Available online at www.sciencedirect.com

SCIENCE DIRECT®

Dyes and Pigments 63 (2004) 239–242

DYES and PIGMENTS

www.elsevier.com/locate/dyepig

Molecular reorientation based diffraction in dihydropyridin doped nematic liquid crystal film

S. Eren San*, Oğuz Köysal, Mustafa Okutan

Department of Physics, Gebze Institute of Technology, P. O. Box 141, Gebze 41400 Kocaeli, Turkey

Received 14 January 2004; received in revised form 1 March 2004; accepted 12 March 2004

Abstract

The change of refractive index, originated by photo induced molecular reorientation, brings about a significant diffraction capability in a liquid crystal system doped by 1,4-dihydropyridin. Results of a grating diffraction experiment are reported for the constructed sample. The accessible diffraction efficiency is roughly of the order of 10% under the optimum conditions and analyzed results propose this novel system to be appropriate and promising for the excitation wavelength of an He–Cd laser.

Keywords: Nematic liquid crystals; Dye doped; Dihydropyridin; Molecular reorientation; Grating diffraction

1. Introduction

Liquid crystals (LC) are highly nonlinear optical materials due to their needed property of activating under relatively low optical fields. Several nonlinear mechanisms so far investigated have revealed the advantages of these materials. The difference in refractive indices, for fields polarized along, and perpendicular to, the director axis brings about a large birefringence property, which is an advantage for various applications [1]. Director axis reorientation based effects causing a change of refractive index and showing several interesting dynamic and storage wave-mixing effects have been extensively studied [1–6]. Compared with others, LC based systems require lower characteristic voltages to be applied for the realization of molecular gratings and relatively lower light power for efficient modulation of refractive index. It is experimentally proven that doping a small amount of dye decreases the required threshold of molecular reorientation further in LC materials [7]. This phenomenon has potential applications such as holographic data storage. Because of the large broadband birefringence of nematic liquid crystals, it is obvious that these highly sensitive films could be applied in a variety of image processing systems operating with low optical power. Since many dyes exist that will cover the entire visible spectrum, such dye-doped nematic films are highly promising candidates for application as very broadband optical

* Corresponding author. Tel.: +90-262-6538497; fax: +90-262-6538490.

E-mail address: erens@gyte.edu.tr (S.E. San).

0143-7208/$ - see front matter © 2004 Elsevier Ltd. All rights reserved.
doi:10.1016/j.dyepig.2004.03.003

modulators and limiters, and other adaptive optics and coherent wave-mixing devices. Although details of molecular reorientation mechanisms are not in the scope of this work, dye molecules are somehow excited by absorbing the pumping beam and transferring their reorientation energy to neighboring LC molecules. These mechanisms are generally explained by Janossy effect, *trans–cis* photo-isomerization, or photorefractive-like reorientation, depending on the type and character of the doped agent [7]. This work investigates the employment of a new dye in a holographic application not previously considered.

2. Experimental

Before the construction of the cells, indium tin oxide (ITO) covered glass substrates were spin coated with polyvinyl alcohol (PVA) at 2000 rpm and were cured at 50 °C for approximately 2 h. The thickness of the coating was ~100 nm (±10 nm) and these coating layers were exposed to surface treatment of unidirectional rubbing with velvet in order to obtain preliminary molecular orientation. The final form of the constructed cell is planar with roughly 2 degree rubbing tilt. Measurement cells were made up of two glass slides separated by Mylar sheets having ~10 μm (±0.5 μm) thickness. These cells were filled by capillary action with the samples. Dye was dissolved within the LC in a tube placed in an ultrasonic water bath for 30 min. Chemical formulas of the dye, 1,4-dihydropyridin (DHP), and nematic host are depicted in Fig. 1. Two samples were prepared; one containing pure E7, one filled with E7 + DHP, 1% (w/w). The excitation wavelength of the dye is 476 nm, which is very close to and consistent with 441.6 nm wavelength of He–Cd laser.

The experimental set up is demonstrated in Fig. 2. It consists of a pumping source divided by a beam splitter into two components having approximately equal power. The pumping source is He–Cd (441.6 nm) whose polarization is arranged to be parallel to preliminary orientation of LC molecules. This polarization is actually

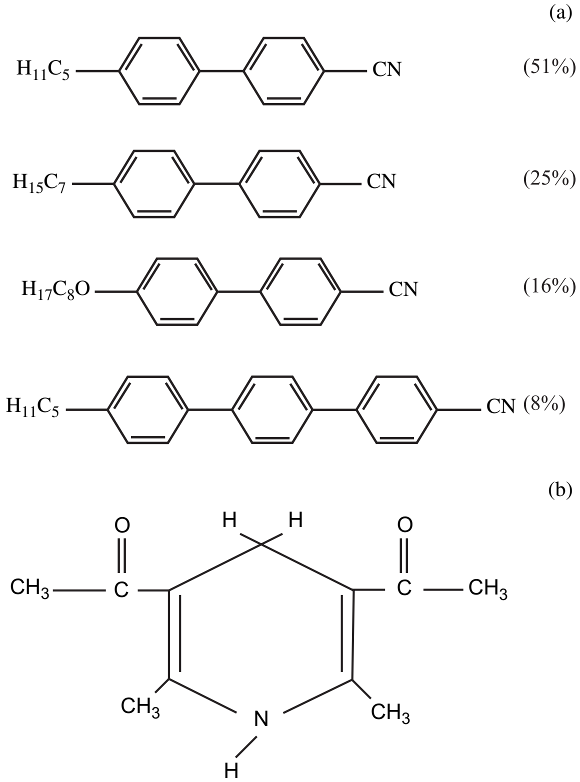

Fig. 1. Chemical formulas of: (a) nematic host, E7; (b) dye, DHP.

