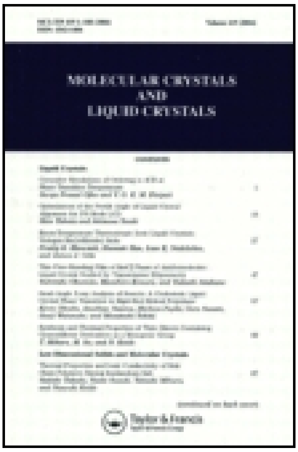

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The Refractive Index Grating Formation in Azo Dye Doped Nematic Liquid Crystal

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The formation of refractive index grating in pure and doped Nematic Liquid Crystal (pure 5CB and doped with SBB) in planar cells has been investigated. A DC voltage is applied to the samples and a He-Ne laser is used as writing beam to form the grating. It is observed that doping the LC with azo dye leads to higher diffraction efficiency with respect to the pure one and lower needed writing beam intensities. These observations are described by orientation of liquid crystal molecules, which can only be detected by P-polarized probe beam.

1. Introduction

Controlling the refractive index of matter, which is possible in nonlinear optical materials, could play a primary role in most of the photonic devices such as optical switches, modulators, memories and holographic gratings. Nematic liquid crystals (NLC) possess several characteristics that make them an appropriate candidate to be used in such devices. Light induced optical nonlinearity, due to reorientation of the liquid crystal (LC) molecules, has gathered a great interest in recent decades [1, 2]. Various reasons have been proposed for explaining the enhancement of refractive index changes in dye doped LC mediums which could be done easier and more than that of pure LCs [3, 4]. For example, the photorefractive effect through the space charges field (E_{sc}) causes the LC molecules to rotate, leading to refractive index changes [5–7]. The Formation of the mentioned space charges field has been studied in many literatures by investigating the creation of photo charges, which mostly focus on dopants and/or impurities ionization, inhomogeneous photo induced conductivity as well as dielectric and conductivity anisotropies of NLC [8–11]. In what follows, a comparison is performed between the grating formation in 20 μm cells of pure and doped 5CB as well as investigation of the effect of writing beam intensity and applied voltage on them. Finally to investigate the cell thickness effect, a 7 μm DDLC sample is also studied for permanent grating formation.

2. Experimental Results and Discussion

The planar aligned cells (HG) were used in the experimental setup of degenerate two wave mixing. The thickness of empty cells was measured via the interferometer. A 20 μm

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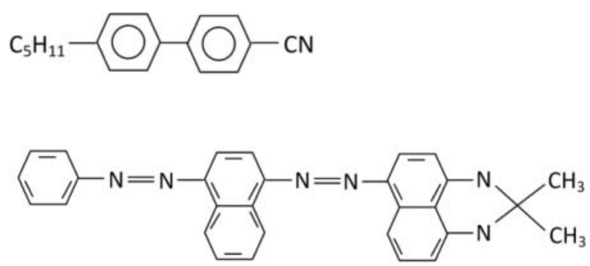

Figure 1. Molecular structure of 5CB nematic liquid crystal (up) and Sudan Black B dye (down).

thickness HG cell was filled with pure 5CB liquid crystal and the other two 20 μm and 7 μm thickness HG cells were filled by 5CB doped with 0.1% wt of the Sudan Black B (SBB) dye. The molecular structure of 5CB and SBB are shown in Fig. 1. Sudan black b is a diazo dye and has a long molecular structure, its rod like molecular shape and lack of lateral groups result in high polarizability of the molecule along the long molecular axis. Because of the mentioned features this dye has a suitable dichroic ratio and order parameter in aligned liquid crystal environments [12–15].

The experimental setup used in this investigation is schematically shown in Fig. 2. Since the maximum absorption wavelength of SBB dye is around 620 nm, a He-Ne laser with wavelength of 632.8 nm is used as the pump beam. Also another He-Ne laser with a very lower power is used as a probe beam.

