Adaptive reflector based on cholesteric liquid crystal film

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Abstract: An optically controllable and adaptive reflector based on azo-chiral-doped cholesteric liquid crystal (ADCLC) film is fabricated. The variation of the photonic bandgap (PBG) with adjusting the helical pitch of the ADCLC is theoretically predicated by Berreman 4X4 matrix and experimentally demonstrated. The PBG of the ADCLC will red-shift when exposed by a UV light. After switching off the UV light, the PBG will gradually shift back to shorter wavelength. This optically controllable and adaptive reflector can be potentially applied on tunable photonic devices or goggles.

1. Introduction

Cholesteric liquid crystal (CLC) is a kind of liquid crystal in which the orientation of molecules rotates along a specific direction and thus CLC has helical structure. Because of the helical structure, the refractive index distribution of CLC is periodic and thus CLC can be regarded as a one dimensional photonic crystal for circularly polarization of light. [1] The central wavelength of the photonic bandgap (PBG) in the one dimensional photonic crystal is determined by the average refractive index and the helical pitch of the CLC. The helical pitch of CLC is defined as the length in which the molecules rotate 2π. The refractive index and the helical pitch of a CLC can be modulated by external fields, therefore the PBG of CLC is tunable. The tunable PBG is one of the most fascinating advantages of CLC and has been widely applied on various fields. [2]

Azo-chiral compound is a compound having azobenzene structure and chirality. Azobenzene can absorb light to transform from *trans* to *cis* form and the different geometric types of these two isomers result in different properties. [3] Therefore, azobenzene compound is a photosensitive material and applied on optically controllable devices. Chirality in the azo-chiral can induce the rotation of liquid crystal molecules and the formation of CLC when the azo-chiral dopant is doped into a nematic liquid crystal host. The ability for a chiral dopant to twist the liquid crystal molecule is the helical twisted power (HTP), which is inversely proportional to the helical pitch of CLC. In an azo-chiral compound, the HTP can be adjusted by changing the ratio of *trans* and *cis* isomers, which can be achieved by illumination of light. [4]

This work demonstrates an adaptive reflector based on azo-chiral-dopant CLC (ADCLC) film in which the PBG can be reversible and all-optically controlled. A theoretical simulation based on Berreman 4X4 matrix method is performed to predict the wavelength of the PBG in the ADCLC. With the illumination of UV light, the PBG of the ADCLC can be shifted to longer wavelength via the photo-induced *trans* to *cis* isomerization of the azo-chiral and thus the lower HTP. When the UV light is switched off, the PBG will gradually shift back to the shorter wavelength.

2. Experiments

The ADCLC mixture is prepared using nematic liquid crystal (MDA-03-3970, purchased from Merck), left-handed chiral dopant (S811, purchased from Fusol Material) and left-handed azo-chiral compound (ChAD-2-S, purchased from BEAM co.). The mixing ratio of MDA-03-3970: S811: ChAD-2-S in this mixture is 74.8:20.5:4.7 by weight. After homogeneously mixed, the ADCLC mixture was injected into an empty cell by capillary effect. The empty cell was composed of two anti-parallel rubbed glass substrates with a cell gap of 23 μm. Since the optical tunability of the reflection is an important characteristic in this work, the photosensitivity of the azo-chiral compound should be investigated by measuring the absorption spectrum with UV

irradiation. The test sample contains 0.5 *wt*% azo-chiral compound dissolved in alcohol. A non-polarized broadband light from a halogen light source (LS-1, Ocean) was aligned to pass through the test sample and a fiber-based spectrometer (Jaz-Combo-2, Ocean) was placed behind the sample to receive the transmitted light for measuring its absorption spectra. A UV (λ=365 nm) light source is placed apart from the cell for about 20 cm. Under UV irradiation, the variation of absorption spectra of azo-chiral can be obtained. For measuring the reflection spectra, a reflection probe fiber (QP400-7-UV-VIS, Ocean) was employed. By connecting the two branches of the fiber to the light source and the spectrometer, the probe of the fiber was set in the normal direction of the sample to measure the reflection spectra directly.

