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Effect of an azo dye (DR1) on the dielectric parameters of a nematic liquid crystal system

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Abstract

The dielectric parameters and relaxation properties of azo dye (DR1) doped E7 and pure E7 liquid crystal (LC) have been investigated in a wide frequency range of 10 k–10 MHz through the dielectric spectroscopy method at room temperature. Dielectric anisotropy ($\Delta\varepsilon$) property of the LC changes from the positive type to negative type and dielectric anisotropy values decrease with doping of DR1. The relaxation frequency f_r of E7 and E7/DR1 LC was calculated by means of Cole–Cole plots. Influence of bias voltage on the dielectric parameters has also been investigated.

Keywords: Liquid crystals; Azo dye; Dielectric spectroscopy; Relaxation frequency

1. Introduction

Organic molecules and liquid crystals (LC) are known to be favorable to photonic and nonlinear optical device applications because of their large optical nonlinearity and rapid optical response [1,2]. In a mixture of LC 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. Furthermore, influence of a dye on the dielectric properties of a liquid has been observed [3–5]. For example, a dye can change refractive indices and the order parameter of LCs.

Molecular orientation of LC molecules determines the electro-optical behavior of the system and external effects may cause molecules to reorient by molecular interactions. Electro-optical measurements are useful such that researchers could demonstrate molecular-reorientation-based changes in capacitance, impedance, dielectric coefficients, and refractive index dispersion. Such experiments have been previously performed on dye-doped and polymer-doped LC [6–8].

There are various works concentrating on the electro-optical characterization of LC [9–12]. The dielectric-spectroscopy technique (DST) has been used by various workers for the study of systems in different phases. This method has been found to be one of the best for the measurement of permittivity and dielectric loss with high accuracy and sensivity [13,14].

The dielectric anisotropy is expressed as $\Delta\varepsilon = \varepsilon_{||} - \varepsilon_{\perp}$, where $\varepsilon_{||}$ and $\varepsilon_{\perp}$ are the parallel and 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), where $\Delta\varepsilon$ is less than zero [15,16]. Variation of $\Delta\varepsilon$ with respect to the spot frequencies

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reveals that LC orientation has p-type property at low frequencies, and as the frequency increases the dielectric anisotropy character shifts to n-type. The measurement of the dielectric relaxation at different frequencies gives information about the dynamics of polar groups and about molecular motion.

Materials containing azobenzene units have been intensively studied because they are promising systems for electro-optical applications such as holographic and digital storage, LC command surfaces, and nonlinear optical devices. Dielectric spectroscopy has been used to investigate the molecular orientation and motions in LC doping with azo dye. Azo dyes are stable and quite polar, having a large dipole moment. Thus, the dielectric permittivities can be sensitively influenced by the orientation motions of the dipoles. Due to the fact that these materials are very interesting and promising for practical applications, it can be suitable for fast electro-optical displays like switches, guest host display and many others.

In this paper, we present experimental study of the dielectric anisotropy analysis in DR1 doped nematic LC E7. It was observed that doping LC with DR1 altered dielectric behavior and relaxation frequency f_r of nematic LCs. We have also extracted dielectric anisotropy $\Delta\varepsilon$ and critical frequency f_c value as well as some other key electrical parameter for pure E7 and E7/DR1 hybrid LC.

2. Experimental

Before the construction of the cells, indium tin oxide (ITO) covered glass windows were treated with polyvinyl alcohol for planar alignment. Measurement cells were made up of two glass slides separated by mylar sheets having ~6.2 μm thickness. These cells were filled in capillary action with the samples at room temperature. The material used was composed of nematic LC from Merck and DR1 powder (95%). Molecular structures of the samples' components are depicted in Fig. 1. As seen, the DR1 molecule consists of [*N*-ethyl-*N*-2-ethylhydroxy]-amino group as the electron donor group (D), and the nitro-electron acceptor group (A), located at the opposite ends of the conjugated chain azobenzene bridge (B). E7 is the mixture of four nematogens (51% K15, 25% K21, 16% M24, and 8% T15).

Two samples were prepared; one of them contains pure E7, the other one was filled with E7/DR1 0.5% (w/w). The measurements were performed at room temperature by using HP 4192ALS impedance analyzer.

3. Results and discussion

The complex dielectric constant of the LC- and DR1-doped E7 is described by

$$\varepsilon^*(\omega) = \varepsilon'(\omega) - i\varepsilon''(\omega), \quad (1)$$

where ε' is the real and ε'' the imaginary part of the dielectric constant. The spectrums of real and imaginary

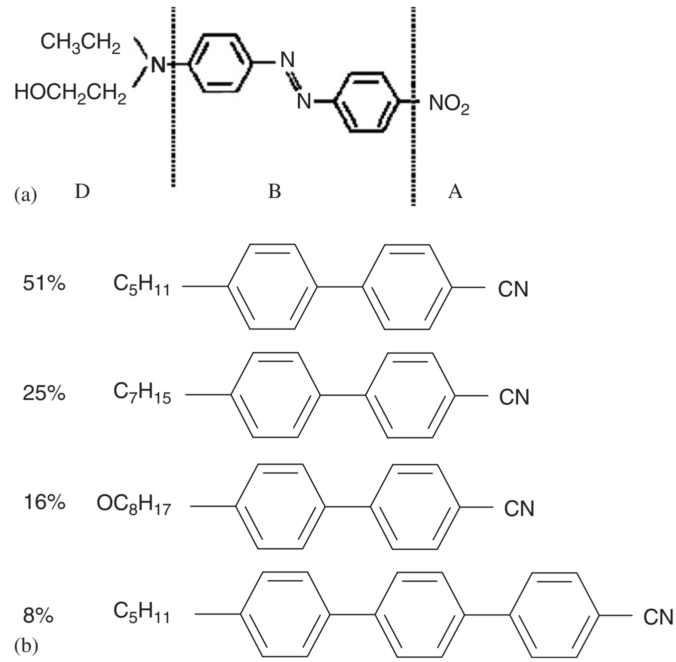

Fig. 1. Molecular structures of the samples; (a) azo dye DR1 and (b) nematic host E7.

parts are respectively called dispersion and absorption curves. Figs. 2(a) and (b) show the real part of the dielectric constant of the E7 and DR1-doped E7 LCs as a function of frequency at different voltages, respectively. As seen in the figures, at a certain frequency value the real part of the dielectric constant ε' increases exponentially with increasing applied voltage. Afterwards, ε' almost does not change with applied voltage. The dielectric constant dependence of the voltage applied has valuable information about reorientation. It is seen in Figs. 2(a) and (b) that when there is no voltage applied, dielectric constant has a minimum value where molecules are in their original orientation. When the applied voltage is increased, orientation starts and as a result of this, the dielectric constant increases with applied voltage. Figs. 3(a) and (b) show the frequency dependence of the imaginary part of the dielectric constant at different voltages for the samples. We see that the loss is minimum without any bias voltage (0 V) but at 20 V dielectric loss is the highest. The imaginary dielectric constant attains a maximum at a critical frequency f_c, which is influenced by an applied voltage. This maximum value corresponds to a dielectric relaxation peak, where a transition takes places from positive to negative dielectric anisotropy. The orientation configurations (pure E7 and E7/DR1) influence the position and intensity of the relaxation peak. The critical frequency f_c values, for the pure E7 and E7/DR1 cells were determined from the position of the peaks, as shown in Figs. 3(a) and (b), and are given in Table 1. The position and the intensity of the peak shift to lower frequencies with increasing applied voltages.

The relaxation phenomenon is characterized by Cole–Cole plot. These curves give useful information about the