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Applicability of TiO_2 nanoparticle towards suppression of screening effect in nematic liquid crystal

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ABSTRACT

We report the preliminary results observed for TiO_2 nanoparticles dispersed nematic liquid crystal. We observed that dispersion of TiO_2 nanoparticles (NPs) in nematic liquid crystal (NLC) has suppressed the undesired ionic effect. However unpurified nanoparticles lead to increase in the ionic conductivity, due to insertion of some more impurities. The pristine and dispersed NPs in NLC have been examined by means of optical texture, optical transmittance and dielectric spectroscopy. The diminution of ionic effects has been attributed to the strong adsorption of ionic impurities on the surface of TiO_2 nanoparticles. Almost all of the ions have been adsorbed on the surface of NPs at a loading of 1 wt.% in NLC. Also we didn't find any considerable change in the transition temperature of NLC, except for 2 wt.% loading. The optical transmittance curve reveals that relaxation processes are faster than the host materials, after the field is turned off. The faster relaxation in dispersed system is ascribed to the decrease in the rotational viscosity and suppressed screening effect. The present study is helpful in understanding the phenomenon of suppressing the screening effect, caused by the ionic movements under applied field of LC based devices, without affecting the transition temperature of liquid crystalline material.

1. Introduction

The enormous development has been made in the area of liquid crystal displays (LCDs) and its impact on science and technology of devices is very distinct. However, in case of LCDs there are a number of unsettled issues such as problem of image sticking, low contrast and low vision angle. The performance of LC (Liquid Crystal) based devices is presided over by the LC used and the alignment layer. The most critical issue concerning the degraded performance of LC devices is the presence of impurity ions, for all the modes used so far e.g. Twisted Nematic (TN), Hybrid Twisted Nematic (HTN), Super Twisted Nematic (STN), Optically Compensated Bend (OCB) mode, etc. The application of electric field across the cell results in the movement of ions and finally got adsorbed at the alignment layer. The electric double layer (EDL) engendered by the adsorbed ions constructs its own field and diminishes the effect of applied field [1]. Therefore the threshold voltage for the LC cell amplifies. Besides the increased threshold voltage the problem of image sticking, image flicking, slow optical response and reduced voltage holding ratio (VHR) is also associated with these ion movement. Therefore much attention had been paid to perk up the display quality in the recent years. Mainly two major approaches have been adopted by the researchers. One is to synthesize the new LC compound of preferred parameters and the other is alteration of LCs by dispersing different guest entities such as dyes [2,3], polymers [4], carbon nanotubes [5,6] and different nanoparticles [7–10]. This post synthesis method for optimizing the LC properties is much quicker and cost effective than synthesis method. Some success has already been realized regarding reduced threshold voltage, improved VHR and faster response [11,12]. The enhanced dielectric anisotropy, birefringence and induced vertical alignment have also been noticed in these dispersed LCs [13–15]. As far as the nanoparticles (NPs) are concerned: ferroelectric NPs, conducting NPs, semiconducting NPs and carbon based NPs have been employed and it is established that each nanoparticles have its individual impact on LC properties [16–19]. The tailoring of the LC properties depends on the nanoparticles used. Significant efforts have been made to study the mechanism of motion of ions in the LC cells in nano dispersed LCs by measuring the transient current, electro-optical properties, VHR, diffusion constant, ion concentration and influence of ion transportation on switching mechanism.

Recently the applicability of TiO_2 nanoparticle in various fields has been realized [20–25]. In this report the realization of suppressing the screening effect caused by the ion impurities in NLC by dispersing TiO_2 nanoparticles has been presented. The study of texture, optical transmission and dielectric measurements has been carried out to estimate the suppression of screening effect. Our experimental results show that the addition of TiO_2 nanoparticles leads to the diminution of transported ion concentration after a particular concentration and the measurement of threshold voltage justifies the observed behavior.

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2. Experiments

A well known nematic liquid crystal 5CB, having positive dielectric anisotropy and chemical stability has been used in the present investigation. The 5CB is intentionally chosen for its high electrical conductivity and ionic contamination, to examine the trapping efficiency of TiO_2 nanoparticles. In this work, we have used five different concentrations of TiO_2 (diameter less than 25 nm) in 5CB i.e. 0.1, 0.2, 0.5, 1 and 2 wt.%. The nanoparticles were first dispersed in ethanol and then stirred for some time to break the agglomeration and then proper concentration has been dispersed in 5CB. For the measurement of dielectric properties and textures we have used homemade planar aligned cells of thickness 8 μm using transparent and highly conducting ITO coated glass plate. Both electrodes have been treated with adhesion polymer (Nylon 6/6) and rubbed unidirectionally. The cell gap has been maintained using Mylar spacer. The cell has been calibrated using CCl_4 and Benzene (AR Grade.) The cells have been filled with five different concentrations including pure 5CB, by capillary action in isotropic phase. The dielectric data has been examined in the frequency range 100 Hz–40 MHz using HP 4194A impedance/gain phase analyzer. The temperature has been maintained with INSTEC hot plate with accuracy of ± 0.1 °C.