3. Results and discussion

The photosensitive property of the azo-chiral compound is verified by inspecting the absorption spectrum of the azo-chiral solution cell, as shown in Fig. 1. The black and curve lines in Fig.1 are the absorption spectra of the azo-chiral solution before and after UV illumination, respectively. It can be clearly indicated that the wavelength of the absorption peak of the azo-chiral solution before UV illumination is around 380 nm. After illuminated with the UV light, the absorption around 380 nm significantly decreases while that around 450 nm rises. The variation of absorption is an evidence to show that the molecular conformation of the azo-chiral compound changes after illuminated by UV light. [5]
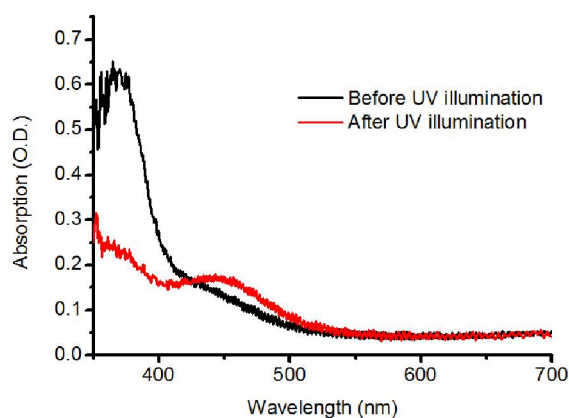

Fig. 1. The absorption spectra of the azo-chiral compound solution. The black and red lines are the absorption spectra before and after UV illumination, respectively.

Figures 2 show the optically controllable reflection spectra of the ADCLC cell at the irradiation times from 0 to 10 min. The reflectivities of the

reflection bands in the ADCLC cell are around 50%, which is the limit of reflection in CLC. Because of the helical structure, CLC can reflects circularly polarized light with the same handedness as the helical sense of the CLC. [6] For a unpolarized incident light, only half of it can be reflected by a CLC at most. The initial central wavelength of the reflection band locates on 550 nm. After illuminated with UV light for 10 minutes, the central wavelength of the reflection band shifts to 603 nm. The wavelength-shifting of the reflection band is attributed to the photo-induced *trans* to *cis* isomerization of the azo-chiral dopant. [7] The different ratio of the *trans* and *cis* azo-chiral compounds caused by the UV light results in the change of HTP in the CLC and thus the wavelength of the reflection band.

The UV-induced variation of the central wavelength of the reflection band is summarized and presented in Fig. 3. The reflected wavelength shifts from 550 nm to 603 nm during the 10 minutes of UV illumination. The variation of the wavelength under the UV illumination is linear. After switching off the UV light, the reflected wavelength relaxes back to 550 nm. In the beginning stage of the relaxation process, the wavelength blue-shifts abruptly. After that, the variation rate of the reflected wavelength becomes slower and finally reaches a stable condition.
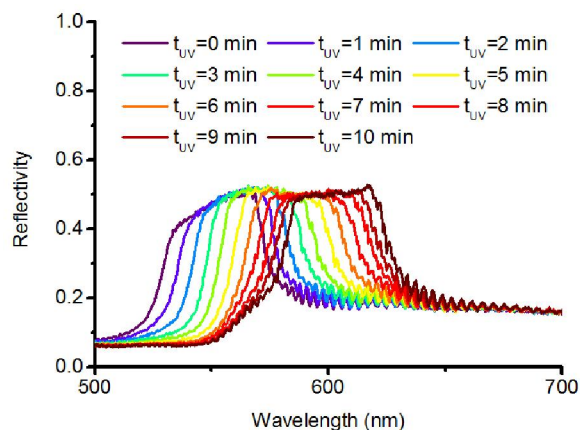

Fig. 2. The variation of the reflection spectra of the ADCLC cell with the illumination of a UV light for 10 minutes.

