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Research Article

Dielectric and Performance Analysis of CdTe Quantum Dots Doped Nematic Liquid Crystal

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ABSTRACT

In this work, cadmium telluride core type quantum dots (CdTe QDs) were dispersed in 4-pentyl-4′-cyanobiphenyl (5CB) nematic liquid crystal (LC) with a concentration of 0.05 % wt/wt; and dielectric properties were investigated by using admittance measurements in the frequency range of 100 Hz - 10 MHz. In order to determine the effects of CdTe QDs in 5CB nematic LC, dielectric anisotropy (Δε), crossover frequency ($f_{crossover}$), critical frequency ($f_{critical}$), real and imaginary parts of permittivity (ε' and ε'') of neat LC and CdTe QDs dispersed LC composites were obtained using the experimental data. Moreover, threshold voltage (V_{th}), splay elastic constant (K_{11}) were also calculated. It was found that V_{th} and K_{11} of QDs dispersed LC are significantly decreased due to the existence of CdTe QDs.

Keywords: *Nematic liquid crystal, quantum dot, electrical and dielectric properties*

CdTe Kuantum Nokta Katkılı Nematik Sıvı Kristalin Dielektrik ve Performans Analizi

ÖZET

Bu çalışmada çekirdek tipi kadmiyum tellür kuantum noktaları (CdTe QDs) ağırlıkça % 0,05 oranında 5CB (4-pentil-4'-siyanobifenil) nematik sıvı kristale (LC) katkılanmış ve dielektrik özellikleri 100 Hz-10 MHz frekans aralığında empedans ölçümleri kullanılarak araştırılmıştır. CdTe kuantum noktaların 5CB nematik sıvı kristal yapıda gösterdiği etkiyi belirlemek için dielektrik anizotropi (Δε), geçiş frekansı (fgeçiş), kritik frekans (fkritik), dielektrik sabiti (ε' ve ε'') değerleri saf ve CdTe katkılı LC için deneysel veriler kullanılarak elde edilmiştir. Ayrıca, eşik voltajı (Vth) ve eğilme elastik sabiti (K11) hesaplanmıştır. CdTe katkılanmasıyla eşik voltajı (Vth) ve eğilme elastik sabitinin (K11) önemli ölçüde azaldığı görülmüştür.

Anahtar Kelimeler: *Nematik sıvı kristal, kuantum nokta, elektrik ve dielektrik özellikler*

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I. INTRODUCTION

In development of the photonics technology, researchers concentrated on unusual nano-materials which are used for modifying the performance of the composite structures. Recently, semiconductor quantum dots (QDs) have been investigated by many researchers because they have promising properties for many areas such as optoelectronics, drug delivery systems, solar cells and lasers.

The various combinations of QDs in different host materials (polymers, liquid crystals (LCs) and etc.) have been studied because of the physical parameters, which are strongly affected and photonics structure was altered by presence of QDs [1-4]. Liquid crystalline materials were used as host materials to understand molecular interaction with nano additives in composite systems. LC materials are well known for their electrical, optical and dielectric properties and they are also very important since they exhibit high dielectric anisotropy ($\Delta\varepsilon$) and low power consumption. The best well known example of a liquid crystal is the nematic phase. This phase is widely used in the display industry, for which molecular reorientation under an applied electric field provides the mechanism for optical switching. In a LC-based system, optoelectronic response of the system is determined by molecular orientation of LC. LC molecules have a strong dipole moment which is affected by external electrical or optical fields. This feature allows the collective orientation of LC molecules. Thanks to these features, LCs were utilized in flexible displays, optical shutters, electrically controlled switches and photonic band gap structures. LC dispersion containing different type of nanoparticles has been investigated by using various materials such as metallic nanoparticles, semiconductor nanoparticles, ferroelectric nanoparticles, polymer nanoparticles and carbon related nanoparticles etc. [4-8].

In this paper, we have studied the dielectric behaviours and the performance analysis of 5CB nematic LC doped with CdTe QDs. It was shown that QDs nano particles interact with LC molecules in a different physical mechanism and leading to important changes in dielectric parameters such a threshold voltage and dielectric anisotropy of the investigated doped system compared with the neat LC material.

