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Diffraction efficiency and dielectric relaxation properties of nickel phthalocyanine doped nematic liquid crystal

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Abstract

The formation of the photoinduced grating and dielectric properties of a nematic liquid crystal doped by nickel phthalocyanine have been investigated to enhance the optical and electrical properties of the system studied by dielectric spectroscopy and diffraction grating measurements. Accessible diffraction efficiency is 7% under the optimum circumstances and analyzed results establishes a better reorientation panorama in the sense that NiPc component improves efficiency. Photoinduced refractive index change Δn was determined by two-wave mixing method. The addition of NiPc to E7 enhances the diffraction efficiency and refractive index change of the LC samples. The dielectric parameters and relaxation properties of nickel phthalocyanine (NiPc) doped E7 and pure E7 liquid crystal have been investigated. Dielectric anisotropy ($\Delta\varepsilon$) property of the LCs changes from the positive type to negative type and dielectric anisotropy values increase with NiPc. The complex dielectric dispersion curves of the LC samples were analyzed Cole–Cole relation and the relaxation process obeys the Debye type relaxation. Consequently, NiPc dopant changes the refractive index, diffraction efficiency, dielectric anisotropy and relaxation parameters of E7/NiPc LC.

Keywords: Liquid crystals; Dielectric anisotropy; Diffraction efficiency

1. Introduction

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. Actually doped LC systems are subject to detailed researches for their possible technological applications [1,2].

Phthalocyanines (Pcs) are another class of materials, which exhibit a high thermal and chemical stability and also high optical absorption in the visible range. Due to their blue or green colour the Pcs were largely used in industry as dyes [3], and more recently due to their semiconducting properties they have proven their applicability in electronic devices such as organic photovoltaic cells and organic light emitting diodes. They are also used in optical recording and optical display devices [4,5].

Presently, metallophthalocyanines (MPcs) science is one of the fastest growing areas of research in chemistry, physics and materials science. MPcs doped structures are of great interest due to their various practical and scientific applications (optical limiting, optoelectronics, etc.). In the scope of this work, we have combined these two modern materials for exploiting both of their beneficial properties at the same time under a unique system. The doping of MPcs, which is typical electron donor materials, in nematic enhances the photoconductivity change and the resulting nonlinearity of the LC.

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

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wave-mixing effects have been extensively studied so far [6–10]. Molecular orientation of LC molecules determines the electro-optical behaviour of the system and external effects may cause molecules to reorient by molecular interactions. Electro-optical measurements could demonstrate molecular-reorientation based changes in capacitance, impedance and dielectric coefficients and refractive index dispersion. Such experiments have been previously performed on dye doped and polymer doped LC [11–13].

There are various works concentrating on the electro-optical characterization of LC [14–17]. The dielectric-spectroscopy technique (DST) has been used by various researchers for the study of systems in different phases. This method has been found to be one of the best ones to make measurement of permittivity and dielectric loss with high accuracy and sensitivity [18,19].

The dielectric-spectroscopy technique (DST) is a powerful technique successfully applied for understanding the molecular details indeed. The dielectric anisotropy is expressed as $\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp}$, where $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are the parallel and the perpendicular components of the electric permittivity, respectively. This is because the critical-frequency (f_c) rise alters the structure type from positive to negative. Regarding the dielectric constant, there are two structure types. One is named as positive dielectric anisotropy (p-type) and its dielectric constant along the director axis is larger than that along the axes perpendicular to the director. $\Delta\varepsilon$ is greater than zero in this case. The other type is named as negative dielectric anisotropy (n-type), $\Delta\varepsilon$ is less than zero [20,21].

Variation of $\Delta\varepsilon$ with respect to the spot frequencies reveals that LC orientation has p-type property at low frequencies, and as the frequency increases the dielectric anisotropy character shifts to n-type.

