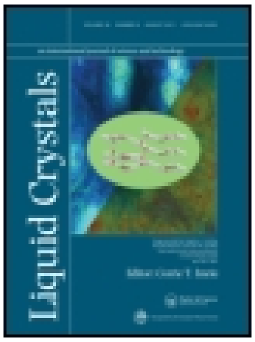

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Study of an interesting physical mechanism of memory effect in nematic liquid crystal dispersed with quantum dots

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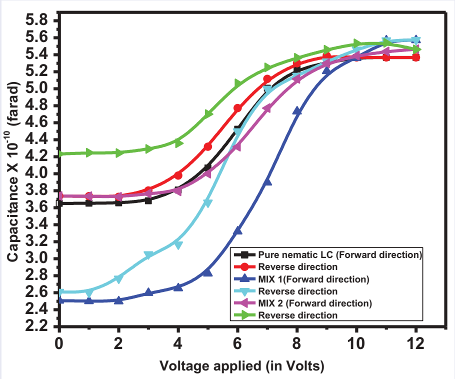
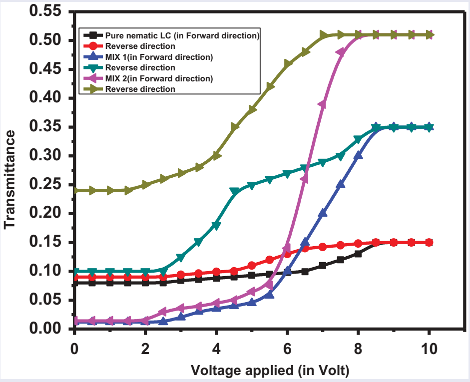
ABSTRACT

The present study is based on effect of dispersing $Cd_{1-x}Zn_xS/ZnS$ core/shell quantum dots (QDs) on the memory behaviour of nematic liquid crystal 2020 with the variation of dopant concentration and applied voltage. Around 26% and 45% memory storage in QDs dispersed nematic matrix (MIX 1 and MIX 2) has been the core finding. The presence of ionic charges at low-frequency regime along with their reduction in QDs dispersed nematic matrix has been confirmed from tan δ curve. Pure nematic LC as well as nematic/QD mixtures depict volatile memory effect that depends upon concentration of QDs. The existence of memory due to storage of charge on QDs has been further confirmed from the dielectric, polarising optical micrographs and electro optical study under the influence of bias voltage. The observation of memory effect is attributed to the ion capturing and ion releasing phenomenon. The dispersion of QDs in nematic material plays an important role to enhance memory parameter by capturing and releasing the ionic charges under the application of bias voltage which has been confirmed from capacitance-voltage curve.





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1. Introduction

The implementation of liquid crystals for electronic data storage devices has attracted the attention of consortium of researchers in both fundamental and applied aspects [1,2]. Among all the liquid crystal materials available, nematic liquid crystals are well versed for their good birefringence property, fast response, low threshold voltage [3–5] etc. Apart from these characteristics some nematic materials have been found to be enriched with the property of reminiscence. However, this behaviour in most LC materials has been found to be of short duration [6,7]. Semiconductor QDs provides a new platform for variation of various optical, electro optical characteristics of LC materials and its orientation. The existence of favourable interaction between QDs in liquid crystal matrix bears immense potential growth for various applications. QDs found possible applications in photovoltaic devices, modern displays, solar cells, photonic etc [8–11]. Researchers around the world have made an endeavour for the amendment in the characteristic properties of LC matrix through the dispersion of nanoparticles [10–12]. The charge retention capability of QDs has led to the emergence of memory effect in QDs which has been found to be time dependent [6,7] and could persist for seconds, minutes and hours. Several attempts have been made for the development of cost effective data storage devices with longer memory effect. The recent development and fundamental understanding of core/shell QDs dispersion in nematic LC helps in exploration of mechanism responsible for observation of memory [13–15].The researchers have reported the emergence of memory in the liquid crystal dispersed with nanoparticles. Various research articles throw light on the memory behaviour of nematic liquid crystal based on the dielectric relaxation phenomenon [14]. S.V. Shiyanowski et al. had reported the dielectric memory effect in nematic liquid crystal. The paper explains the observed behaviour in the presence of alternating field [14]. Pandey et al. had explained the transient memory observed in CdTe QDs dispersed ferroelectric liquid crystals [7]. The emergence of this effect in chiral nematic liquid crystals through the dispersion of CNTs has been reported in works of Raina et al. [16,17]. The study on polymer dispersed nematic liquid crystal films had been performed by Han [18]. Another observation for the field effect in nematic liquid crystals dispersed with CdSe/ZnS QDs had been reported by Konshina et al. [19]. They observed the reversible capacitance change of nematic liquid crystal cell doped with QDs. However, the present work has been performed on nematic LC samples dispersed with $Cd_{1-x}Zn_xS/ZnS$ core/shell QDs.