the dominant light–molecule interaction case. Pumping beams, having ~4 mW (±0.1 mW) power, were intersected on the sample with 3 degree that makes grating constant Λ to be 8.5 μm. Then $\Lambda^2 \gg \lambda d$, diffraction is in the Raman–Nath regime [8]. We also have carried out capacitive measurements whose applicability on the molecular analysis of reorientation has been examined previously [9]. In the current analysis, an impedance/gain phase analyzer (HP 4194 A) was used and various excitation voltages were examined. Measurements were carried out at optimized 10 kHz spot frequency whose rms amplitude is ~495 mV (±10 mV). Fig. 3 shows the dependency of capacitance on the applied DC voltage for pure E7 and doped sample. Dielectric anisotropy, $\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp}$, where $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are, respectively, the parallel and perpendicular of the electric permittivity, is also estimated from this

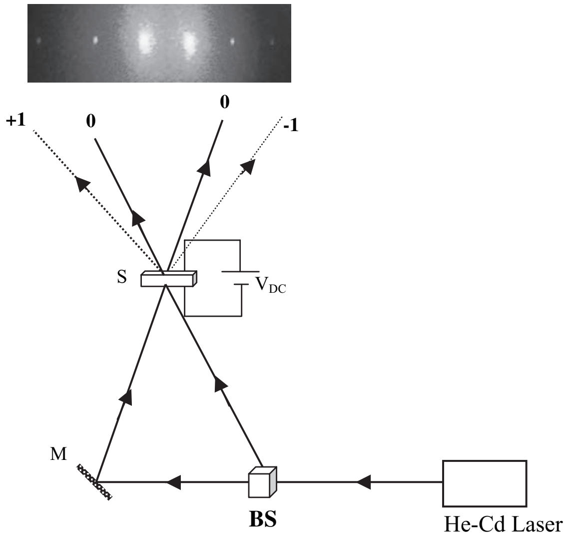

Fig. 2. The experimental set up. BS: beam splitter, M: mirror, S: sample (inset: photographs of self-diffraction spots).

capacitive measurements by eliminating dielectric permittivity of medium, ε, from Eq. (1).

$$C = \varepsilon_0 \varepsilon \frac{A}{d} \tag{1}$$

Here C is the capacitance value, ε_0 and ε are dielectric permittivity values of free space and concerned medium, respectively, A is the plate area and d is the thickness of the cell. By using capacitance values, dielectric constants were calculated according to Eq. (1) from where ε is eliminated. There are two structure types for the dielectric constant. One is the positive dielectric anisotropy (p-type) and its dielectric constant along the director axis is larger than that along the axes perpendicular to the director and $\Delta\varepsilon$ is greater than zero in this case. The other is the negative dielectric anisotropy (n-type) and its dielectric constant along the director axis is smaller than that along the axes perpendicular to the director, $\Delta\varepsilon$ is less than zero [10,11]. By exploiting the tendency of Fig. 3, borders of parallel and perpendicular permittivity (with respect to director axis) regions are determined. $\Delta\varepsilon$ is inferred from the extreme values of these regions and it is calculated to be positive showing our system to be

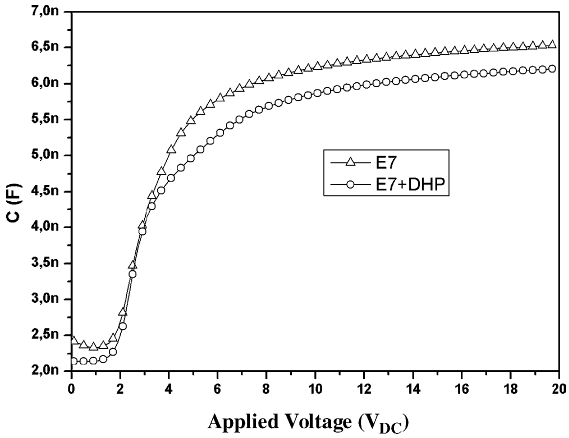

Fig. 3. Dependency of capacitance on the applied DC voltage for pure E7 and DHP doped sample (spot frequency 10 kHz).

determined as p-type. The effect of this DHP dye on $\Delta\varepsilon$ is presented in Table 1.