In this paper, we report the result of our study on nickel phthalocyanine (NiPc) doped to nematic liquid crystal host E7. 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/NiPc. Contrubition of the NiPc to dielectric parameters in nematic liquid crystal E7 was investigated with dielectric-spectroscopy technique. It was observed that doping liquid crystals with NiPc altered dielectric behaviour and relaxation frequency (f_r) of NLCs. We have also extracted dielectric anisotropy ($\Delta\varepsilon$) and critical frequency (f_c) value as well as some other key electrical parameters for pure E7 and NiPc doped E7 liquid crystals.

2. Experimental

Two cells were used whose thicknesses are 9.2 μm. These cells 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 E7/NiPc 2% (w/w). NiPc was synthesised at Department of Chemistry, Gebze Institute of Technology, following the procedure described in [22], which later mixed the LC under the reinforcement of ultrasonic water bath effect. Pure E7 and NiPc doped liquid crystal was injected into sample cell by capillary action with room temperature.

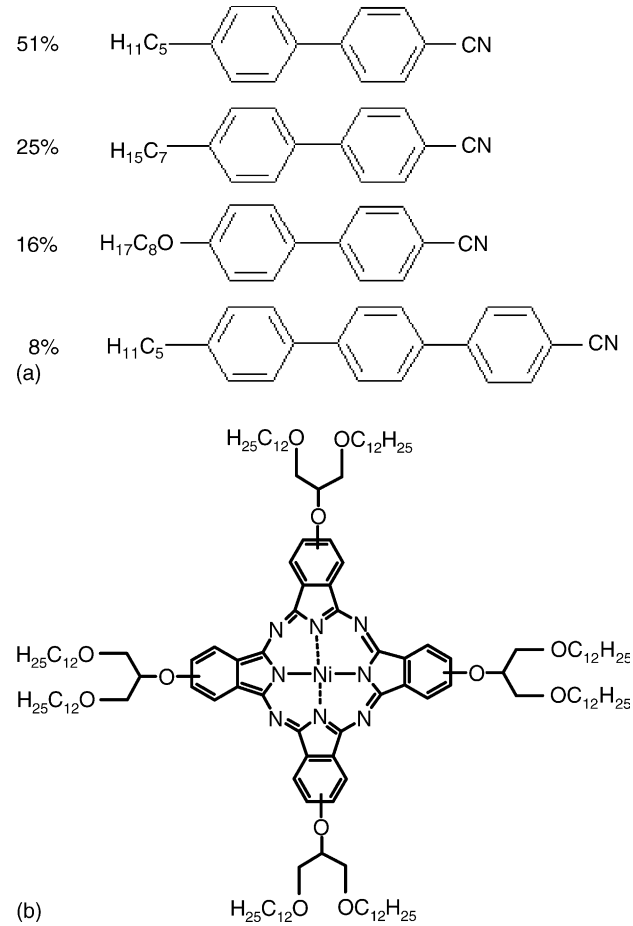

Fig. 1. Molecular structures of the samples: (a) nematic host E7; (b) NiPc.

An experimental arrangement for the two-wave mixing is schematically shown in Fig. 2(a). It consists of a He–Ne (λ = 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. Fig. 3 shows the absorbencies of these samples E7 and E7/NiPc in the visible spectrum. This configuration is appropriate for efficient absorbance to happen at the characteristic wavelength of He–Ne laser around 632 nm. Pumping beams, having 12 mW power, were intersected on the sample with, $\theta = \sim 1.5^\circ$ that makes grating constant Λ to be 24.6 μm and since $\Lambda^2 \gg \lambda d$, diffraction is considered to be in the Raman–Nath regime.

The dielectric parameters were measured in the frequency range of 10 kHz–10 MHz, using impedance analyser interfaced with a computer. Experimental set-up for dielectric spectroscopy is given in Fig. 2(b).

3. Results and discussion

Nematic LC in its various pure and doped forms possesses many attractive and useful nonlinear optical responses. In this