The existence of memory has significant impact on the modern display technology and electronic industry. The QDs are utilised as the storage node with charges used as information carriers while the integrated circuits have been used to perform memory operations such as writing, erasing and reading out the information in QDs [20]. Semiconductor QDs in the electronic industry are used as a means of volatile and non volatile memory devices depending on the requirement of either of the two as both of them have separate individual advantages and disadvantages. Volatile memory devices finds its application in security coded system and electronic data storage devices where the data can be erased as and when required for the security purpose hence no data can be salvaged. In the display technological world, liquid crystal display (LCD) can produce grayscale effect which depends on the amount of charge placed on electrodes. The charge controls the degree of alignment of crystals, hence the amount of light blocked by polarisation effect in LCD [21]. Volatile memory such as RAM (random access memory) used in laptops, computer system, smart phones and other digital electronic system. In such devices, the display requires power to maintain stored information. RAM is a primary memory or main memory (this term is often associated with addressable semiconductor memory). The information is retained as long as power is switched on. But when the power is interrupted the stored data gets lost. Volatile memory has several advantages, its volatility helps in the protection of sensitive information. Without volatile memory smart phones would fail to perform basic operations as accessing files would be slow. RAM or volatile memory is important between the file system and the processing cores, serving information as fast as possible. Critical files (such as operating system, application data, game graphics or any file that needs to be accessed at speed faster than other storage) that are needed by processor are stored in RAM waiting to be accessed. Dynamic RAM (DRAM) stores each bit of information in different capacitor within the integrated circuits and it needs single capacitor to store each bit of information and capacitor leaks charge therefore constant refreshing is required which makes it space efficient and inexpensive. However, SRAM (static RAM) is much faster than DRAM and it does not need constant electrical refreshing meaning thereby, content of DRAM can be changed quickly and easily to store different files but its disadvantage is its high cost. The example of DRAM and SRAM includes main memory and CPU cache memory. The electronic properties and physical configuration of volatile memory makes it faster in comparison to electro mechanical storage devices such as hard drives. In context of security the volatile memory is very secure as it does not retain any record when the power is off. Volatile memory is also used in password protected system (due to its read-write and erase cycles). On the other hand non volatile memory are secondary memory (example flash memory, solid state drivers, ROM, EEPROM) in which data get stored permanently and is not lost when the power shut down. The information is stored in bits (digital form) which can be converted to analog using digital to analog convertor or decoders (made on the semiconductor integrated circuits).

Various research articles emphasised on non volatile memory behaviour however, the present work focuses on volatile memory observed in QDs dispersed nematic system. It has been observed that 0.25 wt% concentration of core/shell QDs show improved memory effect as compared to other mixtures. Consequently, this has been the core outcome of the present study. In this paper, the dispersion of core/shell QDs in nematic material, namely LC-2020 has been studied. The experimental analysis has been performed through dielectric, electro optical measurement and polarising optical micrographs. The presence of core/shell QDs modifies the memory parameter in the dispersed system. The presence of ionic impurities and its reduction has been analysed by tan δ plot. The observed dielectric memory has been confirmed with the textural and electro optical technique (transmittance measurement) which has been attributed to ionic charges in LC medium.

2. Experimental procedure and measurements

2.1 Material used in the scientific study

The host material which has been used in the present study is a dielectrically positive anisotropic ($\Delta\varepsilon = 14.2$) nematic liquid crystal mixture named, LC-2020 (provided by our collaborating Liquid crystal group, Military university of technology, Warsaw Poland) which displayed the phase transition as:

$$\mathrm{Cr} \overset{-20^{\circ}\mathrm{C}}{\rightarrow} \mathrm{N} \overset{107.7^{\circ}\mathrm{C}}{\rightarrow} \mathrm{Iso}$$

Mixtures LC-2020 comprises laterally fluorinated 4′- alkylphenyl-4- isothiocyanatotolane [3,22–25]. The spherical shaped $Cd_{1-x}Zn_xS/ZnS$ core/shell QDs ($x = 0.85$) as a guest entity having diameter 8.5 nm (core diameter 5nm and shell 3.5 nm respectively) [3,11,12,26] is used. The information about the synthesis of $Cd_{1-x}Zn_xS/ZnS$ core/shell QDs has been reported earlier by Bae et al. [26]. The preparation of LC sample cell and core/shell QDs – nematic composite system has been provided in Ref [3]. In order to prepare mixtures, 0.1 wt% and 0.25 wt% of core/shell QDs were dispersed into pure nematic LC followed by ultrasonication for 1 h at isotropic temperature 108°C to obtain homogenous dispersion of core/shell QDs into pure nematic LC [3,11]. These mixtures were termed as MIX 1 and MIX 2 in the manuscript. ITO coated glass plates have been used for the fabrication of planar aligned sample cells (Nylon 6/6 as alignment layer) through photolithography technique. These cells having thickness $\sim 6\mu m$ were calibrated with benzene and then filled with sample by capillary action at isotropic temperature.

2.2 Dielectric measurement

A computer controlled (HP 4194A) impedance/gain phase analyzer attached to (Instec HCS 302) temperature controller had been used to study dielectric parameters (dielectric permittivity and capacitance) of the samples in the frequency range 100 Hz to 10 MHz at 60 °C. The dielectric permittivity has been plotted at a bias voltage of 0 V, 10 V, 0 V after the removal of 10 V instantaneously, 0 V after several min (10, 15, 20, 25, 30, 35, 40, 60 and 70 min removal) for pure nematic, MIX 1 and MIX 2 respectively on a frequency scale to study the existence of volatile memory effect. The chosen magnitude of applied voltage 10V is higher than the threshold voltage (2.9V, 2.8V and 2.5V for pure nematic, MIX 1 and MIX 2, respectively) to ensure the reorientation of liquid crystal molecules in pure and dispersed system. The capacitance-voltage curve or dielectric hysteresis of the samples has been plotted by applying the bias voltage in the forward and reverse direction which shows the charge retention capacity for pure nematic and its dispersed system and it gets saturates at 10V. The plot for tan δ measured in low frequency range 1 Hz to 10 kHz using Solartron (Sl-1260) to confirm the presence of ionic charges in LC medium. The measurement has been recorded at particular temperature 60 °C as the prominent memory effect for the LC system due to molecular orientation has been speculated to be stable at this temperature (the detailed description has been provided in the later part of this manuscript).

