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Molecular reorientation based diffraction in a hybrid liquid crystal system applicable for two different laser sources simultaneously

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Abstract

The change of refractive index, originated by photo induced molecular reorientation, brings about a concordant diffraction capability in a hybrid liquid crystal system consisting two different dyes, effective in different regions of the spectrum, at the same time. Results of grating diffraction experiments are reported for a sample set including two different doping agents with two variable lasers. Accessible diffraction efficiency is ~10% and ~7% for He–Cd and He–Ne lasers, respectively, under optimum circumstances in the hybrid system. Analyzed results propose this novel system to be compatible for two lasers at the same time.

Keywords: Optical materials; Liquid crystal; Dielectric properties; Optical properties

1. Introduction

Liquid crystals (LC) are highly nonlinear optical materials due to their sensitive property activating even under relatively low optical fields. Several nonlinear mechanisms investigated so far have revealed the promising characters 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 opportunity for various applications [1]. Director axis reorientation based effects causing the change of refractive index and observation of several interesting dynamic and storage wave-mixing effects have been extensively studied so far [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 proved 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 that will cover the entire visible spectrum exist, such dye-doped nematic films are highly promising candidates for application as broadband optical modulators and limiters, and other adaptive optics and coherent wave-mixing devices. This work concentrates on the co-usage of two different dyes at the same time in the structure of the same system so that the system would be appropriate for the simultaneous usage of two lasers.

In dye-doped samples light–molecule interaction could take place in different mechanisms dependent on the type of the dye. The anthraquinone derivatives and azo dyes are two important dye categories studied widely. Even though the discussion is still going on about the definite mechanism of dye enhanced molecular reorientation, effect of anthraquinone based dyes is well explained by Jánossy effect [8,9] unlike the azo dye based reorientation, which is being explained by *trans–cis* photoisomerization [3,5]. Methyl red (MR) is a favorite agent in azo dye category and it is extensively studied up to now. This is perhaps the most nonlinear optical material

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known. Such extraordinarily large nonlinearity enables the performance of several all-optical switching, limiting, image modulation, and sensing processes at unprecedented low threshold powers [10–15]. In fact Disperse Blue 14 (DB14) is another important dye, which is an anthraquinone derivative and also investigated in literature [4]. In the scope of this work two of these dyes were used together to reach our aim that is the construction of a system compatible for different lasers of different wavelengths at the same time.

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 they were cured at 50 °C for ~2 h. The thickness of the coating is ~100 nm and these coating layers were exposed to surface treatment of unidirectional rubbing with velvet in order to obtain preliminary molecular orientation. The ultimate form of the constructed cell is planar with roughly 2° rubbing tilt. Measurement cells were made up of two glass slides separated by Mylar sheets having ~10 μm thicknesses. These cells were filled in capillary action with the samples mixed in ultrasonic water bath for 30 min and

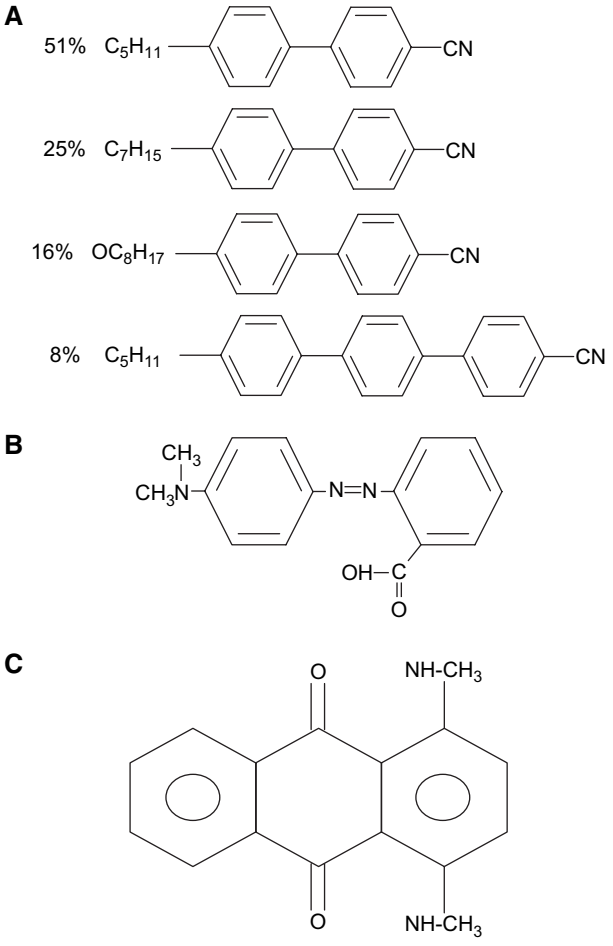

Fig. 1. Chemical formulas of (A) nematic host, E7; (B) azo dye, MR; (C) anthraquinone dye, DB14.