The angle between two writing beams (α) is less than 1 degree and the angle β is about 1.5 degrees. The cell with thickness of 20 μm containing pure 5CB is illuminated by P-polarized writing beams each having 1.7 mW powers with 1.5 mm diameter on the sample and it took 5–10 minutes to start the grating formation. But it is observed that for the doped sample the grating forms instantly with up to 5 diffraction orders (not shown in the Fig. 2). It shows that the grating formed in the cell is a Raman-Nath grating. It is possible to investigate the modulation of refractive index using the simplified Kogelnik's

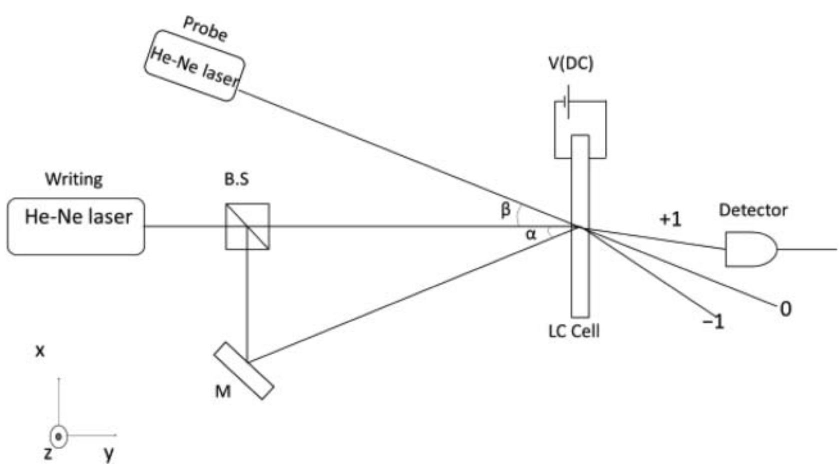

Figure 2. Experimental setup (top view) of two wave mixing. The LC director is in x direction. M and B.S. denote the mirror and beam splitter, respectively.

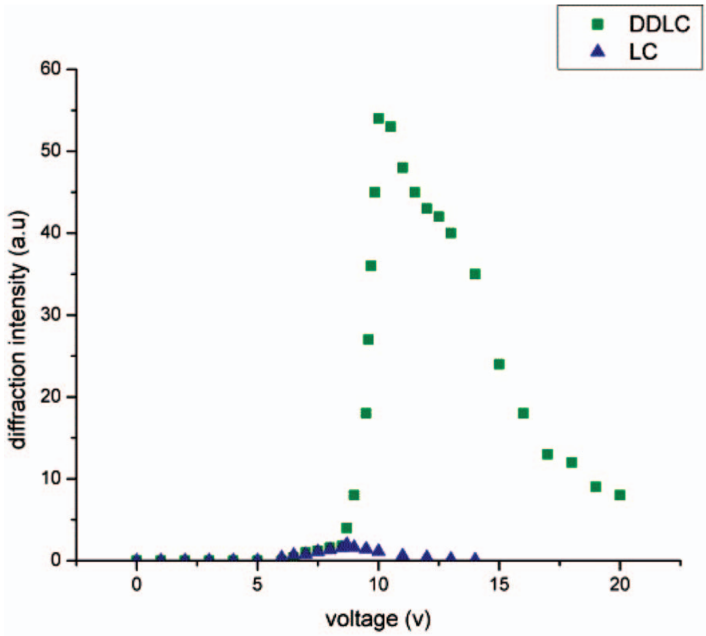

Figure 3. First order diffraction of the probe beam with "P" polarization versus voltage for pure LC (triangles) and doped LC (squares).

formula [16]. Variation of the first order diffracted light intensity with respect to the applied DC voltages is shown in (Fig. 3), in which all the used beams have "P" polarization.

According to the results the ratio of the maximum amount of the first order diffracted light intensity in doped sample is about 20 fold of that in pure sample. Also by increasing the applied voltage, this intensity is vanished beyond 13 volt but remained up to 20 volt for pure and doped samples, respectively. Moreover, the grating formation process in both LC and DDLC samples is studied for "S" and "P" polarizations of the pump beam. In both cases, the created grating is observed by P-polarized and not with the S-polarized probe beam. Additionally, the effect of intensity of writing beams on the diffraction efficiency in both pure and doped samples is investigated. The threshold writing power for the formation of grating in pure LC is about 0.6 mw while for the DDLC sample it is less than 0.1 mW (Fig. 4).