Optical measurement

Polarising optical microscopy is an effective tool for identification of LC phase, defects, contrast and various other properties. The optical technique was performed by taking the optical textures using polarising microscope Radical RXLr-5 fitted with a hot stage. The optical textures at 100 Hz were recorded by placing the sample cell under the crossed position of analyzer and polarizer with the replication of measurement by removing the bias voltage after certain interval of time. The bias voltage was applied using programmable function generator (Tektronix, AFG 3021B). An inbuilt digital camera Jenoptik ProgresCT3 at the top of the microscope has been used to capture the textures. These textural images are directly transferred to the computer by interfaced software.

2.3 Electro optical measurement

The transmittance of the samples at 632.8 nm wavelength (5 mW power) has been measured with the help of applied dc voltage from a programmable function generator (Tektronix, AFG 3021B). We used electro-optical set up in which electric field causes reorientation of director in the plane perpendicular to cell. Since director is the optical axis in nematic LCs, its behaviour can be traced by measuring the transmitted light intensity through the cell and pair of crossed polarizer aligned at an angle of 45° to plane of director reorientation. The temperature of the LC sample cell was controlled and measured with the temperature controller hot plate (HCS302 Instec Co. USA) with an accuracy of ± 0.1 . During experiment output transmitted intensity was measured through the photo detector (Instec- PD02-L1) which was directly fed to digital storage oscilloscope (Tektronix TDS-2024C) in electrical form. The detailed information has already been reported by our group [3]. The % of memory parameter was evaluated using the following relation [27].

$$\mathrm{M.E}\,\% = \frac{T_{Off} - T_O}{T_{On} - T_O} \times 100 \qquad (1)$$

Where T_{On}, T_O are the maximum value of transmittance when the voltage is applied, the initial value of transmittance taken as reference and T_{Off} is the residual transmittance i.e. is the value of transmittance after the removal of bias voltage.

3. Results and discussion

Tan δ study has been performed to disclose the presence of ionic impurities at low frequency (1 Hz to 10 kHz) in LC system. Figure 1 illustrates the graph for tan δ versus frequency at 60° C for pure nematic LC and its mixtures. It depicts that the magnitude of tan δ reduces for both mixtures than that of pure nematic LC. The appearance of peak at low frequency regime (approx. 100 Hz) is due to the presence of ionic relaxation at this frequency range. The reduction in the magnitude of tan δ indicates that the ionic contamination reduces for both mixtures as compared to pure LC. This has been accredited to the ion capturing phenomenon of core/shell QD [3,26]. The conceptual model depicting the reduction of ionic effect issues had already been reported in our previous paper [3]. Core/shell QD effectively adsorbs the ionic impurities on the shell of QDs thereby reducing the ionic impurities or contamination in LC system. It has been observed that the amount of reduction in tan δ magnitude is larger in MIX 2 than in MIX 1 and pure nematic LC. The reason might be due to the fact that in MIX 2 interaction between QDs molecules play the dominant role therefore as the concentration of QDs increases, the ionic contamination decreases as large number of ions gets adsorb on the shell of QDs but this happens only up to critical concentration (i.e. MIX 2 in this case). In the present work, the studies have not been performed beyond the critical concentration. This is due to the fact that beyond the critical concentration, as the concentration of QDs increases the ability of QDs to trap ionic charges reduces [3]. In core/shell QDs the shell of QDs, i.e. ZnS is polar in nature, therefore it facilitates trapping of ionic charges effectively on its surface and does not let ionic charges release from its surface easily [3] but beyond certain concentration of QDs, it causes agglomeration at much higher

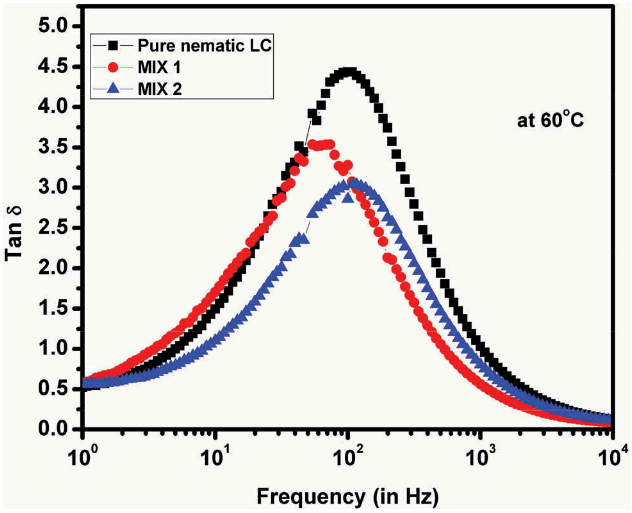

Figure 1. (Colour online) Variation of tan δ on frequency scale ranging from 1 Hz to 10 kHz at 60°C temperature for pure nematic LC and its mixtures with core/shell QDs.

