Available online at www.sciencedirect.com
ScienceDirect
Dyes and Pigments 76 (2008) 13–16
DYES and PIGMENTS
www.elsevier.com/locate/dyepig

Diffraction efficiency and conductivity enhancement of nematic liquid crystals by doping star-like fullerenes

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Received 23 June 2006; received in revised form 27 July 2006; accepted 21 August 2006
Available online 16 October 2006

Abstract

We report the results for a grating diffraction experiment based on the employment of a novel agent, the so-called astralene namely star-like fullerene. Change of refractive index, originated by photo-induced molecular reorientation, causes a reasonable diffraction capability with respect to the results of other doped liquid crystal systems. Accessible diffraction efficiency is ~6% under optimum circumstances and analyzed results establish a reorientation lifetime at the order of 0.8 s. Experimental results also exhibit a dependence of the switching voltage on laser pumping in the reorientation process for doped sample. Analyzed results propose this novel system to be appropriate and quite fine for the excitation wavelength of an He–Ne laser.

Keywords: Liquid crystal; Astralene; Diffraction; Holography

1. Introduction

Liquid crystals (LC) are highly nonlinear optical materials due to their sensitive property activating under even 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 studied extensively 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. Fullerene doped LC systems are also studied for similar purposes [8,9]. Because of the large broadband birefringence of nematic LC, it is obvious that these highly sensitive films could be applied in a variety of image processing systems operating with low optical power. Actually, fullerene and/or dye doped nematic films are highly promising candidates for applications in adaptive optics and coherent wave mixing devices. Also the behavior of carbon nanotubes in nematic LC systems is subject to several interesting researches [10–12] due to the alignment control of nanotubes with their tube axes in the direction of the LC director. Another novel category of carbon nano-particles is the star-like fullerene, the so-called Astralene (ASTR), whose electro-optical behaviors and technological application possibilities are also under investigation [13–15].

This work concentrates on the investigation of holographic data storage possibility of ASTR doped LC samples as well as the contribution of ASTR in terms of the photo-induced characters of nematic LC.

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0143-7208/$ - see front matter
doi:10.1016/j.dyepig.2006.08.016

2. Experimental

Two cells were used whose thicknesses were 14 μm. They were made up of two conductive glass plates (ITO) with planar alignment. One of them contains pure E7 (from Merck). E7 is the mixture of four namatogens (51% K15, 25% K21, 16% M24, and 8% T15). Molecular structures of the sample components are depicted in Fig. 1. The other one was filled with 1% (wt/wt) Astralene, which was mixed with LC under the reinforcement of ultrasonic water bath effect. An experimental arrangement for the two-wave mixing is schematically shown in Fig. 2(a). It consists of an He–Ne ($\lambda = 632.8$ nm) pumping source and this source is split into two components having approximately equal power by a beam splitter. Polarization of laser is arranged to be parallel to preliminary orientation of LC molecules. This polarization is actually the dominant light-molecule interaction case. Pumping beams, having 10 mW power, were intersected on the sample with $\theta \sim 2°$ that makes grating constant Λ to be ~18 μm and since $\Lambda^2 \gg \lambda d$, diffraction is considered to be in the Raman–Nath regime. Conductivities of the samples were also measured under dark and laser illuminated conditions, using impedance analyzer. Experimental set-up for electrical measurements is given in Fig. 2(b). All measurements were carried out at room temperature.

3. Results and discussion

Nematic LC in its various pure and doped forms possesses many attractive and useful nonlinear optical responses. In this work, the character of the prepared system was firstly investigated in terms of the diffraction signals depending on applied dc voltage. There are several possible reorientation mechanisms proposed so far, depending on the doped agents. Although the used agent namely ASTR is employed for the first time in such an aim in this work, it is supposed to exhibit similar behavior to other carbon nano-complexes such as fullerenes. Our explanations on grating formation mechanism came from a model that space-charge complexes originating from the ASTR doping causes an induced electric field, which later reinforces the orientation of the director to be changes. In fact, this way of explanation is adopted from the famous photorefractive-like reorientation model which is very well suited to the characters of our doping agent in many respects such as the donor–acceptor property [16].