According to Fig. 4 the diffraction efficiency of DDLC has a growing rate with increasing the writing beam power, but the results of the pure sample do not show a significant variation.

It is worth mentioning that long exposure time of the thinner sample of DDLC with setting a proper writing intensity causes the grating to become permanent. By illumination of the 7 μm sample after 60 minutes and then turning off the pumps (or even turning off the applied DC electric field) the diffracted light intensity suddenly decreases but does not fall to zero (as illustrated in Fig. 5) and the obtained permanent grating remains for several months.

The Fredericksz transition is measured to be 3.7 and 6.2 volt for pure and doped LCs, respectively. As it can be seen in Fig. 3, for both of the samples the grating forms with the voltages above the Fredericksz threshold. Since for both polarization of writing beams

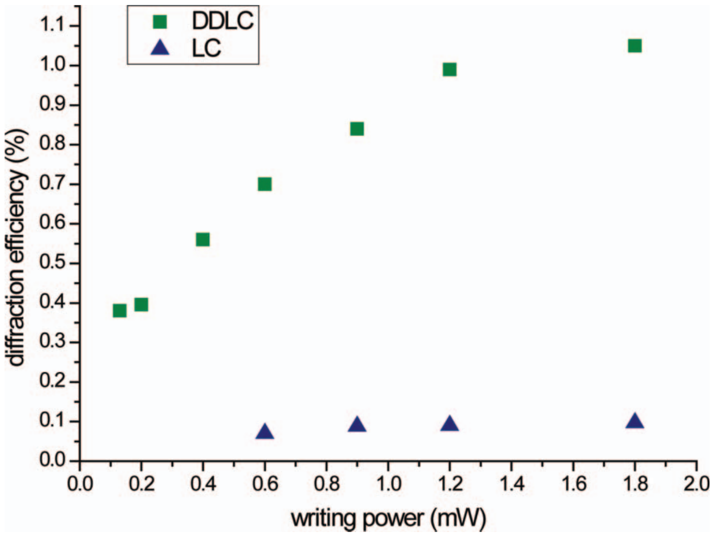

Figure 4. Diffraction efficiency variation versus the power of writing beams (squares for DDLC and triangles for LC).

there is not any observed grating with S-polarized probe beam in the samples, it could be concluded that the formation of the grating is due to the reorientation of LC molecules in *xoy* plane. This result shows that the reorientation is not because of the optical field torque. We believe it is the consequence of ions generation and their accumulation near the surface in bright zones, that induces the space charges field (E_{sc}) with a maximum amount between the bright and dark regions of the interference pattern, leading to a photorefractive

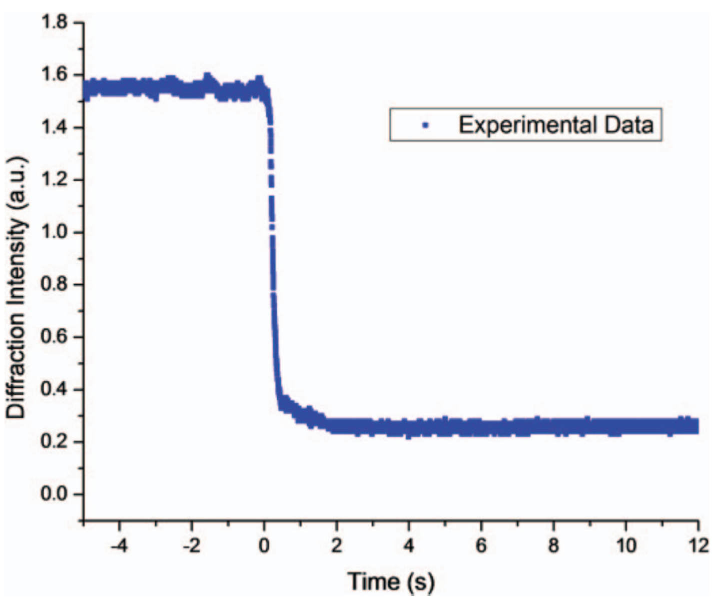

Figure 5. First order diffraction intensity of probe beam versus time for 7 micron sample of DDLC. The 4 mW writing beams are removed at point zero.

like effect. The applied DC field reorients the LC molecules parallel to *y* axis, and the E_{sc} field reorients them toward the *x* direction. Therefore, the competition of these mentioned fields leads to different reorientation of the molecules in periodic regions of the sample and create a refractive index grating. As mentioned above, the generation of E_{sc}, through the photorefractive like effect, causes the reorientation of the molecules in the *xoy* plane. So the grating could be detected by "P" polarization probe beam and not with an "S" polarization.