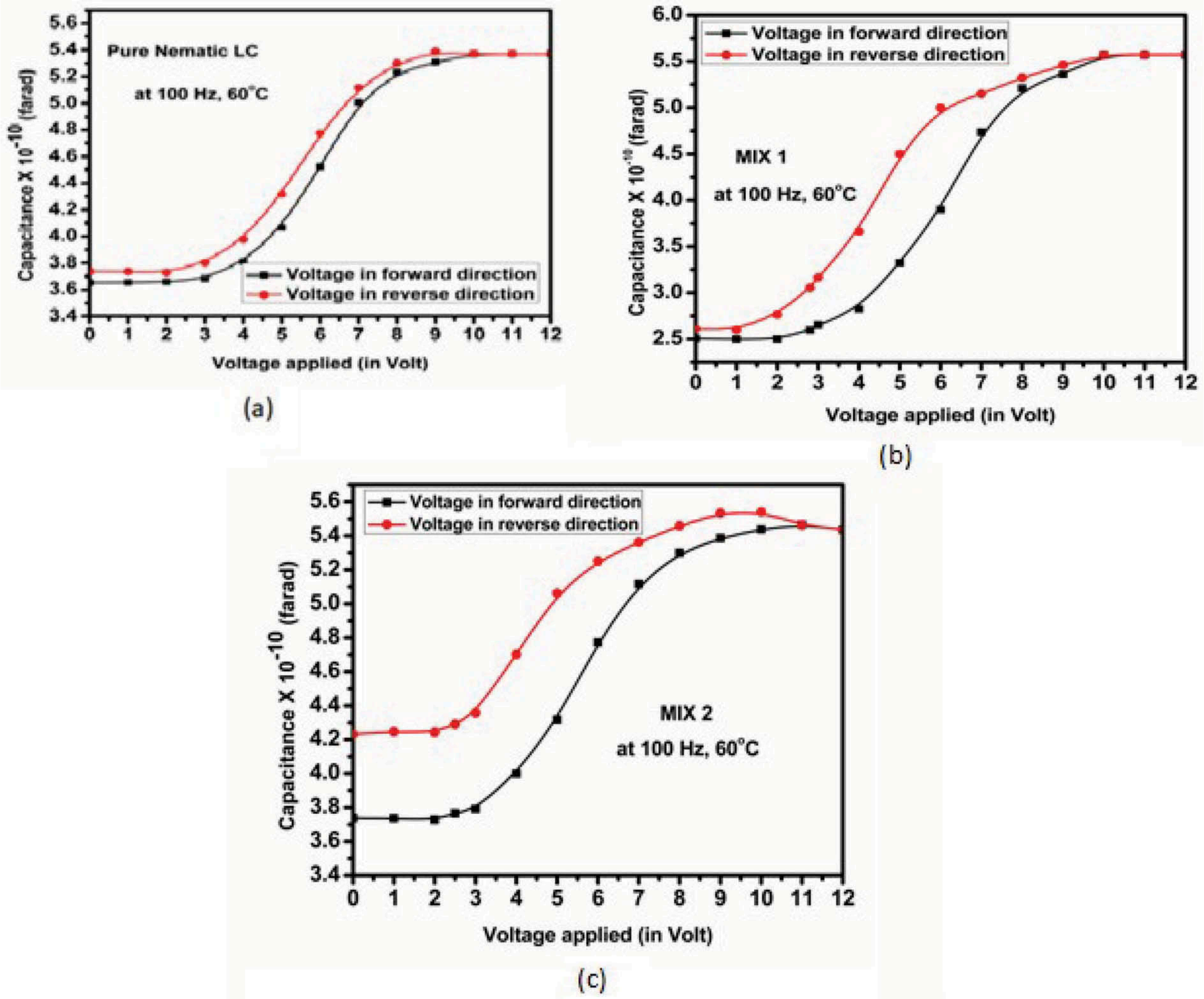

Figure 2. (Colour online) Capacitance as a function of applied voltage acquired at 60° C, 100 Hz frequency and threshold voltage 2.9 V, 2.8 V and 2.5 V for (a) pure nematic LC, (b) MIX 1 and (c) MIX 2 in forward and reverse direction.

concentration thus adversely affecting the LC-based display devices.

Figure 2 shows the voltage dependent capacitance (C-V curve or dielectric hysteresis) at 100 Hz, 60° C observed in pure LC and its mixtures with core/shell QDs. The memory in pure LC is attributed to the structural deformation. It has been observed that in pure LC and its mixtures, when the voltage is applied in forward direction then at threshold voltage (2.9 V, 2.8 V and 2.5 V for pure LC, MIX 1 and MIX 2 as shown in Figure 2) molecule switches therefore the capacitance increases with increase in voltage above the threshold voltage while below the threshold voltage there is no switching in the molecules therefore the capacitance remains constant below V_{th}. The increase in capacitance or charge storage capacity in forward cycle has been due to charging of core/shell QDs under the influence of applied voltage in LC medium. Quantum dots are the storage node with charges utilised as information carriers (due to electronic property of QDs). QD based memory is elucidated on the basis of emission barrier and capture barrier in QDs (i.e. charge storage and charge leakage phenomenon). The formation of emission barrier involves the potential confinement or localisation of energies of QDs. In contrast, capture barrier is considered necessary so as to prevent charge from outside the QDs to enter QDs. while emission barrier is required to prevent charge from leaving the QDs. Now to comprehend the memory operation, we consider hole as information carriers. In the charging of QDs during the writing operation, the application of bias voltage results in energy levels of QDs completely above the Fermi level and holes gets captured from the valence band continuum surrounding the QDs [20]. The capturing phenomenon is exceedingly fast and is termed as charge storage operation or writing cycle.

For erasing process, the bias voltage is applied in reverse direction which leads to increased bending of band around the QDs which causes the narrowing of emission barrier i.e. charge leakage operation or erase cycle. This increases the tunnelling probability and the charge carriers inside the QDs tunnel out through the barrier into the energy band. The read out of the information in QDs is performed through current measurement [20]. However, in the present work we have not performed the current measurement.

