Journal of Optoelectronics and Advanced Materials Vol. 7, No. 6, December 2005, p. 3111 - 3120

THE INFLUENCE OF UV IRRADIATION ON MAGNETO-OPTICAL EFFECTS IN AZO-DERIVATIVE DOPED LIQUID CRYSTALS

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Azo-derivative doped nematic liquid crystals were subjected to different d.c. magnetic fields and optical transmissions of a He-Ne laser beam (632.8 nm, 1 mW) were recorded for different field strengths. In order to follow these effects both Faraday and Voigt configurations were used, i.e. the magnetic field was parallel and perpendicular to the incident light, respectively. It was found that small addition of azo-dyes (2% by weight) induced optical activity into the nematic liquid crystal cells. The rotation angle and the light transmission varied periodically with the applied magnetic field. When subjecting the cells to UV irradiation, changes in the periodical behaviour of light transmission and optical activity were noticed. The cells behave like phase retardation plates, the phase difference depending on cell thickness, magnetic field strength and UV irradiation time.

(Received October 14, 2005; accepted November 24, 2005)

Keywords: Nematic liquid crystal, azo-dyes, rotatory power, photoisomerization, Faraday effect

1. Introduction

The electrical and optical properties of azo-doped liquid crystals have been extensively studied in the last decade, due to their potential applications in optoelectronics and information processing [1]-[5]. As shown by Peltzl [6], the azo-dyes have two stable configurations *trans* and *cis*. The *trans* isomer is energetically more favourable due to its elongated shape and favours the nematic order. Using UV irradiation, a fraction of the azo-dye molecules are converted into the *cis* form. A small amount of *cis* isomer exists in the unexcited state.

Recently, it was found that laser-induced effects are enhanced when adding small amounts of azo-dyes [7], [8]. These phenomena have been explained assuming that the molecular director experienced a light-induced torque [9], [10].

There are other interesting topics, such as magneto-optical effects, which have been less studied. These effects arise when light interacts with the substance in the presence of a magnetic field. The most important are Faraday and Voigt (also known as Cotton-Mouton) effects.

Our work is concerned to the study of magnetic field effects on some azo-dye doped nematic liquid crystals. The paper is organized as follows:

After a short description of the experimental procedure, the results obtained when subjecting liquid crystal (LC) cells, filled with azo-dye doped nematics, are described and discussed. The studies were performed for cells exhibiting different thicknesses, when using both Faraday and Voigt configurations. Experimental data referring to magnetic field effects on light transmission, rotatory

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power and ellipticity are presented and discussed. Finally, the influence of UV irradiation on these properties is explained.

2. Experimental

Liquid crystal cells, with Mylar spacers of different thicknesses, were filled by capillarity with mixtures of nematic liquid crystal (Merck MLC-6601) and small amounts of azo-derivatives. Before filling, the cells plates were chemically and mechanically processed to obtain either planar or homeotropic alignment.

In order to study the magneto-optical effects, an experimental equipment, described in detail in [11], [12], was used. Magneto-optical effects were investigated for both Faraday and Voigt configurations, i.e. the magnetic field was parallel, respectively perpendicular to the incident light (a He-Ne laser beam, 632.8 nm, 1 mW).

3. Results and discussion

All mixtures containing azo-derivatives displayed a small rotatory power. It may be assumed that the *cis* isomer is responsible for this optical activity as it is present, in a small amount, in the nonirradiated mixture. This assumption is in good agreement to some experimental results obtained by Malia et al. [13] and Heppke and Moro [14]. They noticed that bend molecules, such as "banana-shaped" or "bent-shaped", dispersed into a nematic liquid crystal induced chirality, in the case of proper sterical packing. As the cis isomer has a "V" shape, its behaviour is similar to that of a "banana-shaped" molecule. The general behaviour of the azo-doped nematics subjected to magnetic fields does not depend on the chemical structure of the azo-derivative compound [15]. Therefore, in this paper, only the results obtained when using as additive Methyl Orange (2% by weight) will be presented.

