Enhance the performance of liquid crystal as an optical switch by doping CdS quantum dots

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Abstract. The electrical and optical properties results were studied for Cadmium Sulphide (CdS) Nanoparticles/ Nematic liquid crystal (5CB) mixtures. Doping of CdS nanoparticles increases the spontaneous polarization and response time, the increase is due to large dipole-dipole interaction between the liquid crystal (LC) molecules and CdS nanoparticles, which increase the anchoring energy. The electro-optic measurements revealed a decrease (~40\%) in threshold voltage, and faster response time in doped sample cells than Pure 4'-n-pentyl-4-cyanobiphenyl (5CB) nematic liquid crystal.

1. Introduction
Liquid crystal (LC) devices are great interest elements of modern life because of the pervasiveness of their application as a spatial light modulator (SLM), optical antennas, and flat panel display devices. Doping the nematic liquid crystals (NLC) type 4'-n-pentyl-4-cyanobiphenyl (5CB) with small amounts of nanoparticles can stupendously modify the electro-optic response of the NLC host material. Nanoparticles effects result from the influence of these nanoparticles in the liquid crystal/substrate interface, and nanoparticles in the bulk. In this paper, these effects were studied. The Fréedericksz transition happened due to the distribution in the orientational order of the nematic liquid crystal 5CB doped with CdS quantum dots is also studied, as these dispersions are known from earlier studies to affect the initial alignment layers[1]. Low operation voltage is one of the most decisive operators for developing liquid crystal display devices. Nanoparticles doping is a facile method of achieving low threshold voltage [2]. A type of semiconductor material, CdS nanoparticles, have been doped into the nematic liquid crystal. The response time and frequency cut off of nanoparticles-doped liquid crystal were also studied in this work. In addition, there are some parameters as phase transition temperature, orientational order, and dielectric constants have interest effect cause the threshold voltage reduction, and make the doped materials have the same variation behavior with the threshold voltage as they are correlated with the nanoparticles size and doping concentration [3]. Some of the semiconductor nanoparticles as TiO2, ZnO, CdS have been studied for improved the physical properties in case if they doped in liquid crystal [4-8].
In the present paper, an attempt has been made to study the effect of CdS nanoparticles on the electro-optic properties of 5CB LC.

2. Experimental Work
The preparation of Cadmium Sulphide CdS quantum dots (CdS QDs) achieved using the Chemical method. Initially Cadmium chloride CdCl₂, Paraffin, and Olic acid, were mixed in proper way and heated under argon gas with temperature at 160 °C then the Sulfur (S) dissolved in Paraffin Oil to get solution that heated to 220°C. When the solution achieved, the CdS QDs synthesis by mixing this two solution with mole ratio 2:1. The CdS QDs were purified by repeated dissolution in a mixture of toluene: methanol. The detailed synthesis of CdS nanoparticles is also reported in previously published methods [9]. The liquid crystal material was 5CB from Sigma Aldrich Company, has been used as the host material. The LC sample cells of thickness 2nm were fabricated using indium tin oxide (ITO) coated transparent glass substrates has sheet resistance 25Ω and aligning layers of polyimide (PVA) deposited on it. The polyamid layers act as the planar alignment of 5CB LC molecules. The polyimide layers were scribed by a fleecy material in order to provide a uniform planar alignment of LC. The cell was assembled so that the rubbing directions of the opposite aligning layers were antiparallel. The cell gap was done by the glass spacers of appropriate size, (20 μm). The pure and doped NLC samples were prepared using doping of CdS NPs with two concentration of 0.05wt%, 0.25 wt% into NLC. The homogenized mixture of CdS /NLC was then filled in the space of LC sample cells (middle of the cell layers) by capillary action and sealed using adhesive materials. The electrodes for the LC cell were connected at the ITO surface of the cells using the Aluminum material.

The electro-optical measurements were carried out using the experimental setup puts in ‘figure 1’. The sample cell was set between two linear polarizers so that the angle between the polarizers plan is 90°, while the angle between the polarizer plan and the rubbing direction of polyimide layer was 45°. The electro-optical variations were recorded on a digital storage oscilloscope (Tektronix TDS2024B).