Capacitance is a measure of charge storage capacity. In the present work, sample cell holder behaves as capacitor plates. These capacitor plates are filled with dielectric material (LC and LC+ QD mixtures). In case of pure nematics, the increase in capacitance in first cycle has been due to the presence of ionic charges in LC medium. However, in LC-QDs mixtures, presence of core/shell QDs effectively stores these ionic charges on the surface of shell and the charge storage capacity of LC-QDs dispersed system increases because as the concentration of QDs increases, LC-QDs and QDs-QDs interaction plays the dominant role apart from LC-substrate and LC-LC interaction. Core/Shell QD are semiconducting in nature. When an electric field is applied to LC-core/shell QDs dispersed system, the dipole moment of core/shell QDs affects the dipole moment of nematic LC molecules up to higher extent. The higher conc. of core/shell QDs increases the number of ions produced by doping therefore dielectric constant increases for dispersed system [3]. When the reverse voltage is applied, the stored charge on the QDs leaks from its surface therefore the capacitance decreases in reverse cycle (Due to charge leakage).

After 10 V applied bias the charge retention capacity saturates. Therefore, 10 V may be regarded as the saturation voltage for charge retention capacity in pure LC and its mixtures. Now, when the voltage is applied in the reverse direction the LC molecules does not relax back to its original orientation therefore, it does not retraces its original path and as the voltage reduces the charge retention capacity or capacitance also reduces due to release of ionic charges. The complete removal of bias voltage in reverse direction shows that there exists residual capacitance which gets stored in the form of reminiscence or memory. The amount of remnant capacitance indicates the distinguished memory effect in pure LC and its mixtures. For pure nematics it has been observed that this residual capacitance amounts to around 2% of its original value at 0 V while for MIX 1 and MIX 2 its percentage has been observed to be around 4% and 13% of its original value. The enhanced percentage of remnant capacitance for MIX 2 indicates the pronounced memory for MIX 2 in comparison to pure LC and MIX 1. Therefore, the dielectric hysteresis curve for pure LC and its mixture with QDs confirms the dielectric memory effect.

Figure 3(a-c) depicts the dielectric permittivity versus frequency (100 Hz to 10 MHz) for pure LC and its mixtures with QDs (MIX 1 and MIX 2) at 60° C, fixed bias 0 V and 10 V respectively. It has been observed that the ionic charges persist in low frequency region approximately up to 1 kHz (as shown in Figure 1 and inset of Figure 3) thereafter the ionic charges gets suppressed. The presence of these ionic charges is responsible for the dielectric memory which persisted over few minutes in pure nematic LC and its mixtures with QDs. It has been found that applying a bias of 10 V, dielectric permittivity reaches to higher value and ionic charges at low frequency regime gets suppressed than that at 0 V applied bias. The replication of measurement by removing the bias voltage has been performed. It has been clear from the figure that the pure nematic LC itself shows memory effect due to the interaction of weak anchoring layer of polymer with both substrate and liquid crystal [28]. When the nematic liquid crystal cell is heated up to isotropic temperature, the adsorbed molecules on the substrate are detached from it and become free at the interface. On cooling the cell from isotropic to nematic phase with applied field, the molecules are adsorbed again on the substrate along the electric field direction. The heating process is obligatory to attain uniformly memorised orientation and it aids the alignment of molecules along the field direction. This memory effect of the molecular orientation appears to be achieved by the adsorption of molecules on the substrate along the field direction. However, this memory state can be erased when LC cell is again heated to an isotropic temperature. The reduction in the value of dielectric permittivity at 100 Hz for pure nematic LC at 0 V after 10 V instantaneously was found almost 50% of its original value. This indicates that the ionic charges in LC medium reduces (as compared to 0 V) due to the application of 10 V applied bias and even after removing 10 V instantaneously, the ionic charges in the LC medium remain suppressed (as these ionic charges do not achieve their original 0 V state). The persistence of these suppressed ionic charges in pure nematic LC after removing 10 V instantaneously shows the existence of memory. The conceptual description about the trapping of ionic charges and electrode polarization phenomenon had already been provided in our

