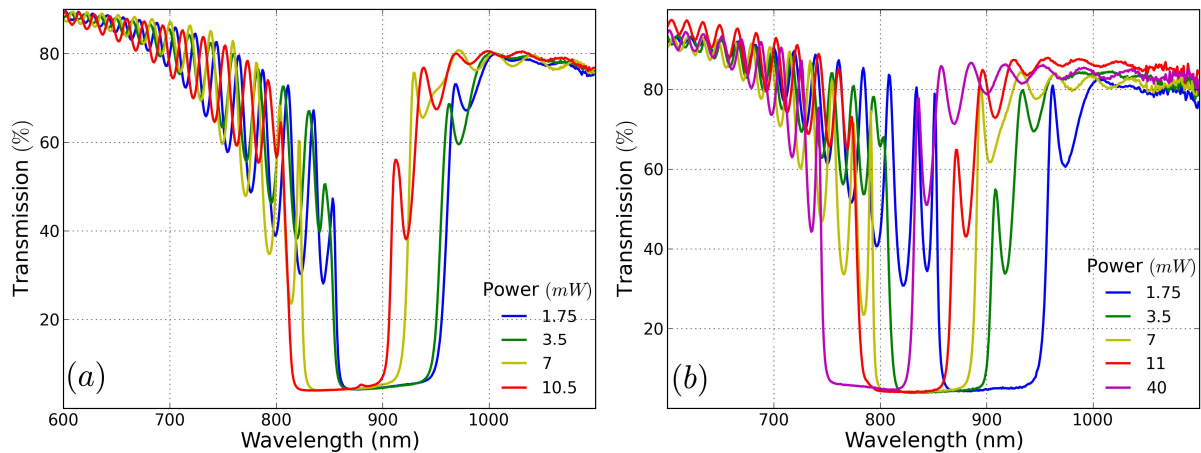


Figure 3. Transmission spectra (for right-handed circularly-polarized light) for devices exposed to various powers of UV light (365 nm) from a) one side and b) two sides

To understand the reason for the shift, the refractive indices of the cells (without chiral dopant) are estimated for 2 powers of the UV light (11 and 40 mW). The cells are illuminated from two sides for 1 minute. The blue shift corresponds to a decrease of the refractive indices as shown in figure 4.

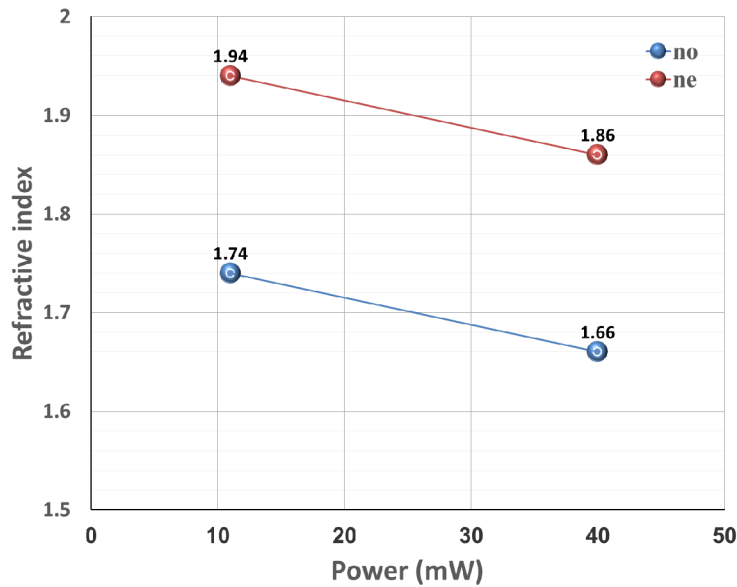


Figure 4. Ordinary and extra-ordinary refractive indices of devices exposed to two powers of UV light.

To investigate the effect of duration time of UV illumination on the network structure and photonic band gap, the cells with 8  $\mu\text{m}$  thickness are exposed to UV light with a power of 30 mW for 1 and 2 minutes. Figure 5 shows the blue shift of the PBG by applying UV light for these two durations. The shift is without degradation or disruption.

