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Effect on response time and diffraction efficiency of co-usage azo dye and carbon nanoparticle in nematic liquid crystal

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ABSTRACT

In this work, the formation of the photo-induced grating and nonlinear optical properties such as diffraction efficiency (η), refractive index modulation (Δn), nonlinear index coefficient (n_2) of nematic liquid crystal (E7) doped by azo dye (Methyl Red) and C60 have been investigated by diffraction grating measurements. Diffraction efficiencies of 441 nm pump and 632 nm probe beams were measured in two-wave mixing experiment. Maximum diffraction efficiency was found 26% doped with both 1% MR and 0.5% C60, while cells without C60 had maximum diffraction efficiency of 19% under 30 mW laser illumination. Rise time was found to increase with Methyl Red concentration. The nonlinear index coefficient, n_2, was calculated to be 11×10^{-3} cm^2/W and highly depend on MR concentration.

1. Introduction

There is enormous interest in the development of holographic and diffractive optical devices for integrated optics, displays, optical interconnects, optical data storage, and optical computers. Recent research has concentrated on the development of materials with high diffraction efficiency, resolution, and sensitivity [1–5]. Liquid crystals (LCs) are highly nonlinear optical materials due to their susceptible property activating under even relatively low optical fields and are a class of materials exhibiting thermodynamically stable but only partially ordered phases. Several nonlinear mechanisms investigated so far have revealed the promising characters of LCs. The difference in refractive indices, for fields polarized along, and perpendicular to, the director axis brings about a large birefringence property from the visible to the infrared spectral regime. This property is an opportunity for various applications [6]. Director axis reorientation-based effects causing the change of refractive index and observations of several interesting dynamic and storage wave-mixing effects have been extensively studied so far [7–10]. Molecular orientation of LC molecules determines the electro-optical behavior of the system and external effects may cause molecules to reorient by molecular interactions. Actually doped LC systems are subject to detailed researches for their possible technological applications. The nonlinear properties of LCs can be greatly enhanced by doping with carbon nanoparticles; these properties include photorefractivity, holography, electro-optical, and reorientational effects [11,12].

Organic molecules and liquid crystals are known to be favourable for photonic and nonlinear optical device applications because of their large optical nonlinearity and rapid optical response [13,14]. In a mixture of a liquid crystal and dichroic dye, the collective orientation of the LC molecules under the action of an electric field influences that of the dye molecules. This phenomenon is called guest–host interaction. Azo dyes and their derivatives have been widely used as guest additives in condensed optical materials to develop novel optoelectronic devices. It had previously been found that the presence of a dichroic dye in a LC affects some properties of the pure host. For example, a dye can change refractive indices and order parameter of the LCs.

Carbon nanoparticles (CNs) are currently the subject of intense research because their extraordinary mechanical, chemical, thermal, electrical and optical properties. Presently fullerene science is one of the fastest growing areas of research in chemistry, physics and materials science. Fullerene-doped structures are of great interest due to the their various practical and scientific applications (optical limiting, optoelectronics, etc). Fullerenes and their derivatives have been widely used as guest additives in condensed optical materials to develop novel optoelectronic devices. The doping of fullerene in nematic enhances the photoconductivity change and the resulting nonlinearity of the LC.

In this paper, we report the result of our study on the optical properties of planar nematic LC containing both azo dye MR and carbon nanoparticle C60. We compare results for cells con-

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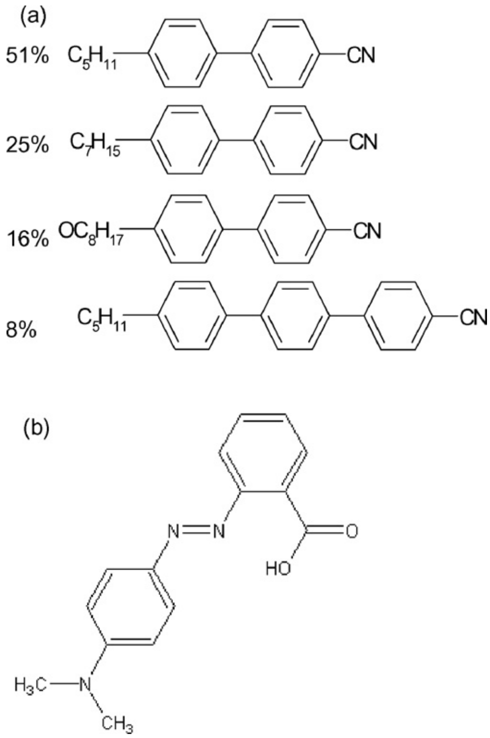

Fig. 1. Chemical formulas of: (a) Nematic host, E7; (b) Methyl Red, (2-(4-(dimethylamino)phenylazo)benzoic acid).

taining various percentages of MR with and without the presence of fullerene C60. The character of the prepared systems was investigated in terms of the diffraction signals depending on applied dc voltage with using two-wave mixing experiment. We measured diffraction efficiency for pure E7 and E7/C60/MR. Contribution of the MR and C60 to nonlinear refractive index coefficients and refractive index parameters in nematic liquid crystal E7 was investigated. We have also extracted rise time under 441 nm He–Cd laser illumination.