3. Results and discussion

Fig. 1 shows the textures observed under cross polarized condition for pure and dispersed nematic liquid crystal. The uniform color throughout cell confirms the homogenous alignment of the nematic molecules. The insertion of low concentration of nanoparticles does not show any appreciable change in the texture, which confirms that at low concentration these particles are homogenously dispersed in the nematic matrix. However further dispersion of nanoparticles shows some bright patches in the nematic matrix. These bright patches cover the whole region when concentration of nanoparticles is increased to 2 wt.%. As it is clear form texture that agglomeration of nanoparticles starts at 0.5 wt.% concentration and they further change the orientation of the nematic molecules in the region of their surface which results in bright patches.

From the dielectric relaxation we have observed two relaxation phenomena (not shown here). In the low frequency region, the contribution from the conducting ions has been observed. The absorption observed in the homogenous geometry, located in low megahertz region is attributed to the restricted rotation about the molecular short axis.

The ac conductivity has been calculated at 200 Hz using dielectric loss as $\sigma_{ac} = \varepsilon_0\omega\varepsilon''$ where ε_0 is the free space permittivity, ω is the angular frequency and ε'' is the dielectric loss of the material. The measured ac conductivity has been schemed against concentration of nanoparticles as shown in Fig. 2. It is clear from Fig. 2 that ac conductivity increases up to 0.2 wt.% filler concentration and then it abruptly decreases and almost saturates after 1 wt.% concentration of nanoparticles. It has already been reported that very minute concentration of dispersion of TiO_2 nanoparticles efficiently trims down the moving ion density [26]. The result observed in our case is quite different from those reported earlier. It is worth to mention here that we have used TiO_2 as it was procured without any further purification. It is well known that TiO_2 itself comes with impurities such as Fe, Co, Cr, Cu, Ni, Mn, etc. It is also possible that ionic impurities may appear from LCs itself, the alignment layers, and the adjoining glue or may be created during the filling procedure. So there is antagonism between the inserted and trapped impurities. It is worth to mention here that at higher concentration of nanoparticles, the agglomeration of nanoparticles reduces the exposed surface area. However the exposed surface area is still large enough to effectively adsorb the ions. Therefore we can conclude that at low concentration of nanoparticles in LC, the conductivity is primarily administrated by the ion contamination, but further increase in concentration will increase the number density of TiO_2 nanoparticles, as a result which will efficiently trap the impurities at its own surface. At some critical concentration almost all of the impurities will be trapped and no further decrease in conductivity is observed.

To confirm this conductivity behavior we have also measured the threshold voltage for various concentrations of nanoparticles in NLC, as tabulated in Table 1, by an independent experiment. The initial increase in the threshold voltage clearly points towards the increased screening effect due to additional impurities. It is easily perceived that the TiO_2 nanoparticle dispersed LC cells possess lower threshold voltage as compared to the pristine one for ion concentration greater than

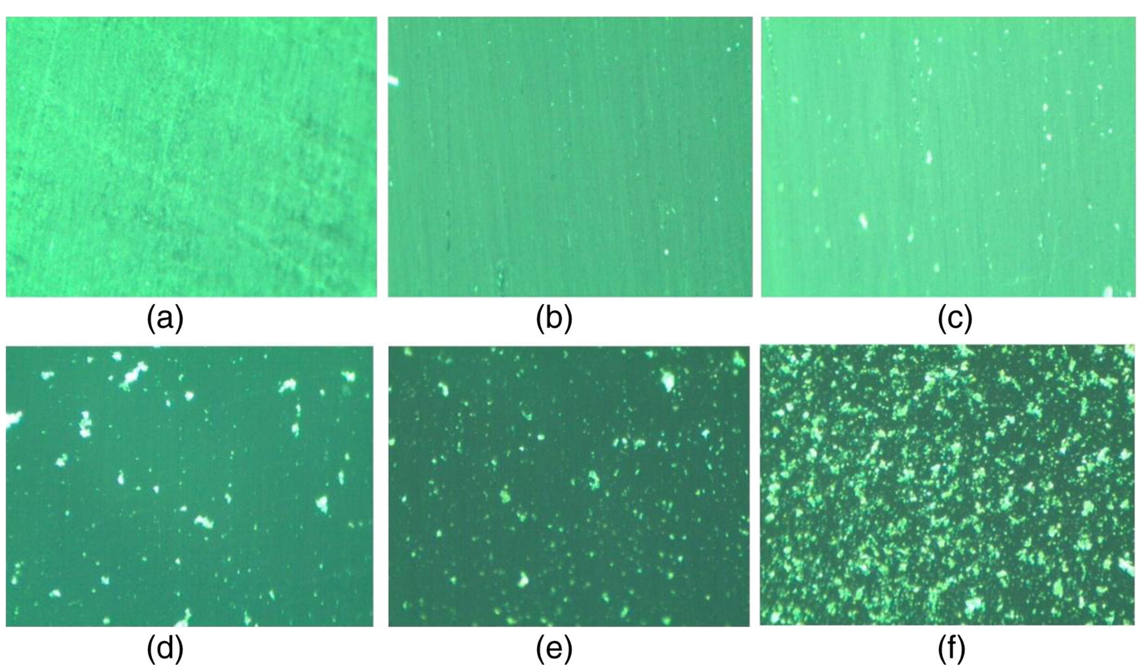

Fig. 1. Texture observed under cross-polarized condition (a) 5CB (b) 5CB + 0.1% (c) 5CB + 0.2% (d) 5CB + 0.5% (e) 5CB + 1% (f) 5CB + 2% wt/wt nanoparticles.