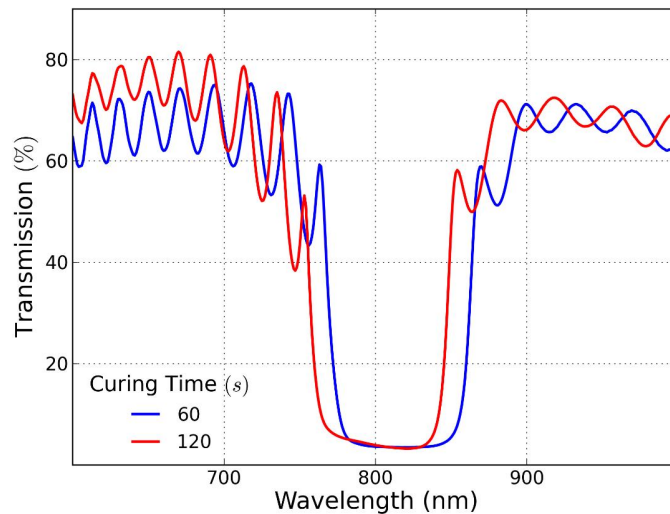


Figure 5. Transmission spectra (right handed circularly polarized light) for devices which are cured with 30 mW UV light (365 nm) during 1 and 2 minutes.

Finally we have investigated the influence of the device thickness on the network structure and photonic band gap by injecting the mixture into the cells with 4, 8 and 10  $\mu\text{m}$  thicknesses. After being filled with the mixture, the cells are exposed to 30 mW UV light for 1 minute. The transmission spectra for these devices shown in figure 6 demonstrate that the PBG shifts to the red in thicker devices, or equivalently that the pitch increases in thicker cells. It is obvious that the

transmission within the PBG decreases by increasing the thickness of the mixture<sup>32</sup>. The fact that the PBG shifts to the red with increasing thickness is most likely related to the fact that the average UV power over the thickness of the LC layer is smaller due to UV absorption.

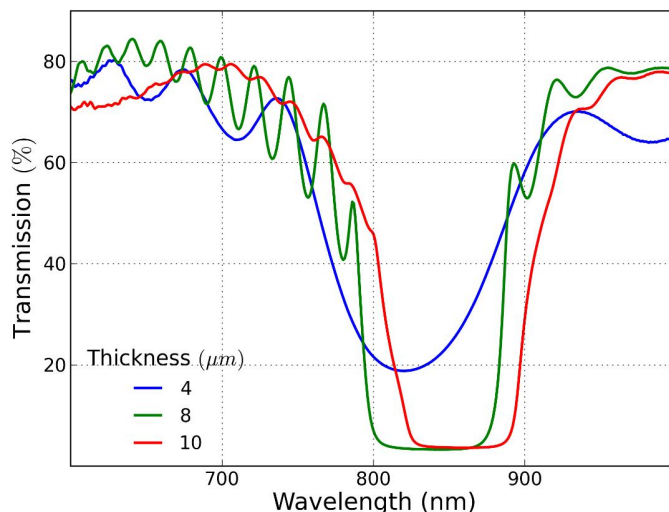


Figure 6. Transmission spectra (right-handed circularly-polarized light) for devices with various thicknesses which are illuminated by a 30-mW UV light (365 nm) for 1 minute.

#### 4. CONCLUSION

We have demonstrated a wide shift of the photonic band gap for a mixture of photo-polymerizable LC, nematic LC and a chiral dopant, by changing the power and time duration of the UV illumination and the thickness of the cell. The PBG can be shifted over 110 nm with relatively high stability and reflectivity, without any noticeable degradation or disruption. We can conclude that UV illumination plays an important role in controlling the photonic band gap of the CLC mixture. The shift is due to a decrease in the refractive indices, but the physical mechanism for this decrease is not yet clear. Further experiments are required to find out the underlying mechanism.

#### 5. ACKNOWLEDGMENTS

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