3.1. Magneto-optic effects under Faraday configuration

Under magnetic field, the mixtures experience a Freedericksz transition, the critical field being given by

$$H_c = \frac{\pi}{d}\sqrt{\frac{K_1}{\chi_a}}, \qquad (1)$$

where d is the cell thickness, K_1 the splay elastic constant and χ_a the anisotropy of magnetic susceptibility.

When subjecting the LC cell to magnetic fields higher than H_c, the light transmission and the rotation angle varied quasiperiodically. The results are shown in Fig. 1 and Fig. 2, for planar oriented LC cells.

The oscillations of the transmitted light are due to the interference of extraordinary and ordinary rays passing through a birefringent slab. Similar results were obtained when a LC cell was subjected to a d.c. electric field [16]. The transmitted light intensity is given by

$$I = I_0 \sin^2[2\Phi(B)]\sin^2\frac{\delta}{2}, \qquad (2)$$

where $\Phi(B)$ is the angle between the optical axis of the monochromatic light wave and the director of the LC molecules and [17]

$$\delta(B) = \frac{2\pi d}{\lambda}\Delta n(B)\sin^2\theta(B), \qquad (3)$$

where $\theta(B)$ is the angle between the optical axis of the LC and the light propagation direction, d is the cell thickness and $\Delta n = n_e - n_o$ the LC birefringence.

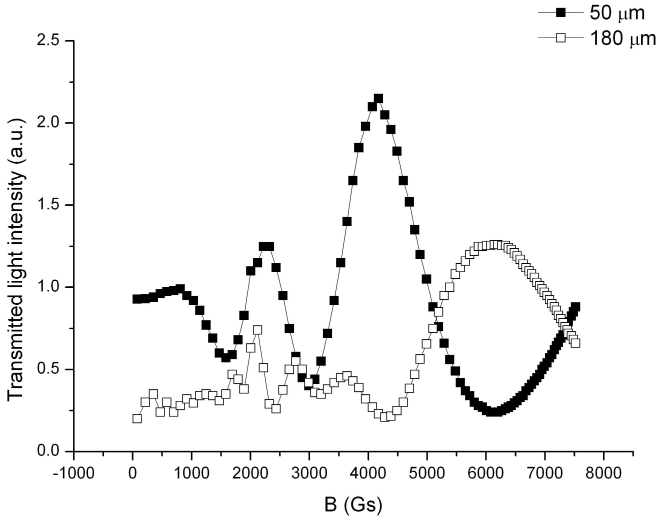

Fig. 1. Light transmission versus magnetic field strength for LC cells with planar alignment and two different thicknesses.

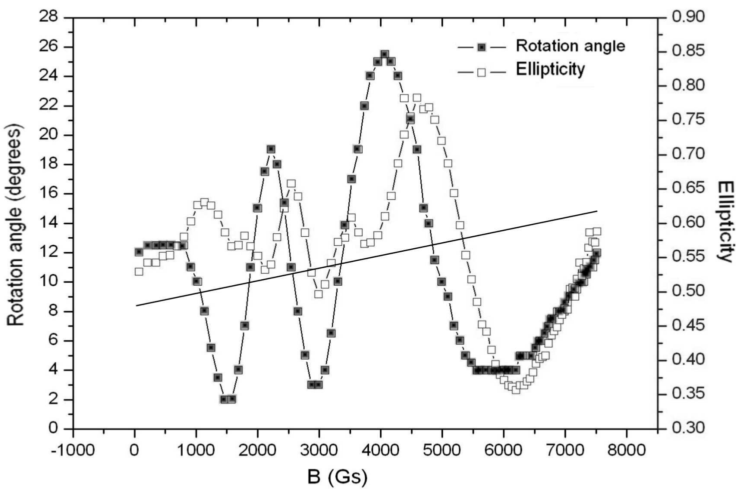

Fig. 2. Rotation angle and ellipticity versus magnetic field strength for a LC cell with planar alignment and 50μm thickness. The straight line gives the mean value of the rotation angle.