As explained in the previous paragraphs, the shift of the reflection band is resulted from the photo-induced isomerization of the azo-chiral compound and thus the change of the HTP. To investigate how much the HTP varies, the simulated reflection spectra of the ADCLC cell before and after UV illumination by using 4X4 Berreman matric method are demonstrated, as shown in Fig. 4. The 4X4 Berreman matrix method is a widely used method for calculating the wavelength of the photonic

bandgap in CLC. [8-10] In Fig. 4(a), all the parameters for simulation are identical to the experimental conditions. For example, the cell gap is 23 μm, the concentrations of the chiral dopant and the azo-chiral compound are -11.3 μm^{-1} and 12 -μm^{-1}, and their concentrations are 20.5 wt% and 4.7 wt%, respectively.
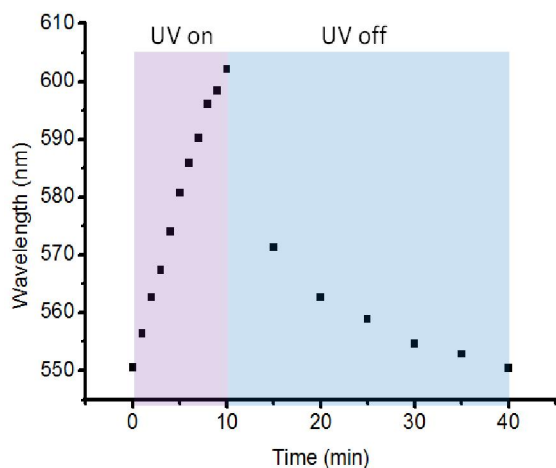

Fig. 3. Variation of the reflected wavelength of the optically controlled reflection band of the ADCLC cell.
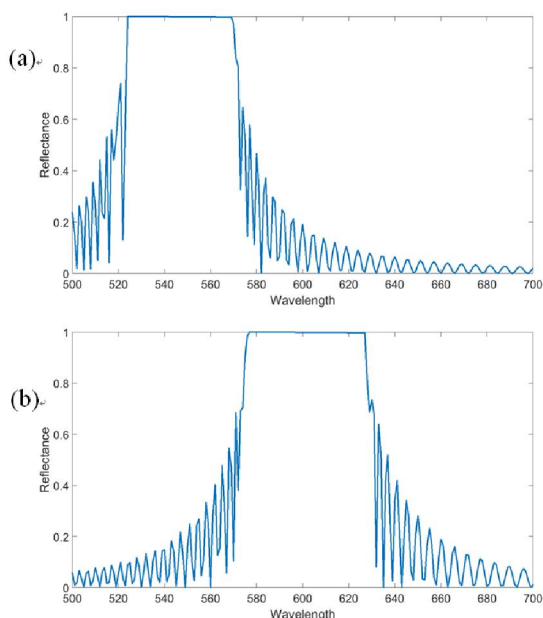

Fig. 4. The simulated reflection spectra of the ADCLC cell (a) before UV illumination and (b) after UV illumination by 4X4 Berreman matrix method.

The negative value of the HTP represents the chirality is left-handed and thus the ADCLC in this work is left-handed. The most important parameters in the simulation is the HTP of the azo-chiral compound

since only the HTP of the azo-chiral compound will change during the UV illumination. Therefore, various HTP values are considered in the simulation for the ADCLC cell after UV illumination. It is found that the wavelength of the reflection band is identical to the experimental result when the HTP value is set as 6.4 μm^{-1}, as shown in Fig. 4(b). The simulated results reveal that the HTP value of the azo-chiral compound in the ADCLC cell decreases from 12 μm^{-1} to 6.4 μm^{-1} with the UV illumination. It is also worthy noticing is that the polarization of the incident light is set as a left-handed circular polarization, which has the same handedness as the helical sense of the ADCLC. Due to the correspondence of the handedness between the light polarization and the azo-chiral compound, the reflectivity of the reflection band in the simulation is unity. In the experimental results, the reflectivity is only 50% because the incident light is unpolarized.

7. Conclusion

In this paper, we have succeeded in fabricating an adaptive reflector based on an ADCLC film which reflection band can be optically controlled. The optically tunable wavelength of the reflector is based on the photo-induced isomerization of the azo-chiral compound and thus its HTP value. The reflection bands of the reflector before and after UV illumination are consistent with the related simulation results by using 4X4 Berreman matrix method. Such a thin film and soft reflector has potential in the development of all-optically controllable and adaptive optical devices.

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