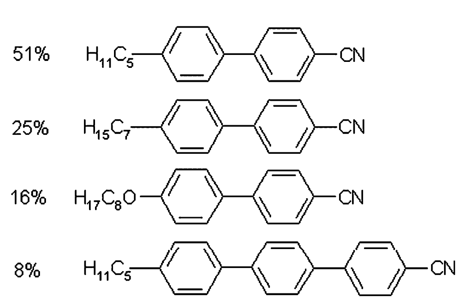

Fig. 1. Components of the nematic liquid crystal, E7.

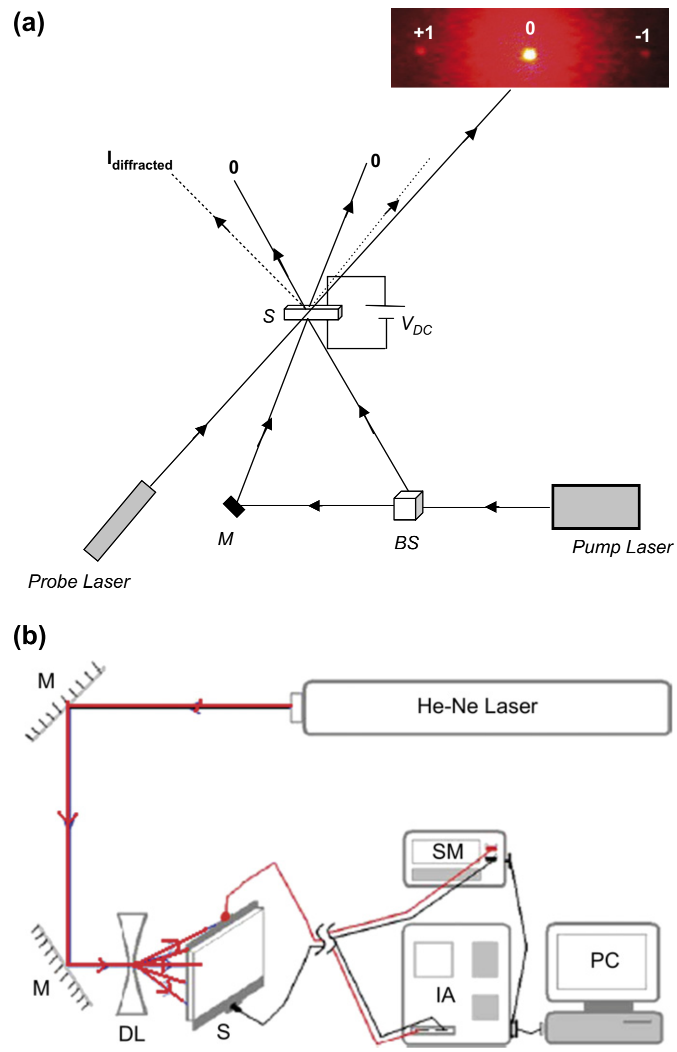

Fig. 2. Experimental set-up (a) for the two-wave mixing (inset: photographs of self-diffraction spots), BS: beam splitter, M: mirror and S: sample; (b) for the electrical measurements, M: mirror, DL: diverging lens, S: sample, IA: impedance analyzer, SM: source meter.