Table 1
Contents of measurement samples in percentage (w/w)

I	Pure E7
II	1% DB14 in E7
III	1% MR in E7
IV	0.5% DB14 + 0.5% MR in E7 (Hybrid)

chemical formulas of used dyes and nematic host are depicted in Fig. 1. Four samples were prepared, one of them contains pure E7, one is filled with E7 + MR, another contains E7 + DB14 and the other one, named as hybrid in this paper, contains E7 + MR + DB14. Table 1 demonstrates the contents of measurement samples in percentage (w/w) and Fig. 2 shows the absorbencies of these samples in visible spectrum. This figure reveals the fact that, the sample containing DB14 + MR at the same time has two peaks around the characteristic wavelengths of two of the concerned lasers as it was tried to be constituted while single agent containing samples give us expected peaks of their colors. The experimental set up is shown in Fig. 3. It consists of a pumping source, which is splitted into two components having approximately equal power by a beam splitter. The pumping source is arranged to be modular and two lasers were used: He–Ne (632.8 nm) and He–Cd (441.6 nm). Polarization of lasers is arranged to be parallel to preliminary orientation of LC molecules. This polarization is actually the dominant light–molecule interaction case. Pumping beams, having ~4 mW power, were intersected on the sample with ~3° that makes grating constant Λ to be 12.2 μm for He–Ne and 8.5 μm for He–Cd. Since $\Lambda^2 \gg \lambda d$, diffraction is in the Raman–Nath regime for both of these two lasers [16]. We also have carried out capacitive measurements whose applicability on the molecular analysis of reorientation was examined before [17]. In this analysis 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. Fig. 4 shows the dependency of capacitance on the applied DC voltage for pure E7 and hybrid

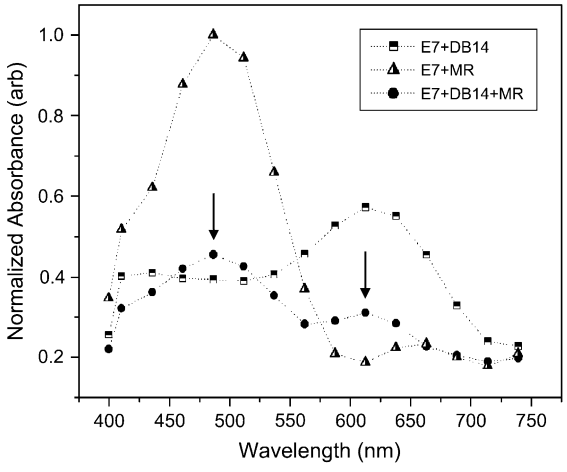

Fig. 2. Absorbance spectrum of dye-doped samples.

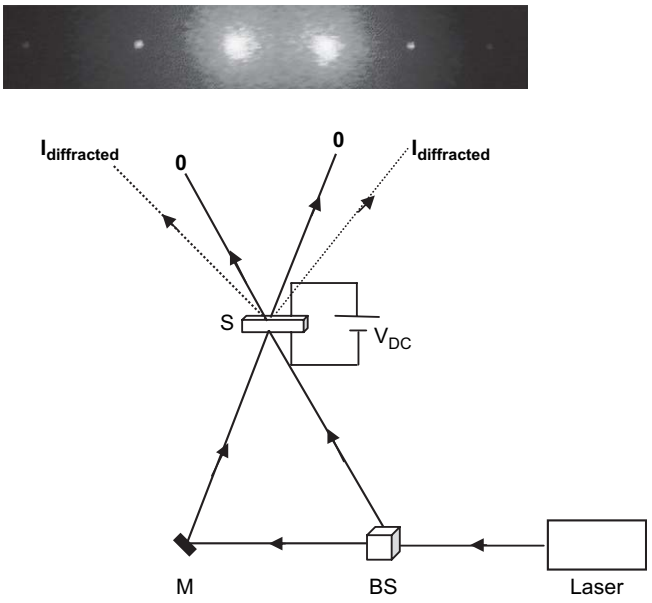

Fig. 3. The experimental set up (inset: photographs of self-diffraction spots). BS: beam splitter, M: mirror, S: sample.

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 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 which ε is eliminated. Regarding the dielectric constant, there are two structure types. One is

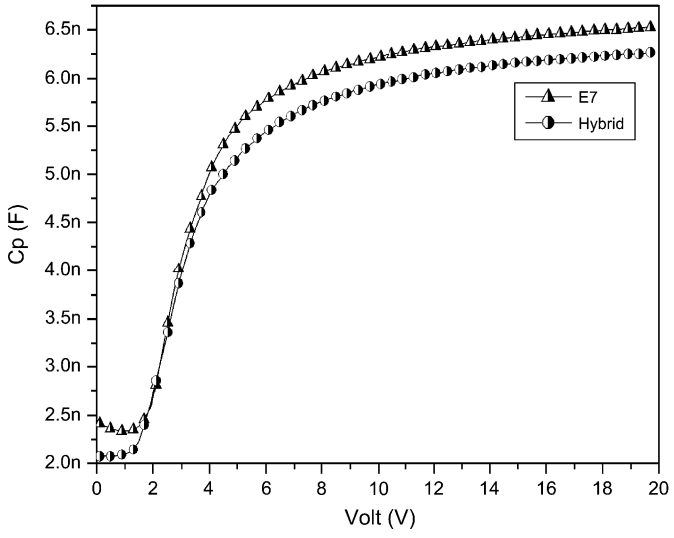

Fig. 4. Dependency of capacitance on the applied DC voltage for pure E7 and hybrid sample (spot frequency 10 kHz).