2. Experimental

Eight cells were used whose thicknesses are 8.9 μm. They were made up of two conductive glass plates (ITO) with planar alignment. One of them contains pure E7 coded liquid crystal which is purchased from Merck. E7 is the mixture of four nematogens (51% K15, 25% K21, 16% M24, and 8% T15). Methyl Red, (2-(4-(dimethylamino)phenylazo)benzoic acid) and carbon nanoparticle C60 from Aldrich Chemical Company. The molecular structures of these chemicals, except for C60, are shown in Fig. 1. MR has been an interesting dye for doping LC material. One of the main features of the MR, under the action of light, they can change their molecular confirmation. This phenomenon is called *trans–cis* isomerization. In the *trans*-form, molecules are rod-like and aligned with LC molecules in the same direction. In the *cis*-form, MR molecules forced to the alignment of surrounding LC molecules. In the visible region the optical absorbance of the azo dye was maximum at 498 nm. It is shown in Fig. 2. The dye, MR, is an appropriate agent for the realization of absorbency at the characteristic wavelength of He–Cd laser. It is explicitly shown that the absorbance of the dye-doped sample matches with the characteristic wavelength of He–Cd laser, 441 nm. The extinction coefficient was calculated $k = 1, 2$ at 441 nm.

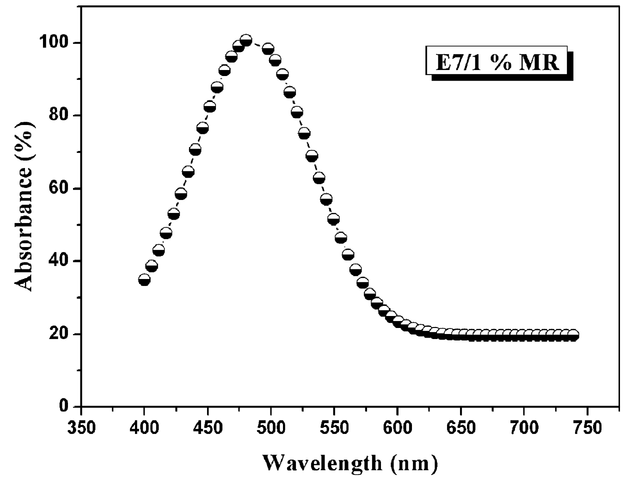

Fig. 2. Absorbance spectra for E7/1% MR.

The other cells were filled with Methyl Red at percentage ranging from 0.1% to 1% and 0.5% Fullerene (C60), 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. 3. It consists of an He–Cd ($\lambda = 441.2$ 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. In order to provide exact polarization, two Glan–Thomson polarizer placed in front of the excitation beams. This polarization is actually the dominant light-molecule interaction case. Pumping beams,

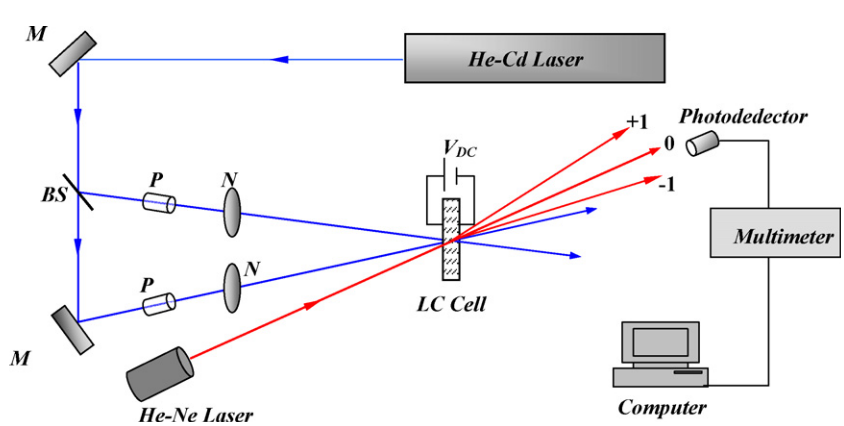

Fig. 3. Experimental set-up for the two-wave mixing BS: beam splitter, M: mirror, P: polarizor, N: neutral density filter.