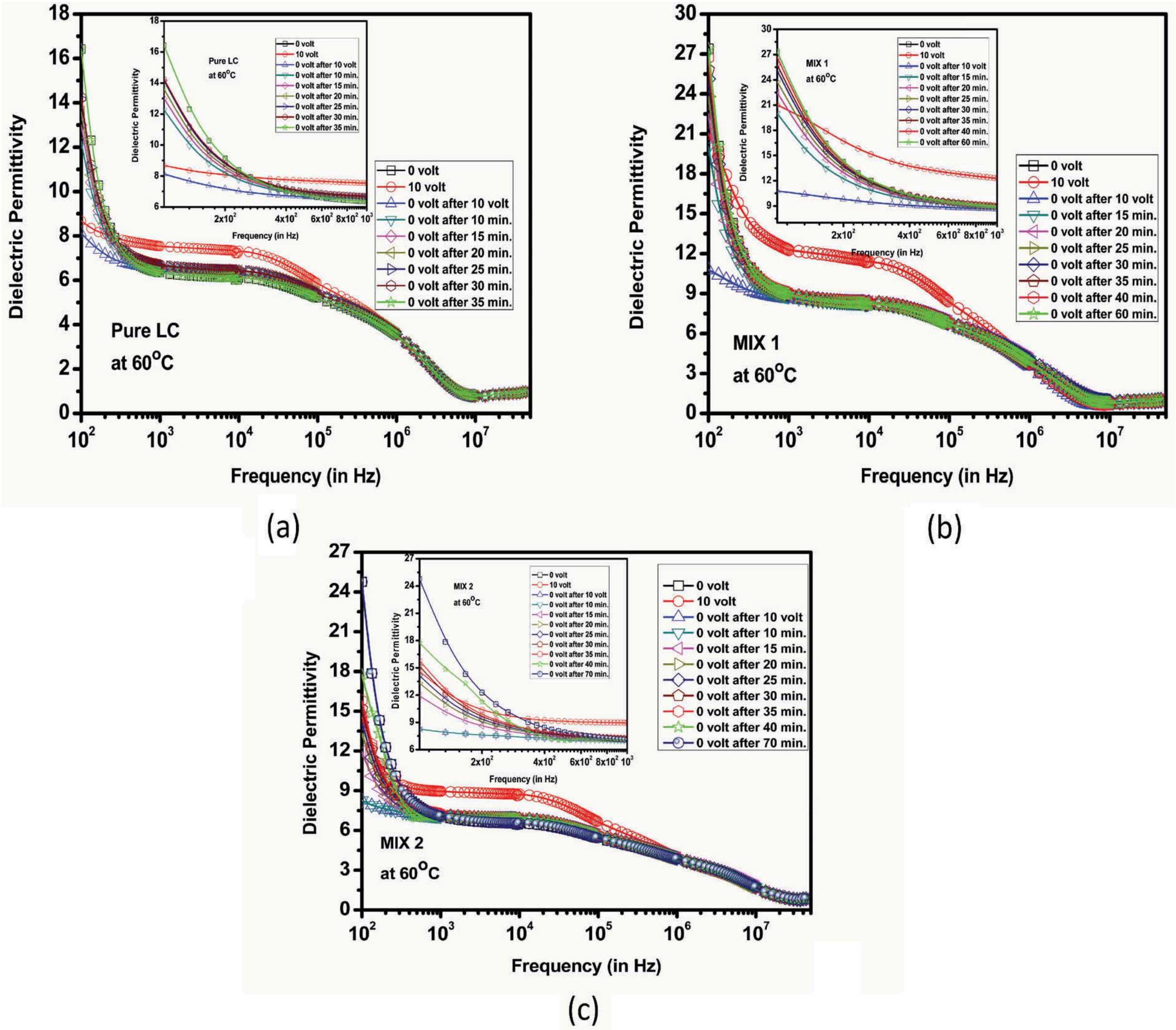

Figure 3. (Colour online) Variation of dielectric permittivity on frequency scale ranging from 100 Hz to 10 MHz at 60°C with 0V applied bias, 10V applied bias, several min. (10 min., 15 min., 20 min., 25 min., 30 min., 35 min. 40 min., 60 min., 70 min.) after removal of bias for (a) pure nematic LC, (b) MIX 1 and (c) MIX 2. The dielectric permittivity regains its original value after 35 min of removal of bias for pure nematic LC, after 60 min of removal of bias for MIX 1 and after 70 min for MIX 2. The inset in figure represents the zoomed area from 100Hz to 1000 Hz for pure nematic and its mixtures with core/shell QDs.

previous work [3]. After 10 min, the ionic charges at low frequency in the LC medium increases (i.e. ion releasing) but still these charges do not regain its original 0 V state as shown in inset of Figure 3(a). This has been indicated from the value of ε_r which was found almost 25% of its original value meaning thereby as the time passes, the orientation of nematic molecules changes in a slow fashion in such a way that the ionic charges are released in the medium and after several minutes (i.e. 35 min) ionic charges attain its original state 0 V (i.e. volatile memory as the initial 0 V permittivity overlaps with final 0 V after 35 min. of removal of bias). This confirms that the ion capturing and releasing phenomenon depends on time and the progression of time leads to release of ions thereby reducing the charge retention capacity or capacitance which has been discussed in the later part of this paper. However, the retention of memory state for mixtures has been observed which is found to be dependent on QDs concentration. Figures 3(b) and (c) shows that the presence of QDs induces prominent changes. The value of dielectric permittivity for MIX 1 instantaneously after removing a bias of 10 V was found almost 61% of its original value. After 10 min the charge retention capacity reduces to almost 27% of its original value whereas the changes observed in the value of ε_r for MIX 2 at 0 V after 10 V instantaneously (around 68% of its original value) signifies that the ionic charges has been reduced significantly in the vicinity of QDs (due to adsorption of ions on the shell of QDs), thereby showing enhanced memory effect. After 10 min though the charge retention capacity reduces it is almost 53% of its original value still it holds largest charge retention in comparison to pure LC and MIX 1. It is found that charge stored on QDs released in slower fashion and it takes several minutes to discharge completely (i.e. initial 0 V permittivity overlaps with final 0 V after removal of bias for 60 min. in MIX 1 and 70 min. in MIX 2). MIX 2 has high concentration of QDs which means more availability of storage nodes therefore enhanced memory. Hence C-V plot describes the memory effect using electronic property of QDs in anisotropic medium. After one cycle the capacitance of the cell is found to be different compared to starting states and these differences persist for some time hence termed as volatile memory effect.