3. Results and conclusion

Grating diffraction experiments are the basis for performance evaluation of holographic applications. Therefore, the character of the systems was investigated in terms of the diffraction signals depending on applied DC voltage. The origin of diffraction is the molecular reorientation taking place in bright regions and grating is formed with bright–dark periodicity reinforced by interference pattern. Among the possible reorientation mechanisms, Janossy effect (dye enhanced optical torque) is the dominant factor of reorientation according to our experimental observations and the molecular shape of the dye. Once the dye molecules absorb laser energy they become excited and the LC molecules minimize their angular momentum so that the increase in the total angular momentum, caused by the energy absorption of dye molecules is compensated. This could be realized by the reorientation of LC host molecules.

Table 1
Dielectric anisotropy values of pure E7 and doped sample

	E7	E7 + DHP
$\Delta\varepsilon$	13.65	12.78

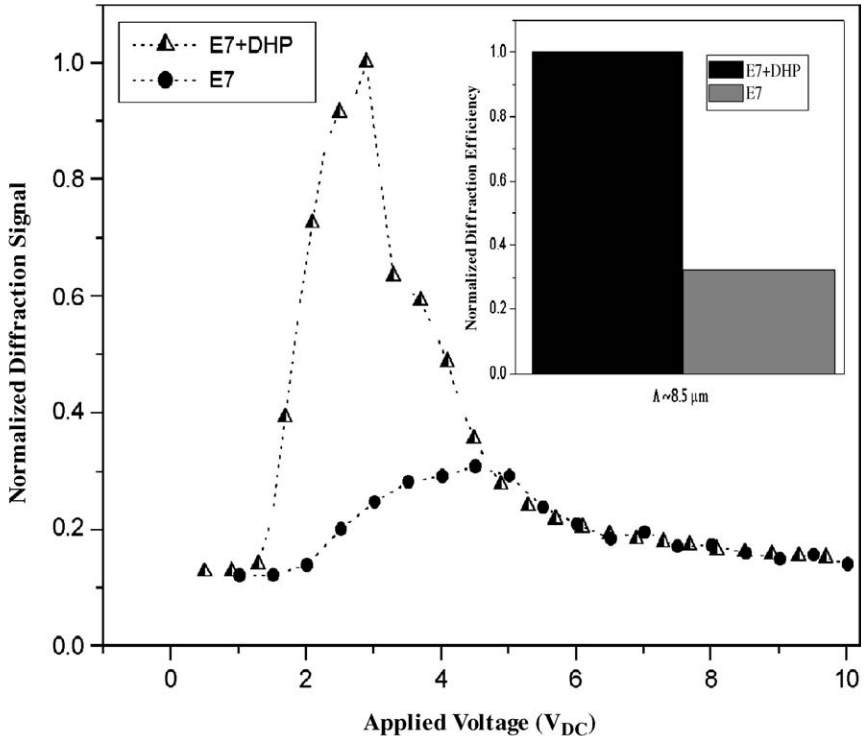

Fig. 4. Dependency of normalized diffraction signals on the applied DC voltage for pure E7 and DHP doped sample (inset: normalized values of diffraction efficiency).

Self-diffraction spots were considered in experiments and diffraction efficiency was measured as the intensity ratio of the first-order diffraction beam to the incident beam in the absence of one side of the two beams. For the constructed system, diffraction efficiency is $\sim 10\%$ ($\pm 1\%$) under optimum circumstances that are intersection angle of lasers $\theta = 3°$, $V_{DC} = 3$ V for laser intensities ~ 4 mW (± 0.1 mW). Fig. 4 demonstrates the dependency of diffraction signals on the applied DC voltage. As can be seen, the required amount of voltage for diffraction peaks is being shifted to lower values in the dye-doped sample and diffraction efficiency is significantly enhanced. The specialty of the examined LC system is mainly the doping dye which is used in this application for the first time. The results obtained and the performance evaluation of the system reveals the promising character of this dye in similar applications.

References

[1] Khoo IC, Shih M, Wood MV, Guenther BD, Chen PH, Simoni F, et al. Proc IEEE 1999;87(11):1897.
[2] Bartkiewicz S, Januszko A, Miniewicz A, Parka J. Pure Appl Opt 1996;5:799.
[3] Galstyan TV, Saad B, Denariez-Roberge MM. J Chem Phys 1997;107(22):9319.
[4] San SE, Köysal O, Ecevit FN. Opt Commun 2002; 212/4–6:405.
[5] Wang YJ, Carlisle GO. J Mater Sci Mater Elect 2002; 13:173.
[6] Miniewicz A, Bartkiewicz S. Parka J Opt Commun 1998; 149:89.
[7] Simoni F, Francescangeli O. J Phys Condens Matter 1999; 11:439.
[8] Hecht E, Zajac A. Optics. Massachusetts: Addison-Wesley; 1974.
[9] Okutan M, Köysal O, San SE. Displays 2003;24:81.
[10] Matsumoto S, Kadota I. Liquid crystals—fundamentals and applications. Tokyo, Japan: Kogyochosa-kai; 1991.
[11] Kawamoto H. Proc IEEE 2002;90:4.