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Tuning phase retardation behaviour of nematic liquid crystal using quantum dot

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We here report on the phase retardation behavior of nematic liquid crystal (NLC) doped with CdSe quantum dot (QD). A study of birefringence and relative permittivity in 4-octyl-4′-cyanobiphenyl (8CB) NLC and its variation with doping of QDs has been presented. The study shows improvement of NLC ordering after addition of QDs. The observed higher value of birefringence in QD doped NLC system has been attributed to improved alignment due to additional order in NLC by self assembled QDs. The improved order of NLC system has also been explained by a schematic illustration for pristine and QD doped NLC system. Study of relative permittivity has also revealed the ordering effect in QD dispersed NLC system.

1. Introduction

Nematic liquid crystals (NLCs) are the widely used LC in the production and fabrication of LC displays worldwide. Commercial displays use twisted nematic cells with 2–3 μm cell gap. The small cell gap provides a better alignment to NLC molecules throughout the cell due to surface stabilization [1,2]. However thick cells used in laser beam steering devices, tunable focus lenses and optical switches; the alignment is not maintained far from the electrode area due to splay and bend elastic deformations [3–5]. Therefore a change in director axis is observed in the middle regime far from the electrodes. Liquid crystals are anisotropic materials; the change in director gives rise to change in the values of different physical parameters. Therefore it is necessary to align the LC molecules more effectively to use them in LC devices. For positive dielectric anisotropic LC, $\varepsilon_{||} > \varepsilon_{\perp}$ ($\varepsilon_{||}$ is relative permittivity along the long molecular axis and $\varepsilon_{\perp}$ is relative permittivity perpendicular to it). Hence for perfectly aligned NLC $\varepsilon_{\perp}$ show minimum value at a particular temperature. However any disturbance in the alignment of NLC molecules shows an increase of $\varepsilon_{\perp}$ due to contribution from $\varepsilon_{||}$. Therefore dielectric anisotropy $\Delta\varepsilon = \varepsilon_{||} - \varepsilon_{\perp}$ as well as birefringence $\Delta n = n_e - n_o$ (n_e and n_o indicate the extraordinary and ordinary refractive index, respectively) varies throughout the same LC cell.

Doping of nanoscale materials in liquid crystal has been carried out by many research groups for improved performance of LC materials [6–8]. Different nanoparticles and carbon nanotubes have shown its importance in the alignment of LC system [9–11]. However the large aggregations of these nanomaterials itself is a problem to utilize them in LC devices. A number of reports on self assembly of quantum dots (QDs) in liquid crystals have shown induced alignment in liquid crystals [12–15]. QDs show high charge transfer properties and therefore a considerable interaction is observed between QDs and LC molecules. The mutual interaction between QDs and LC impose order on each other and therefore improves the alignment of LC molecules [12]. In the present study we have performed the birefringence measurement and dielectric study of pristine and QD dispersed NLC system to come up with a more ordered, highly birefringent NLC system.

2. Experimental details

In the present work, we have utilized the QD's self assembly behavior in NLC material to study its effect on birefringence and

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dielectric behavior of NLC system. We have used CdSe quantum dots to dope in highly polar 8CB (4-octyl-4′-cyanobiphenyl) nematic liquid crystal. The used CdSe QDs having diameter of 2.4 nm has been stabilized by capping of octadecylamine ligands to prevent from large aggregations [16]. CdSe QDs have been dispersed in liquid crystal with three weight percentage of QDs: 0.1%, 0.2% and 0.4%. The QDs were added to LC in chloroform and mixed gently and left the sample for 24 h, so that solvent get evaporated by itself. The sample was further heated to evaporate the solvent completely from sample.

The samples for dielectric and birefringence study have been filled in 5 μm thick planar aligned ITO coated cells obtained from Instec Inc (USA). The dielectric measurement has been carried out using Solartron impedance/gain phase analyzer (Sl 1260). Birefringence study has been conducted on self designed optical setup using transmittance method (polarization modulation technique) [17,18]. The transmitted light intensity (I) passing through LC cell after the crossed polarizer is given as

$$I = I_o \sin^2\left[\frac{\pi d \Delta n}{\lambda}\right] \quad (1)$$

Here I_o is the intensity of the incident light, d is the thickness of sample cell, Δn is the birefringence and λ is the wavelength of the laser light (633 nm). The optical signal has been detected by a photo detector (PD02-L1, Instec, USA) which fetch the data to an oscilloscope (TDS-2024C, Tektronix). A programmable function generator (AFG-3021B) has been used to apply the voltage across sample cell. The temperature of samples has been monitored using a temperature controller (HCS-302, Instec) with an accuracy of 0.1 °C.