For a planar oriented sample, $\theta \approx \pi / 2$ and $sin^2 \theta \approx 1$. Therefore, instead of Eq. (2) we have to consider

$$I = I_0 \, sin^2 [2\Phi(B)] sin^2 \left[\frac{\pi d}{\lambda} \Delta n(B) \right]. \tag{4}$$

From the results presented in Fig. 2 we may conclude that the linear polarized light of the He-Ne laser beam, when passing through the sample, becomes elliptically polarized. The ellipticity is given by $tan\,\eta = \sqrt{B/A}$, where B and A are the half-axes of the ellipse, which can be determined experimentally using the formula

$$tan\,\eta = \sqrt{\frac{I_{min}}{I_{max}}}\,, \tag{5}$$

where I_{min} is the light intensity measured by rotating the polarizer up to the maximum extinction of the transmitted light and I_{max} is the maximum intensity of the transmitted light.

As shown in Fig. 2, the ellipticity varies quasiperiodically when increasing magnetic field strengths.

If the polarizer is eliminated, the LC cell behaves as a retardation plate (Table 1). When the ellipticity has a minimum value one obtains a wave (λ) or a half-wave ($\lambda/2$) retardation plate (corresponding to the minimum or maximum for the rotation angle, respectively). A quarter-wave retardation plate ($\lambda/4$) is obtained when the ellipticity acquires a maximum value.

By examining the results given in Table 1, we may infer that the type of retardation depends on both cell thickness and magnetic field strength.

Table 1. Liquid crystal phase retardation plate characteristics obtained for two cells with different thicknesses, under magnetic field.

B (Gs)	NMO 50 μm	NMO 180 μm	B (Gs)	NMO 50 μm	NMO 180 μm
1138.5	λ/4		3530	λ/4	
1470		λ	3840	λ/2	
1580	λ		3955		λ/4
1790	λ/4		4280		λ
2005		λ/4	4700	λ/4	
2220	λ/2		4990		λ/4
2550	λ/4		5870		λ/2
2990	λ		6200	λ	
3200		λ/2			

The qusiperiodical changes of the rotation angle, occurring when increasing magnetic field strengths, are due to displacements of molecular director. Recently, Brasselet et al. [18] and Krimer et al. [19] have shown that, when a circularly polarized light is passing through a liquid crystal, the molecular director experienced both precession and nutation movements with different frequencies. If we take into account that any linear polarized beam may be considered as a superposition of two opposite circularly polarized beams, then the qusiperiodical changes in the rotation angle are due to the competition between the above mentioned movements experienced by the molecular director.

A similar behaviour of the rotation angle was reported by Mansuripur [20] when examining Faraday effect in some magnetic materials.

We estimated the mean value of the rotation angle and its dependence on the magnetic field. As shown in Fig. 2, this dependence is given by a straight line. This is an indication that the mean value of the rotation angle depends linearly on B, as in Faraday effect.

When the LC cells are subjected to UV irradiation, changes in the light transmission (Fig. 3) and rotation angle (Fig. 4) are noticed. The intensity of the transmitted light decreased after irradiation. This effect may be explained as follows:

As a result of irradiation, the number of *cis* isomers is increased. As known, when generating *cis* isomers, the nematic order is disturbed and, consequently, the intensity of transmitted light is decreased.

The rotation angle is increased by UV irradiation as a result of generation of new *cis* isomers, inducing optical activity. A slight shift in the positions of maxima of the rotation angle is noticed.

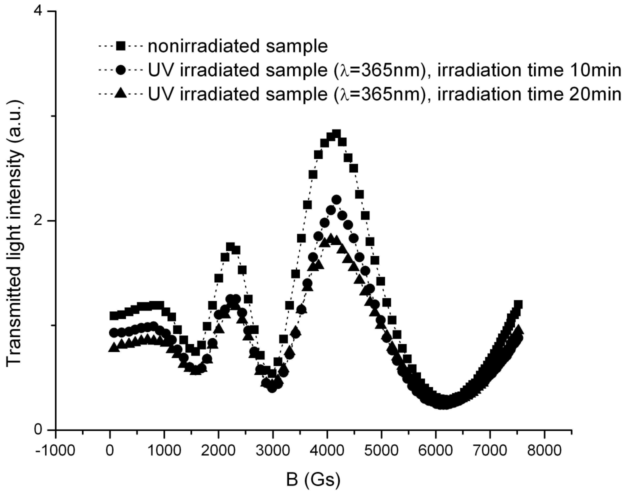

Fig. 3. The influence of UV radiation on the transmitted light intensity, for a cell of 50 μm thickness.