![Figure 1](image)

**Figure 1.** Experimental setup for measuring the electro-optical properties of the LC samples.

3. Results and Discussions

3.1. The Structure, Morphology and the Shape of CdS QDs:
The XRD test has patterns of the prepared CdS QDs shows the presence of the diffraction peaks at the (100), (002), (101), (220) planes. All peaks in the XRD pattern give indicate to the structure, which is hexagonal wurtzite structure. ‘Figure 2a’ shows the XRD patterns of CdS QDs, which have peak position illustrate in ‘figure 2 b’, which are agreed with the standard data get from PCPDFWIN. The average particle size of the CdS QDs calculated from the Scherrer formula is (6.62 nm).
Figure 2. The XRD patterns for (a) prepared CdS QDs and (b) Bulk CdS.

The SEM image of CdS QDs shows the spherical clusters of CdS QDs, while the grain size estimated was about 20nm as shown in figure 3.

Figure 3. The SEM images of CdS QDs.

The EDX analysis of CdS QDs to get the purity and the concentration of each compounded inside the CdS film was the Cadmium 34 at% and the sulfur 14 at % as shown in ‘figure 4’.
Figure 4. The EDX of CdS QDs

3.2. The Electro-optic Properties

3.2.1. Frequency Response
The frequency that the device of LC/CdS have maximum transmittance as an optical switch is 200 Hz for pure LC optical switch device, while for the tow devices that have the concentration of doping with 0.05 wt% and 0.25 wt%, the frequency response for these was 250 Hz as in ‘figure 5’.
Figure 5. The Frequency Response of the Pure LC, LC/CdS with 0.05wt% and with 0.25wt% optical switch

3.2.2. Threshold Voltage

The threshold voltage of the LC device and LC/CdS optical switch is measured when it starts to respond. ‘Figure 6’ shows the relation between applied voltage and output voltage record from the detector as a function of the transmission of the pure LC and for LC/CdS with two concentration of doping. The threshold voltage was 1.4 volt for pure LC optical switch while for LC/CdS optical switch was 1 V, for both doping concentration 0.05 wt% and 0.25 wt%.

The threshold voltage has reduced with the addition of nanoparticles in the pure nematic liquid crystal optical switch because of the increased charge density of the nano-nematic composite system which reduced an energy barrier. The doping of CdS NP (0.25% by weight) nano-particle in the LC layer generates free electron, CdS NP, these generated free electrons enter into the LC layer and therefore charge density increases near the interface. This results in the smaller electric field and thus a smaller threshold voltage is required.
3.2.3. Rise Time

The rise time have been calculated from 10% to 90% of the steady state of the signal of the response voltage of the pure LC optical switch device that shown in ‘figure 7’, which was 7.5ms.while the rise time for LC/CdS optical switch can be illustrated in table (l) which was 5 ms for the 0.05wt% and 4ms for the 0.25wt%. ‘figure 8’ shows the response signal of LC/CdS optical switch.

Figure 6. The Threshold Voltage of Pure LC, 0.05wt %, and 0.25wt% Optical Switch

Figure 7. The Response Signal of Pure LC Optical Switch
The addition of nanoparticle provides enhancement interaction to the dipole moment of nematic liquid crystal molecules. Therefore, the higher concentration of nanoparticles causes to decrease the response time of NPs/NLC mixture. The mechanics of CdS nanoparticle in liquid crystals is based on the orientational vector distribution of the dipole moment of nanoparticle and that can be characterized by an orientational order parameter. This distribution catalyzes the coupling strength to increase the responding for liquid crystals and stabilizes the nematic phase of the liquid crystal.

3.2.4. Fall Time
The fall time calculated from 90% to 10% of the steady state of the signal was 58.75 ms for the pure LC optical switch, while the fall time was 55 ms for the 0.05 wt% and 50 ms for the 0.25 wt%.

3.2.5. Response Time
The response time calculated from 0% to 62.5% of the steady state of the signal was 12.5 ms for pure LC optical switch. While the response time was 4.375 ms for the 0.05 wt% and 3 ms for the 0.25 wt%.

4. Conclusions
The effect of CdS QDs doping into nematic liquid crystal mixture has been studied electro-optic measurements. Doping of CdS QDs improves the response time and threshold voltage than pure NLC, due to the tremendous increase in dipole moment of NLC molecules. A decrease in the threshold voltage about 40% was also noticed in the doped sample than pure NLC sample, that showing an improved switching behavior. The cutoff frequency of CdS/NLC optical switch was 250 Hz, which greater than Pure LC optical switch (200 Hz). Fast response time from 12.5 ms for pure LC to 4.3 ms for 0.05 wt% sample and 3 ms for 0.25 wt% sample.

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