Another experimental procedure used to study the possible presence of memory effect includes study of textural changes and electro optical measurement. Figure 4 depicts the tabular format of polarizing optical micrographs at 60°C, 100 Hz frequency that involves 3 rows and 5 columns. The columns correspond to action of QDs with nematics: at 0 V, 10 V bias, 0 V after 10 V instantaneously, 10 min after the removal of bias, 35 min. removal for pure nematic, 60 min (MIX 1) and 70 min. (MIX 2). The rows correspond to (a) pure nematic LC (b) MIX 1 (c) MIX 2. These figures confirm the observation of existence of volatile memory in pure and its mixtures through colour changes. The POM (polarising optical micrographs) confirms the memory effect in the pure and dispersed system. Panel 4 (A–E) corresponds to column, panel 4 (A) shows the bright state of pure nematic LC with its mixtures at 60 °C before the application of any bias voltage to the cell. The optical textures of mixtures with core/shell QDs are marked by changes in colour, which indicates that QDs dispersion has influenced the orientation and ordering (alignment) of nematic molecules. The dark state was achieved upon the application of 10 V bias as depicted in panel 4 (B). The POMs of 3rd column panel 4 (C) (0 V after 10 V instantaneously) shows the emergence of electro optical memory in pure and its mixtures. It depicts an inability of nematic molecules to instantly switch to its original state because of the presence of QDs in nematic matrix and it stabilises the switched state of the mixtures for a period of few minutes. Once the molecule switches its state, it tends to retain its switched state for a short interval of time even after the removal of 10 V bias instantaneously. The

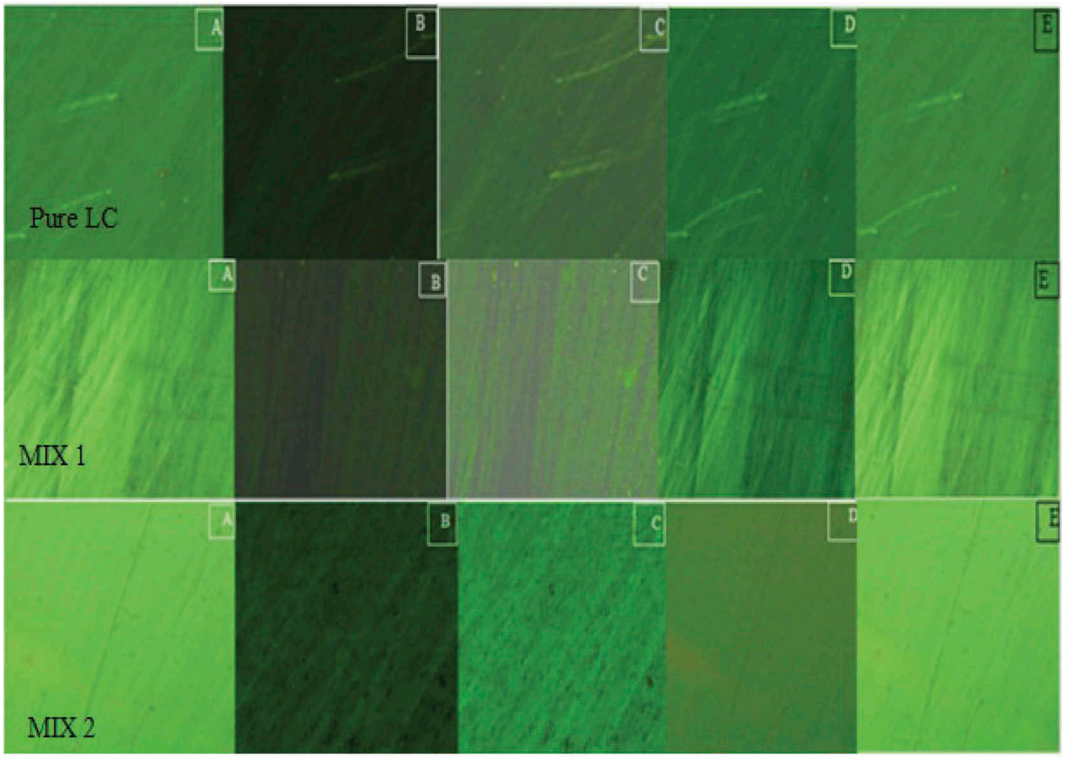

Figure 4. (Colour online) Tabular format for polarizing optical micrographs at 60°C, 100 Hz where the rows correspond to (a) pure nematic LC (b) MIX 1 and (c) MIX 2. The columns corresponds to action of applied bias (A) 0 V, (B) 10 V (C) 0 V after 10 V instantaneously (D) 0 V after 10 min of removal of bias, (E) 0 V after 35 min of removal of bias for pure nematic LC, after 60 min of removal for MIX 1 and after 70 min of removal for MIX 2.