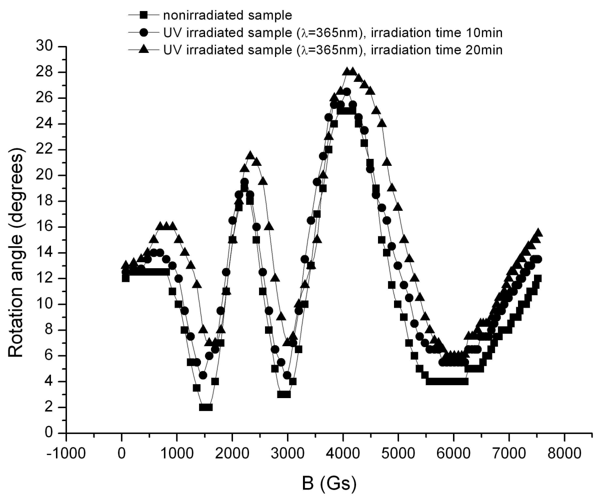

Fig. 4. The influence of UV radiation on the rotation angle, for a cell of 50 μm thickness.

3.2. Magneto-optic effects under Voigt configuration

Homeotropically aligned samples were used to examine magnetic field effects in Voigt configuration. Under such circumstances, the critical magnetic field for Freedericksz transition is given by

$$H_c = \frac{\pi}{d}\sqrt{\frac{K_3}{\chi_a}}, \tag{6}$$

where K_3 is the bend elastic constant.

When using magnetic fields higher than the critical one, quasiperiodical changes in light transmission, rotatory power and ellipticity were noticed (Fig. 5 and Fig. 6).

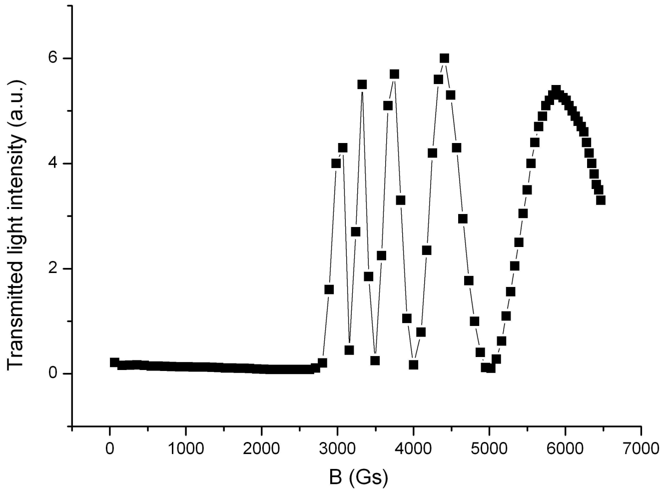

Fig. 5. Light transmission versus magnetic field strength, for a homeotropically aligned cell with 60 μm thickness.

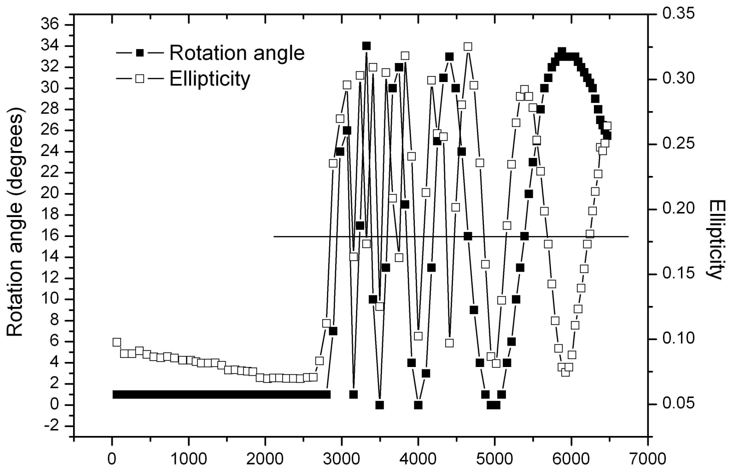

Fig. 6. Rotation angle and ellipticity versus magnetic field strength, for a homeotropically aligned cell with 60 μm thickness. The straight line gives the mean value of the rotation angle.