The reorientation happens in bright regions and grating is formed by the bright–dark periodicity that is experienced and reinforced by the interference pattern. Fig. 3(a) demonstrates the dependency of diffraction signals on the applied dc voltage for pure E7 and E7/ASTR. Probe diffraction of 1.2 mW He–Ne laser was considered in the analysis of the diffraction efficiency. Diffraction efficiency η was calculated as the intensity ratio of the first-order diffraction beam to the transmitted zero-order beam. For the studied system, diffraction efficiency is ~6% (±1%) under optimum circumstances when the intersection angle of beams $\theta = 2°$, $V_{dc} = 11$ V for pumping beam powers ~10 mW (±0.01 mW), while pure E7 has just 3% diffraction efficiency. Fig. 3(b) demonstrates the normalized diffraction efficiency as the figure of merit. As can be seen, diffraction efficiency is significantly enhanced in the ASTR doped sample. Although the required amount of voltage for the maximum attained efficiency is relatively high with respect to pure E7 sample, the enhancement factor is still promising in the optimization point of view.

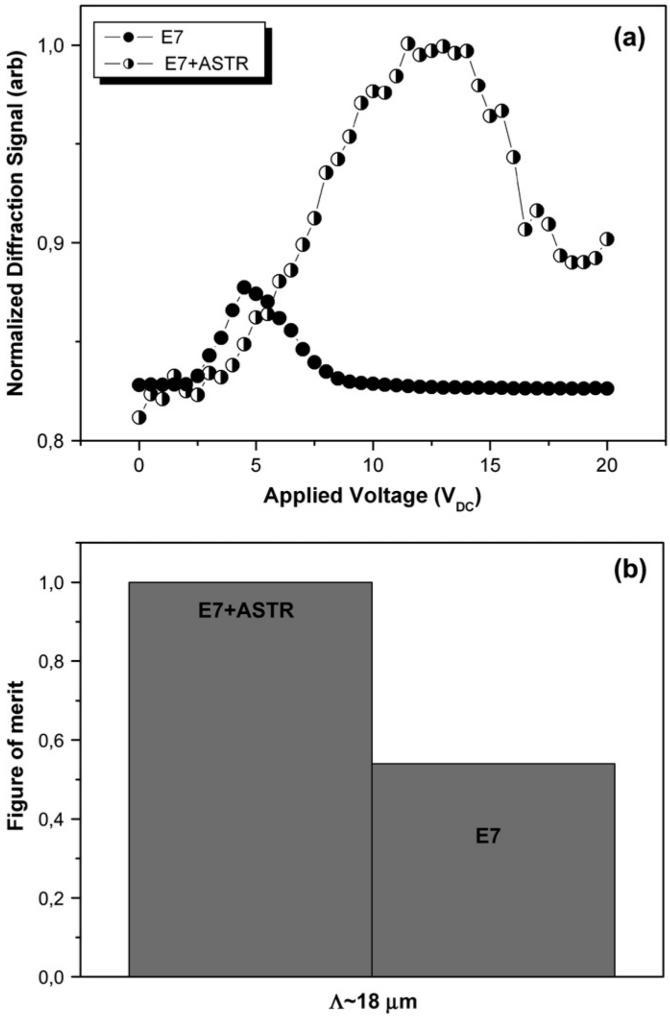

Fig. 3. (a) Dependency of normalized diffraction signal on the applied dc voltage; (b) figure of merit.

Dynamic behavior of the proposed system was also studied by oscilloscope trace (Fig. 4). First-order diffraction signal was acquired at two different voltages for ASTR doped sample. The signal increases sharply when two of the pumping beams are on and then it saturates. From these data, the characteristic reorientation time is evaluated to be 0.8 s under 11 V bias maximum efficiency condition.

