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Pristine and quantum dots dispersed nematic liquid crystal: Impact of dispersion and applied voltage on dielectric and electro-optical properties

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ABSTRACT

In this work, we have dispersed $Cd_{1-x}Zn_xS/ZnS$ quantum dots (QDs) in nematic liquid crystal (LC) BBHA which shows negative dielectric anisotropy ($\Delta\varepsilon = -2.90$) [1]. The impact of QDs dispersion, applied bias and concentration of QDs on the dielectric permittivity, dielectric loss, response time, transmittance and birefringence as a function of frequency and temperature for planar alignment has been studied. We have observed that dispersion of QDs in pure nematic LC influences these properties. Due to QDs dispersion the birefringence increases and this helps in the alignment and ordering of nematic molecules. Under applied bias the ionic contributions to the dielectric loss as observed in low frequency region are suppressed and the relaxation frequency is shifted towards higher frequency side. We have made an effort to explain the observed behaviour of pristine and dispersed systems on the basis of interactions between QDs and nematic molecules.

1. Introduction

Dispersion, i.e. the incorporation of small quantities of nanomaterials into a nematic LC, is one of the most prominent processes to tailor the properties of anisotropic nematic fluids. Recently, the studies on the effects of dispersed nanomaterials (NMs) in LCs have become an active interdisciplinary area attracting a lot of attention [1–4] from both academia and industry because the dispersion of NMs can tailor the properties of mixture suitable for LC devices [5–16]. The quantum dots (QDs) have emerged as better candidates, in comparison to other types of NPs, in terms of synthesis, versatility and size homogeneity and show alignment capability in LCs with the change in concentration, i.e., concentration dependent self-assembly. The QDs have also been proved to be better candidate for applications in quantum computing, biology, photovoltaic devices and light emitting diodes, etc [5–8]. Recently, the dielectric and electro-optical properties of pristine and QDs dispersed LCs have been investigated by various groups [10,11]. Konshina et al. [14,15] have studied the dynamics and relaxation optical response of nematic LC doped with CDSe/ZnS quantum dots. They have found that the relaxation time of the LC increases significantly, that is, in the reduction of optical response time.

It has been observed that the alignment of nematic molecules in the presence of QDs depends upon the QDs size, capping agent and the structure of nematic molecules. The alignment of nematic molecules has pronounced influence on the anisotropic properties of nematic systems.

The present work concerns with the study of the dielectric and electro-optical properties of pristine and $Cd_{1-x}Zn_xS/ZnS$ QDs dispersed nematic LC, p-Butoxybenzylidene, p-heptylaniline (BBHA), as a function of frequency and temperature for the planar alignment. Dielectric permittivity, dielectric loss, relaxation frequency, optical textures, response time, birefringence, and transmittance have been investigated, in detail. The spectra of dielectric properties in 0.5% wt./wt. and 1% wt./wt. concentration of QDs, characterized by interactions of QDs and nematic molecules, were used to reduce the dielectric permittivity in planar alignment cell with and without applied bias voltage. Further, the ionic behaviour has been suppressed in the low frequency region and relaxation modes shift towards higher frequency side. In the sec. 2, we give the experimental detail and sec. 3 is devoted to the results and discussions. Paper ends with the summary and conclusion in sec. 4.

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2. Experimental

We have performed measurements on the nematic LC BBHA which exhibits phase sequence Cry↔20 °C↔Sm A↔55 °C↔N ↔83 °C↔IL; the numbers in-between two phases represent the transition temperatures. The $Cd_{1-x}Zn_xS/ZnS$ graded core/shell quantum dots used here for the dispersion, are semi conducting quantum dots with x = 0.42 and size 8.2 nm [17]. They can be dispersed in most non-polar organic solvents such as toluene, chloroform, hexane, etc. With very low organic impurity, these quantum dots are specifically designed as emitters for optoelectronic applications such as display and solid state lighting. We mix an appropriate amount (in the weight ratio 0.5% and 1%) of the QDs into the pure nematic and then homogenized with an ultrasonic mixer at 90 °C for 1 h and uniform dispersion of QDs was ensured. The pure and the QDs dispersed nematic LC was filled in the assembled cells at a temperature higher than the isotropic temperature of the nematic LC material by capillary method. It was cooled slowly under small a.c. electric field after filling the sample in the cell and the alignment of the sample was confirmed under the crossed polarizing optical microscope. The correct and proper alignments of the nematic molecules are extremely important for the precise measurement of electrical properties and which in turn, influences dielectric parameters. Thus, correct alignment plays an extremely important role in determining molecular geometry. Fig. 1 shows optical micrographs of the dispersed QDs (0.5% and 1% wt./wt. concentration) in the nematic medium. It is important to mention that on visual observation of the optical texture, homogeneous dispersion is seen and the core shell QDs help in the alignment of nematic molecules. A proper alignment of the nematic molecules are extremely important for the precise measurement of electrical properties and which in turn, influences dielectric parameters. Thus, proper molecular alignment plays a crucial role in determining molecular geometry.