In this case, the transmitted light intensity is given by

$$I = I_0 \, sin^2[2\Phi(B)] sin^2\left[\frac{\pi d}{\lambda} \Delta n_{eff}(B)\right], \tag{7}$$

where $\Delta n_{eff} = n_{eff} - n_o$ is the effective birefringence of the liquid crystal cell and

$$n_{eff} = \frac{1}{d}\int_0^d \frac{n_e n_o}{\sqrt{n_o^2 \sin^2\theta(z) + n_e^2 \cos^2\theta(z)}}dz\,, \tag{8}$$

where n_e, n_o are the refractive indices of extraordinary and ordinary rays, respectively. θ is the angle between the molecular director and the light propagation direction. The boundary conditions for homeotropic alignment are $\theta(z=0) = \theta(z=d) = 0$.

As for Faraday configuration, the light emerging from the LC cell is elliptically polarized, which is an indication that the LC cell behaves as a retardation plate (Table 2).

Table 2. Liquid crystal phase retardation plate characteristics obtained for different magnetic field strengths under Voigt configuration.

B (Gs)	NMO 60 μm	NMO 180 μm	B (Gs)	NMO 60 μm	NMO 180 μm
1 840		λ/4	3 410	λ/4	
2 030		λ	3 495	λ	
2 110		λ/4	3 580	λ/4	λ/4
2 190		λ/2	3 750	λ/2	λ
2 280		λ/4	4 000	λ	
2 370		λ	4 100		λ/4
2 460		λ/4	4 175	λ/4	
2 630		λ/2	4 410	λ/2	
2 710		λ/4	4 490		λ/2
2 890		λ	4 650	λ/4	
3 070	λ/4	λ/4	5 020	λ	λ/4
3 155	λ		5 390	λ/4	
3 240	λ/4		5 600		λ
3 325	λ/2	λ/2	5 925	λ/2	

The effects induced by UV irradiation are slightly different when this configuration is used. The influence of UV irradiation on the intensity of transmitted light and rotation angle are shown in Fig. 7 and Fig. 8. As expected, the transmitted light intensity is decreased, while the rotation angle is slightly increased as a result of UV generation of new *cis* isomers. For the irradiated LC cell, the positions of maxima and minima of transmitted light intensity and rotation angle are shifted to higher magnetic field values.

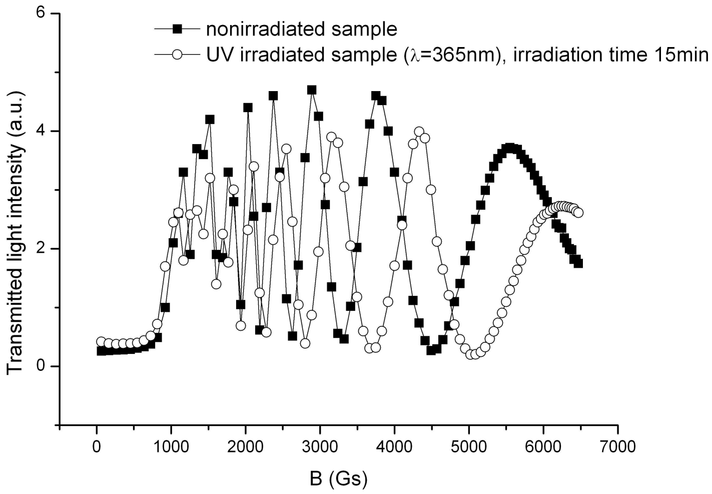

Fig. 7. Light transmission versus magnetic field strength, for a nonirradiated and irradiated LC cell, homeotropically aligned, with 180 μm thickness.