Table 2
Dielectric anisotropy values of pure E7 and hybrid sample

$\Delta\varepsilon$	E7	Hybrid
	13.65	12.35

called positive dielectric anisotropy (p-type) and its dielectric constant along the director axis is larger than that of it along the axes perpendicular to the director and $\Delta\varepsilon$ is greater than zero in this case. The other type is called negative dielectric anisotropy (n-type) and its dielectric constant along the director axis is smaller than that of it along the axes perpendicular to the director, $\Delta\varepsilon$ is less than zero [18,19]. By exploiting the tendency of Fig. 4, 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 yielding our system to be determined as p-type. $\Delta\varepsilon$ deviation of our hybrid sample is presented in Table 2.

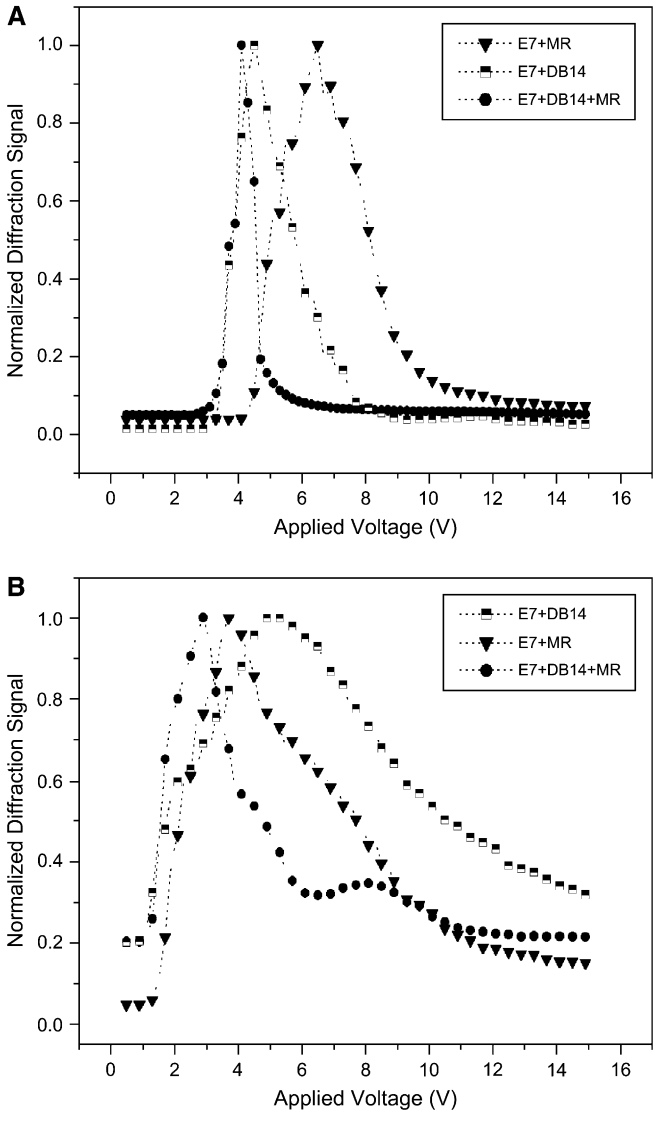

Fig. 5. Dependency of normalized diffraction signals on the applied DC voltage with (A) He–Ne pumping and (B) He–Cd pumping.

3. Results and conclusion

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 happening in bright regions and grating is formed with bright–dark periodicity reinforced by interference pattern. 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 hybrid system, diffraction efficiency is ~10% and ~7% for He–Cd and He–Ne lasers, respectively, under optimum circumstances that are intersection angles of lasers $\theta \sim 3^\circ$, $V_{DC} \sim 4$ V for laser intensities ~4 mW. Fig. 5 demonstrates the dependency of diffraction signals on the applied DC voltage. As it can be seen, the required amount of voltage aid for diffraction peaks is being shifted to lower values both under He–Ne pumping, Fig. 5a, and under He–Cd pumping, Fig. 5b, in the hybrid sample. This might be a noteworthy advantage depending on the purpose and structure of LC designs indeed.

Actually the specialty of the examined LC system is mainly the employment of two doping agents having principally different absorbance characteristics in the structure of the same system so that it would be appropriate in two different spectral regions. We think this character has important applications in technology and it is proposed to check a similar sample and experiment in Bragg regime. As a consequence, the sample including MR and DB14 at the same time exhibits applicability for two different lasers at the same time with relatively moderate efficiencies. Obtained results and performance evaluation of the system encourage the works on such hybrid designs for similar purposes.

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