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Electro-optic and dielectric behavior of a FLC material having doped with a non-mesogenic polar molecules

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Abstract

Liquid crystal mixtures of non-mesogenic polar molecule with a commercial ferroelectric liquid crystal (FLC) mixture were prepared. Two mixtures were prepared by mixing 0.5% (w/w) and 1% (w/w) of polar molecules with commercial FLC mixture. Comprehensive studies of dielectric and electro-optic properties of the commercial FLC mixture and the polar molecules doped FLC mixtures have been made as a function of temperatures. Our studies reveal a higher tilt angle in lower concentration (0.5%) mixture but in case of 1% mixture tilt angle is decreased in comparison to 0.5% mixture. The spontaneous polarization of the commercial FLC mixture and other two mixtures is almost equal in magnitude at all temperatures. At the lower temperature region of SmC* phase, Goldstone mode (GM) dielectric strength of the commercial FLC mixture and low concentration (0.5%) mixture is found almost equal but it is slightly higher in case of high concentration (1%) mixture. With the increase of temperature GM dielectric strength of both the doped mixtures rapidly converges at different temperatures which are much lower than the temperature of transition (T_C) from SmC* – SmA phase. The results have been discussed.

PACS: 61.30

Keywords: Ferroelectric liquid crystal mixture; Dielectric relaxations; Electro-optic; Pitch

1. Introduction

During the last two decades, tilted chiral smectic phases (SmC*) have attracted much interest in the field of liquid crystal (LC) research, because of their potential applications in electro-optic devices [1,2]. The chiral ferroelectric SmC* phase represents a spatially modulated structure [3–5]. Dielectric properties of ferroelectric LCs (FLCs) have been extensively studied both theoretically and experimentally [6–15] in the past. Ferroelectric LC (FLC) with higher tilt angle could improve a perfectly dark state problem and a high contrast ratio to the display devices based on FLC. There is no conventional way to increase the tilt angle of a FLC material. Researchers are engaged in synthesising FLC with higher tilt angle. In parallel, for a long time researchers have attempted to study modulated FLC structure by several means such as the FLC in random and confined geometries. Dielectric and electro-optic properties of polymer dispersed LC (PDLC), polymer stabilized FLC (PSFLC) and dye doped FLC system have attracted attention [16,17].

The aim of the investigation is to enhance the dielectric and ferroelectric performance of FLC mixture (ZLI 5014-100) after having doped with a non-mesogenic polar molecule, containing a certain dipole moment. In this report, we have studied the dielectric and electro-optic properties of a commercial FLC mixture and two other mixtures, in which

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the commercial FLC mixture has been doped with polar molecules in different ratios. Using dielectric spectroscopy and elector-optic study, we showed the evidence of modulated FLC parameters in doped system.

Moreover, the most fundamental parameters of an FLC are the tilt angle (θ), i.e. the angle between the director and the smectic layer normal, and the spontaneous polarization P_S. Here, from the experimental data of electro-optic studies we have calculated the coupling constants between polarization and tilt.

The purpose of the present work is to study the effect on the various display parameters e.g. tilt angle, spontaneous polarization, pitch and the dielectric permittivities of a FLC mixture ZLI 5014-100 when doped with a non-mesogenic polar molecules.

2. Experimental

2.1. Sample preparation

The materials under investigation consisting of a commercial ferroelectric liquid crystal mixture ZLI 5014-100 and two other mixtures containing FLC ZLI 5014-100 doped with different concentration of a polar molecule (4,4 dimethyl amino pyridine). We denote the commercial FLC mixture ZLI 5014-100 as FLC mixture, the mixture containing FLC mixture and 0.5% (w/w) of the polar molecule as mix1, the mixture containing FLC mixture and 1% (w/w) of the polar molecule as mix2. The commercial FLC mixture exhibits a phase sequence as follows:

K 10 °C SmC* 65 °C SmA* 70 °C Ch 72 °C Iso.

Since we are interested in SmC* and SmA phases the transition temperature T_C from SmC* to SmA phase for mix1 and mix2 have been determined by polarizing microscopy and found almost the same as that of commercial FLC mixture. The phase transition temperature T_C of mix1 and mix2 is broaden by 1 K.

The structure of the polar molecule (4,4 dimethyl amino pyridine) is given in the Fig. 1. The homogeneity of the mixture containing polar molecule has been obtained by heating the vial containing the mixture, to a few degrees above the isotropic temperature and shaking the mixture thoroughly for sometimes. The structure of the polar molecule used in present studies is given below.

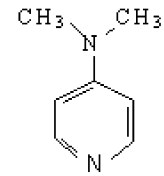

Fig. 1. Structure of the 4,4-dimethyl amino pyridine.

2.2. Measurements

The planar aligned ITO coated cells (manufactured by EHC Co., Japan) with thickness 10 and 50 μm were used for the measurement of spontaneous polarization and tilt angle of the mixtures and only 50 μm thick cell was used for the measurement of pitch. Both cells were used for the measurement of dielectric permittivities of the mixtures. A Mettler hot-stage (FP52) with FP5 controller has been used for heating purpose.

The cells were filled with the samples at the isotropic temperature of the samples. A good quality mono-domain structure of FLC molecule inside the cell was obtained by slowly cooling the cells and simultaneously applying a low frequency (10 Hz, 1 V/μm) ac field. Pitch plays a significant role in promoting surface stabilization and that determines the increase and decrease of the dielectric strength depending on the loose or tight binding of the pitch respectively. The homogeneously aligned 50 μm thick cell showed a fringe pattern in the SmC* phase and that operates as an optical grating because of the periodicity of the refractive index due to helical structure of the molecules inside the cell. An optical microscopic method has been employed to determine the pitch by measuring the width of the dark and bright lines. The width of a pair of bright and dark lines corresponds to the full pitch of the SmC* phase [18]. The pitch length by the microscopic method has been obtained by keeping the cell under a polarizing microscope and window based Image-J software was used to measure the pitch length in comparing with a standard length [18,19], for the precise measurement as shown in Fig. 5.

For the automatic dielectric measurements in the frequency range from 10 Hz to 13 MHz, a Hewlett Packard impedance analyzer (HP4192A), controlled by a Pentium II computer, has been used. After calibration with air and toluene; the cells is filled with mixtures and it has been used for the dielectric measurements. Dielectric spectra have been fitted with Havriliak–Negami fitting function [20] to get the dielectric strength and relaxation frequency of the dielectric processes. The Havriliak–Negami fitting function is given below

$$\varepsilon'' = \frac{\sigma_0}{\varepsilon_0}\cdot\frac{1}{\omega^s} + \sum_{k=1}^{N}\mathrm{Im}\left\{\frac{\Delta\varepsilon_k}{[1+(\mathrm{i}\omega\tau_k)^{\alpha_k}]^{\beta_k}}\right\} \quad (1)$$

where $\Delta\varepsilon_k$ the dielectric strength and τ_k the relaxation time of each individual process k involved in dielectric relaxation, ε_0 the vacuum permittivity and σ_0 is the conduction parameter. The exponents α and β are empirical fit parameters, which describes a symmetric and asymmetric broadening, respectively, of the relaxation peaks. The spontaneous polarization has been measured by polarization reversal method using a function generator (HP33120A), an indigenous linear amplifier and a storage type oscilloscope (HP54603B). For the spontaneous polarization measurements the triangular wave signal of magnitude 2 V_{rms}/μm and of frequency 50 Hz has been used. For the response time data a square wave signal of frequency 50 Hz and of magnitude 2 V_{rms}/μm has been used. The