3. Results and discussion

To study the effect of CdSe quantum dots on 8CB, we have first recorded the POM images of planar aligned samples under cross polarizer condition. Fig. 1 shows the bright and dark states of pristine and QD doped NLC system. All the bright and dark images have been recorded with same alignment direction with respect to analyzer and polarizer. It can be observed that the addition of QDs is not showing any visible aggregation in doped system except for 0.4% QD concentration (Fig. 1(g, h)). Furthermore the color of bright state for 0.1% and 0.2% QD concentration in NLC is almost identical but different from pristine NLC. Adding further QDs to NLC system i.e. 0.4% QD, shows the matching texture as of pristine NLC with slight aggregation of QDs. It indicates that addition of QDs is shifting the phase retardation of NLC system and for higher concentration it comes back to original state.

Fig. 2 shows the variation in effective birefringence (Δn_{eff}) for pristine and QD doped NLC system with change in $T - T_c$. The birefringence show a decreasing trend with increase in

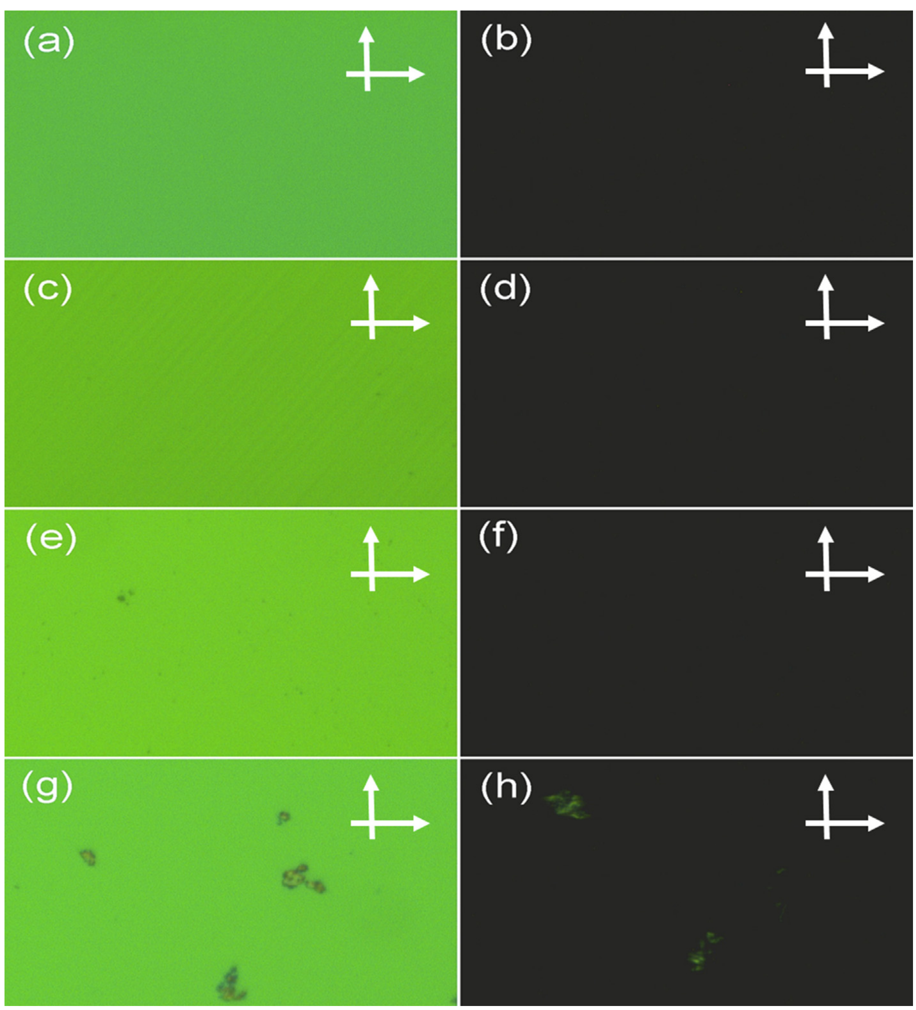

Fig. 1. Polarizing optical micrographs of (a) bright, (b) dark state of pristine 8CB; (c) bright, (d) dark state of 0.1% CdSe QD doped 8CB; (e) bright, (f) dark state of 0.2% CdSe QD doped 8CB; (g) bright, (h) dark state of 0.4% CdSe QD doped 8CB. Crossed arrows show the crossed polarizers.