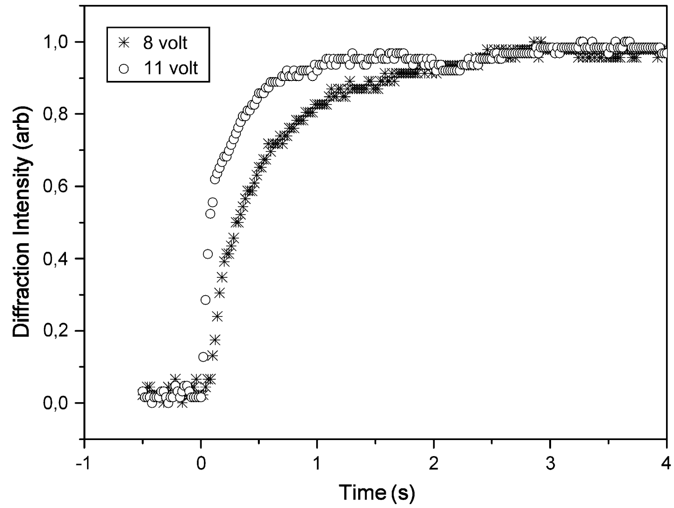

Fig. 4. Time dependency of first-order probe diffraction under 10 mW pumping.

There are several researches concentrating on the electrical behaviors of LC systems under laser illumination [17,18]. Actually such an investigation not only gives fruitful results for understanding the reorientation mechanism, but also provides an infrastructure for optimization works. In this sense, photoconductivity measurements of pure and ASTR doped samples are depicted in Fig. 5. As can be seen from this figure, doping 1% ASTR increases the LC conductivity almost 40 times and while there is no change in dark and laser induced conditions in pure sample, ASTR doped sample exhibits laser induced conductivity enhancements, particularly at moderate bias voltages. Increasing tendency of ASTR doping on the photoconductivity is obvious. This is because of the charge-carriers implemented by ASTR components. These charge-carriers shift the switching voltages of reorientation to lower voltage values as well. According to experimental evidences, photorefractive-like space-charge fields manage the dominant

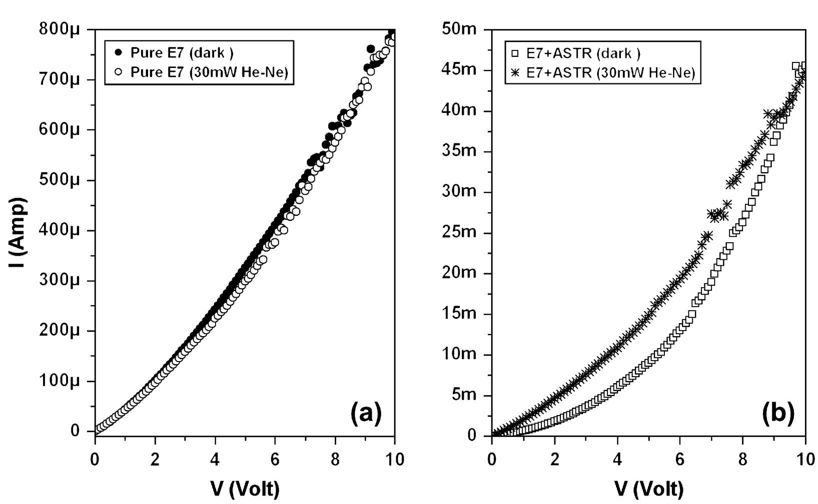

Fig. 5. Photoconductivity measurements of (a) pure and (b) ASTR doped samples.

portion of the reorientation. Actually, this is in consistency with the expectations coming from the composition of this dopant.

4. Conclusion

The goal of this work is to propose a novel carbon structure as a doping agent for dynamic holography and to investigate its contributions to the basic characters of LC. Although ASTR is not the best working doping, according to the works performed so far, it still promises successful future in some possible applications in terms of the design and possible fraction optimizations. Six percent diffraction efficiency was achieved with ($\Lambda \sim 18\ \mu m$, $V_{DC} \sim 11$ V for laser intensities ~ 10 mW) in the proposed composite. Photorefractive-like reorientation is found to be the main reorientation mechanism indeed. Performance evaluation of the examined system encourages works on hybrid designs including carbon based nano-structures.

Acknowledgements

Special thanks go to Dr. A. Ponomarev and Dr. D. Dvarnikov for synthesizing and providing us the doping material Astralene.

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