For applied voltages above 10 volts, the external field suppresses the E_{sc} and causes the reduction of the periodic refractive index changes. So, by further increasing the applied DC voltage, the diffraction intensity tends to become zero (Fig. 3). The important issue is that the time spent for grating formation in pure LC is believed to be dedicated to ionization of LC impurities, where, its reduction in DDLC is related to the photo-excitation of the dye molecules in which the presence of external DC electric field leads to ionization of dyes. Also the structure of dye molecules is an important parameter in the generation of E_{sc} in which in dye doped LC the number of ions producing E_{sc} is considerably more than that of pure case thus leading to higher efficiency in this sample (Fig. 4).

3. Conclusion

The experimentally obtained results show that the formed grating with both "S" and"P" polarization of the writing beams is only detected by P-polarized probe beam. This is due to the reorientation of LC molecules that occur in *xoy* plane and it could not be generated by the optical torque. So, it is possible to include other phenomena such as photorefractive like effect. The difference between threshold powers in LC and DDLC samples and also the growing rate of diffraction efficiency with increasing the writing power are explained by the ion generation conditions. In DDLC sample, by increasing the writing beam intensity the amount of photo-generated ions increases and leads to a larger E_{sc} field in the sample, which results in to a higher diffraction efficiency. However, in the studied pure sample, the mentioned amount (which is different from that in doped sample) reaches to its saturation value quickly.

Finally, it is observed that for thinner cells under a long illumination time the formed grating remains for several months. This is believed to be related to the attachment of the ions to the cell's surface which affects the reorientation of inner LC molecules in the cell.

References

[1] Janossy, I. & Lloyd, A. D. (1991). *Mol. Cryst. Liq. Cryst*, *203*, 77.
[2] Janossy, I. & Kosa, T. (1992). *Opt. Lett., 17*, 17.
[3] Petrrosian, A. & Residori, S. (2003). *Optics Communications*, *228*, 145.
[4] Muenster, R., Jarasch, M. & Shen, Y. R. (1997). *Physical Review Letters*, *78*(1), 42.
[5] Klysubun, P. & Indebetouw, G. (2002). *Applied Physics*, *91*(3), 897.
[6] Khoo, I. C., Chen, K. & Williams, Y. Z. (2006). *IEEE Journal of Selected Topics in Quantum Electronics*, *12*(3), 443.
[7] Gunter, P. & Huignard, J. P. (2007). *Photorefractive Materials and their Applications, 2*, Springer.
[8] Khoo, I. C., Li, H. & Liang, Y. (1994). *Opt. Lett.*, *19*, 1723.
[9] Khoo, I. C. (1996). *IEEE Journal of Quantum Electronics*, *32*, 3.
[10] Bartkiewicz, S., Januszko, A., Miniewicz, A. & Parka, J. (1996). *Pure Appl. Opt*, *5*, 799.
[11] Parka, J. (2002). *Opt. Elect.Rev.*, *10*(1), 83.
[12] Ghanadzadeh, A., Zakerhamidi, M. S. & Tajalli, H. (2004). *Journal of Molecular Liquids*, *109*, 143.

[13] Ghanadzadeh, A., Ghanadzadeh, H. & Ghasmi, G. (2000). *Journal of Molecular Liquids*, *88*, 299.
[14] MajlesAra, M. H., Bahramian, R., Mousavi, S. H. & abolhasani, M. (2009). *Journal of Molecular Liquids*, *149*, 18.
[15] MajlesAra, M. H., Mousavi, S. H., Salmani, S. & Koushki, E. (2008). *Journal of Molecular Liquids*, *140*, 21.
[16] Matczyszyn, K., Bartkiewicz, S. & Sahraoui, B. (2002). *Optical Materials*, *20*, 57.