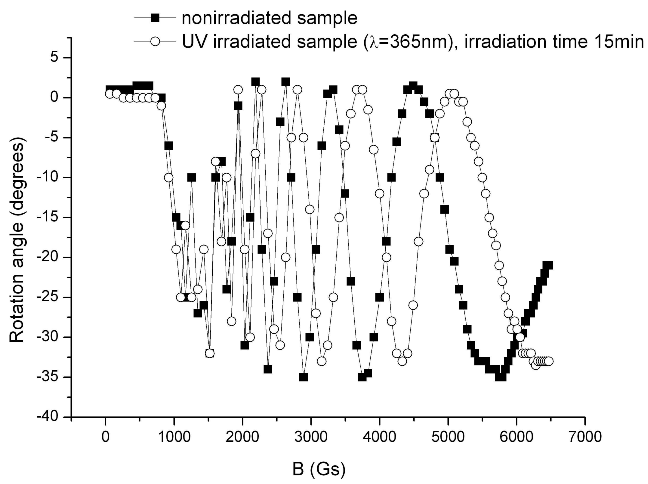

Fig. 8. Rotation angle versus magnetic field strength, for a nonirradiated and irradiated LC cell, homeotropically aligned, with 180 μm thickness.

This may be explained as follows: When a homeotropic alignment is involved, the benzene rings of the *cis* isomer lie in a plane perpendicular to the magnetic field. Under magnetic field action, the benzene rings are oriented parallel to the field direction, in order to minimize the free energy. To fulfil this condition, a higher energy (higher magnetic field strength) is required.

Changes in the ellipticity, as a result of UV irradiation, are shown in Fig. 9. Although only a slight decrease for $tan\,\eta$ is observed, when examining the irradiated sample important changes in the positions of maxima and minima in the $tan\,\eta = f(B)$ plot are noticed. For example, when $B = 5600Gs$, the nonirradiated cell behaves as a λ retardation plate, while the UV irradiated cell behaves like a $\lambda / 4$ plate.

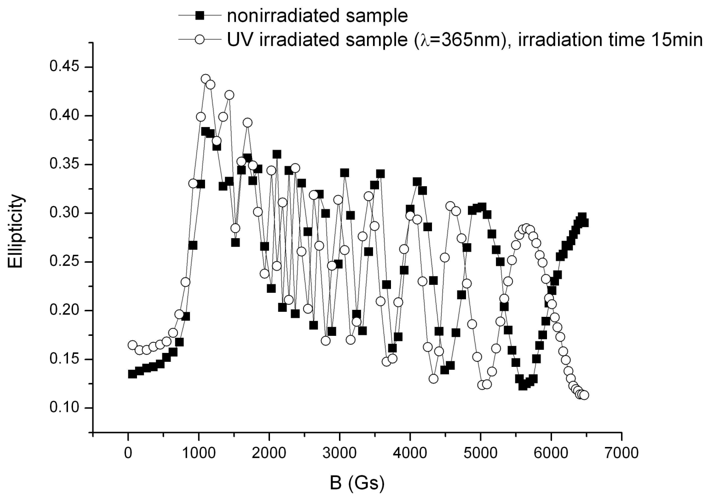

Fig. 9. Ellipticity versus magnetic field strength, for a nonirradiated and irradiated LC cell, homeotropically aligned, with 180 μm thickness.

Consequently, the phase retardation type of an azo-doped nematic cell is controlled by its thickness, magnetic field and UV irradiation time.

Finally, we estimated the mean rotation angle in a LC cell homeotropically aligned (Fig. 6). It results a constant value, i.e. the mean rotation angle does not depend on the magnetic field strength. Therefore, no linear Faraday effect is obtained when using Voigt configuration at normal incidence. This result is in good agreement with the general considerations referring to magneto-optical effects.

5. Conclusions

The linearly polarized light of a He-Ne laser beam is converted into elliptically polarized one, when passing through azo-dye doped LC cells.

A Faraday-like effect was noticed when the magnetic field was applied parallel to the incident light direction: the mean rotation angle increased linearly with the magnetic field.

When using Voigt configuration, at normal incidence, the mean rotation angle keeps a constant value when increasing/decreasing magnetic field strengths.

We consider that the cis isomer is responsible for the induced optical activity. The percentage of this isomer is increased by UV irradiation ($\lambda = 365nm$) and changes in the light transmission, optical activity and ellipticity are revealed.

Azo-dye doped LC cells subjected to magnetic field behave like retardation plates, the retardation type depending on the cell thickness, magnetic field strength and irradiation conditions.

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