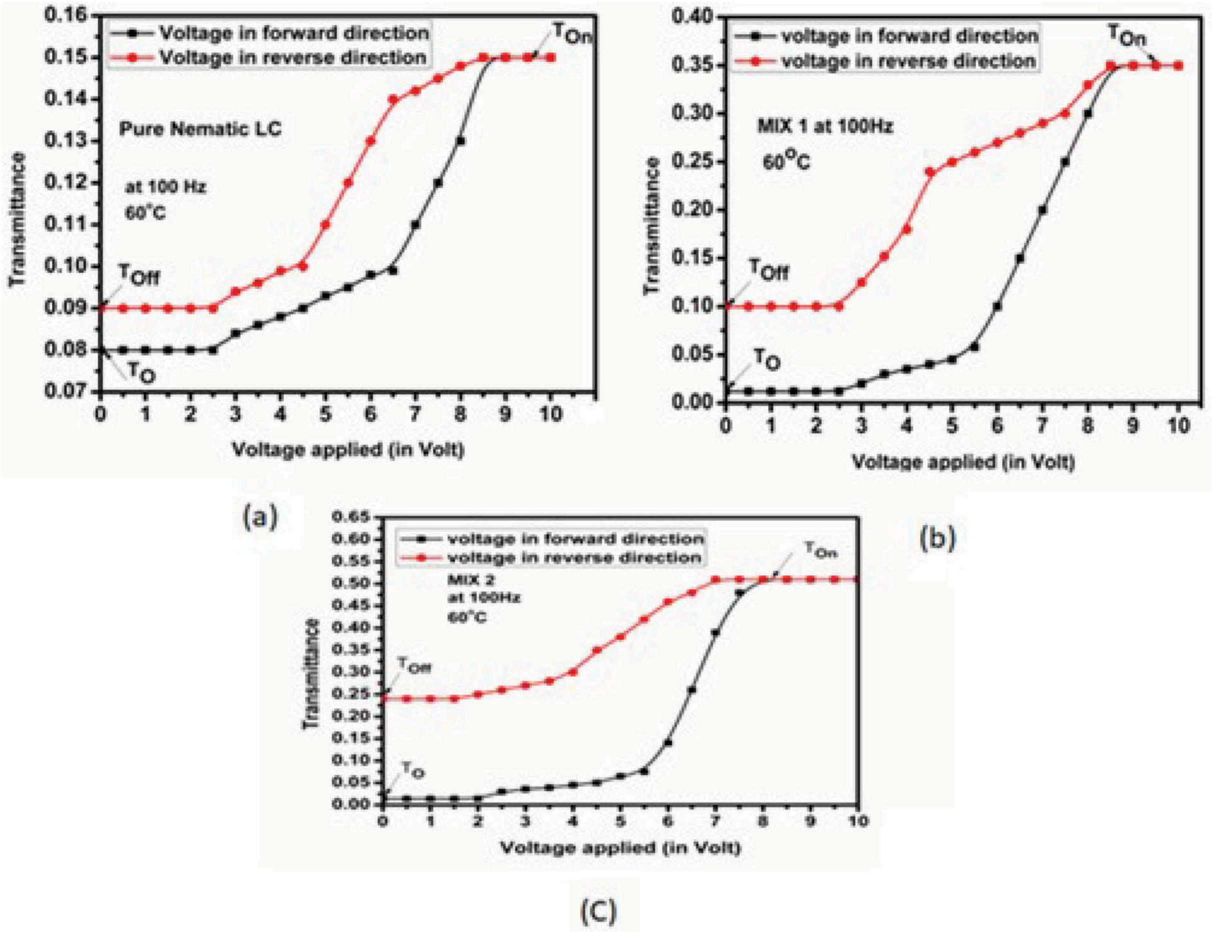

Figure 5. (Colour online) Variation of transmittance with applied voltage at 60 °C for (a) pure nematic LC, (b) MIX 1 and (c) MIX 2 in both forward and reverse direction.

memory state last (i.e. 0 V after 10 min panel 4 (D)) but this effect starts fading away with the passage of time. The memory state in pure and MIX 1 samples almost switched back to original state (i.e. bright state 0 V) after 35 min. and 60 min. of removal of bias as shown in panel 4 (E). However, MIX 2 did not return to its original state even after 10 min. of removal of bias and it takes longer time than pure and MIX 1 to return to its original state (i.e. after 70 min. of removal of bias panel 4 (E)). Thus, POM reconfirms our observation about the memory in pure and its mixtures with QDs and enhanced memory for MIX 2 as compared to pure nematic LC.

Figure 5(a-c) depicts the transmittance versus applied dc voltage at 60° C for pure nematic LC and its mixtures. The figure clearly confirms the memory effect in pure LC and its mixtures with QDs. The existence of memory in pure nematics and its mixtures with QDs has been obtained from the calculation of memory parameter percentage (from equation (1)). It has been observed that for pure nematic LC, % of memory parameter is almost 14.2% whereas for MIX 1 and MIX 2, it is found to be around 26% and 45%, respectively. These values of memory parameter shows that pure nematic LC exhibit small memory effect, MIX 1 exhibits large memory effect in comparison to pure LC and pronounced memory effect has been shown in MIX 2. The figure clearly represents the increase in the transmittance with voltage and it reaches to saturation value after certain voltage. The saturation transmittance in the presence of applied bias voltage is termed as saturation/maximum transmittance which has been marked in figure as T_{on}. When the voltage is applied in reverse direction, the transmittance reduces but it does not retain its original path i.e. it exhibit hysteresis. It has been observed that even after removal of bias voltage there exists residual transmittance which is termed as T_{off} shown in figure. This residual transmittance is different from the initial transmittance value which was taken as reference value of transmittance T_o as depicted in figure. Hence the presence of hysteresis clearly confirms our observation of volatile memory effect. This effect has been observed at low frequency only because at higher frequency the hysteresis loop no longer exist due to the diminution of ionic charges at higher frequency. Therefore, it has been termed as 'Volatile'.

4. Conclusion

The present paper reveals the influence of $Cd_{1-x}Zn_xS$/ZnS core/shell QDs on the memory behaviour of liquid crystalline material. The core finding of the work is to study the effect of QDs on the memory behaviour through dielectric, optical and electro optical technique in pure nematic LC. A remarkable increase in the memory parameter has been observed for 0.25 wt% concentration of QDs dispersed into nematic material. The observed behaviour degrades by dispersing very high concentration of QDs therefore, the dispersion of 0.25 wt% concentration of QDs into LC-2020 has been found to be suitable for observing enhanced memory effect. The volatile memory in the investigated sample can be utilised in the data storage, ion- impurity free devices and display technology. The suppression of undesired ionic impurities in QDs dispersed nematic material is another outcome of the present work. This outcome promotes the understanding of the influence of semiconductor QDs dispersion on memory behaviour of liquid crystals. The increment in the charge storage capacity for dispersed system plays the significant role in electronic data storage devices. The information in the digital memory devices get stored in the form of bits which can be converted into analog form using decoders. Hence the research concludes that the memory devices are effectively utilised by consortium of researchers in decoding display technology.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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