Fig. 2 shows the polarizing optical microscopic texture of pristine and QDs dispersed nematic LC for planar aligned cells at a temperature 75 °C. Fig. 2(a) and (b) refer, respectively, to pristine nematic and QDs dispersed (1 % wt/wt) nematic LC. Improved alignment of nematic molecules can be seen due to dispersion of QDs in pure BBHA material. The fruitful textures have been obtained with the dispersion of QDs in nematic exhibiting the increase in birefringence. The optical textures have been given only to the provided the information about the alignment of LC molecules. They are preferentially oriented along the optic axis of the material.

2.1. Dielectric measurements

The dielectric measurements have been carried out using a computer controlled impedance/gain phase analyzer (HP4194A) in the frequency range 1000 Hz to 10 MHz. The measurements in the high frequency range have been limited to 10 MHz because of the dominating effect of the finite sheet resistance of ITO coating on the glass plates and the lead inductance of the cells. The temperature has been maintained by using a computer controlled hot plate (Instec Corporation USA). Experiments have been performed by ramping temperature at a very slow heating rate of 0.5 °C min^{-1} with a temperature stability better than ±0.1 °C.

2.2. Electro-optical measurements

A suitable square wave (20Vpp and 5 Hz) has been applied to the cells using a function generator. He–Ne laser beam of wavelength 632.8 nm as the input signal is detected by a photo-detector (Instec-PD02LI) connected directly to a digital storage oscilloscope (Tektronix TDS-2024C). The cell is placed between the polarizer and analyzer which are in a crossed position. The cell is then set at an angle of 45° for maximum transmittance. The nematic sample cells were held at different temperatures using control hot plate. The cell works as a phase retarder, thereby altering the polarization of light. The output waveform is then used to determine the rise time and fall time. The rise time (τ_{on}) and fall time (τ_{off}) of pristine and QDs dispersed nematic LC system have been evaluated using the equation [8],

$$\tau_o = \tau_{on} + \tau_{off} \quad (1)$$

$$\tau_{on} = \tau_{90} - \tau_{10} \quad (2)$$

and

$$\tau_{off} = \tau_{10} - \tau_{90} \quad (3)$$

Here, τ_{on} is the time required for the transmittance to rise from 10% to 90% and τ_{off} is the time required for the transmittance to fall from 90% to 10%.

3. Results and discussion

3.1. Dielectric properties

The dielectric relaxation phenomenon for the pristine and the QDs dispersed nematic LC samples has been analysed using standard Cole-Cole relation [18]. The study of dielectric properties provides information about the molecular structure and mechanism of molecular process. Generally, in a molecular process two types of relaxation along short and long molecular axes of the director occur. We measured the dielectric permittivity, (ε') and dielectric loss (ε'') for both the pure and QDs dispersed nematic systems. The influence of frequency and applied bias, at a fixed temperature 70 °C, on the dielectric permittivity of pure and QDs dispersed nematics has been shown in Fig. 3 for the planar aligned cells. It can be seen that below the relaxation frequency, the values of ε' is higher in both cases without bias and with bias as compared

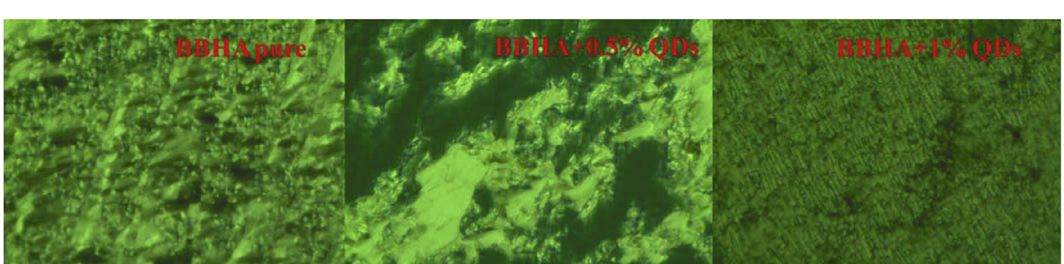

Fig. 1. Polarizing optical micrographs of pristine and QDs dispersed nematic LC BBHA for unaligned cells.