II. MATERIALS AND METHODS

In this work, the 5CB coded nematic liquid crystal purchased from Sigma Aldrich Chemical Company was used for the host material. It has high positive dielectric anisotropy in low frequency regime. Dispersed agent CdTe (λ=610 nm emission) QDs supplied by Sigma Aldrich Chemical Company. Pure LC and doped LC with agent material CdTe QDs were prepared. The ratio of CdTe QDs was chosen 0.05 % wt/wt in nematic LC material. Then, the solution was mixed with ultra-sonic water bath at 50 ^{0}C for one hour to obtain uniform mixture. The preparation of the solution was followed by the injection of these solutions into ITO coated glass cells that has thickness of ~10 µm using capillary action. For the investigated pure and QDs doped LC samples, dielectric spectroscopy technique was chosen for dielectric parameters characterization. Dielectric measurements have been carried out by a computer controlled Novacontrol Alpha A Dielectric/Impedance Analyzer in the frequency range 100 Hz to 10 MHz at room temperature at 1 V with test signal of 100 mV$_{rms}$. Afterwards, current-voltage (I-V) measurements of the samples were held using a Keithley 2400 source meter between 0 V and 10 V bias ranges.

III. RESULTS AND DISCUSSIONS

The electrical permittivity, which is defined as the interaction with the electric field, is a complex quantity and consists of real and imaginary parts [5].

$$\varepsilon^* = \varepsilon' - i\varepsilon'' \tag{1}$$

ε' is the real part of the electrical permittivity and is a measure of the energy amount stored in the material by applying an external electrical field. ε'' is the imaginary part of the electrical permittivity and symbolizes the energy losses in the material. Figure 1 shows the voltage-dependent variation of the real part of the electrical permittivity for different frequency values for the measured samples. It is seen that along with the applied voltage, there is a molecular orientation in the pure and doped samples; additionally, the total polarization is increased. Therefore, after a critical voltage value, an increase in ε' occurs. However, at high frequencies, this behavior is different because of the change in the sign of anisotropy of the liquid crystalline samples. Hence, no significant change in the real part of the electrical permittivity value is observed in high frequency regions for both samples.

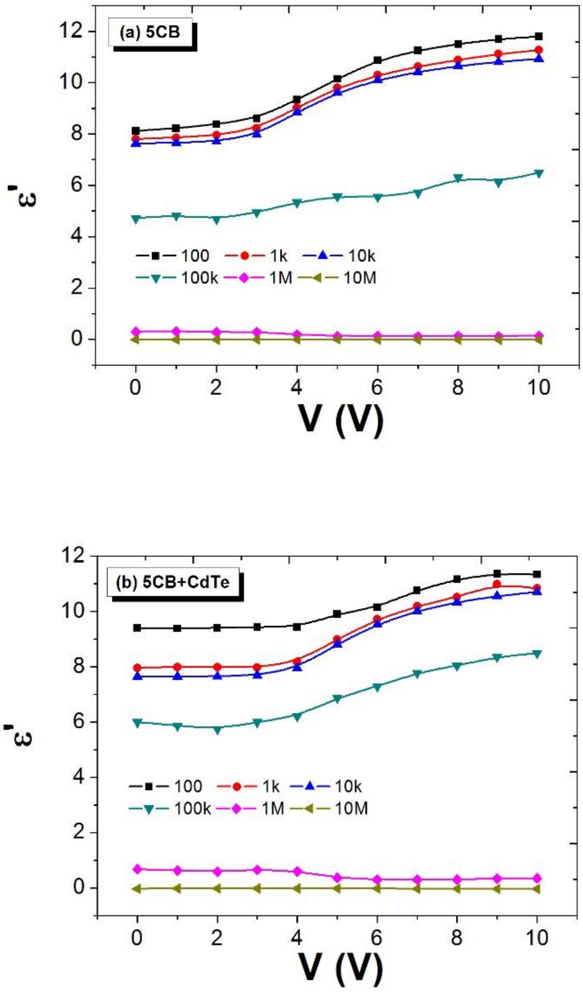

Figure 1. *ε'–V plots of the* ***(a)*** *pure 5CB and* ***(b)*** *doped with CdTe QDs*

Comparison of the ε' values at high frequency regions in Figure 1 do not indicate any significant difference between the response of the samples against the bias voltage. However, the difference between the responses of the samples against the frequency of the ac signal is slight. Figure 2 shows frequency response of ε' and ε" values for pure and doped samples. It is clearly shown that ε' decreases with increasing the frequency value since the dipoles cannot follow the test signal due to their lifetime lag behind the period of the field (Figure 2(a)). Therefore, polarization of the sample is decreased since liquid crystalline molecules cannot orient, thus lower ε' values are obtained.

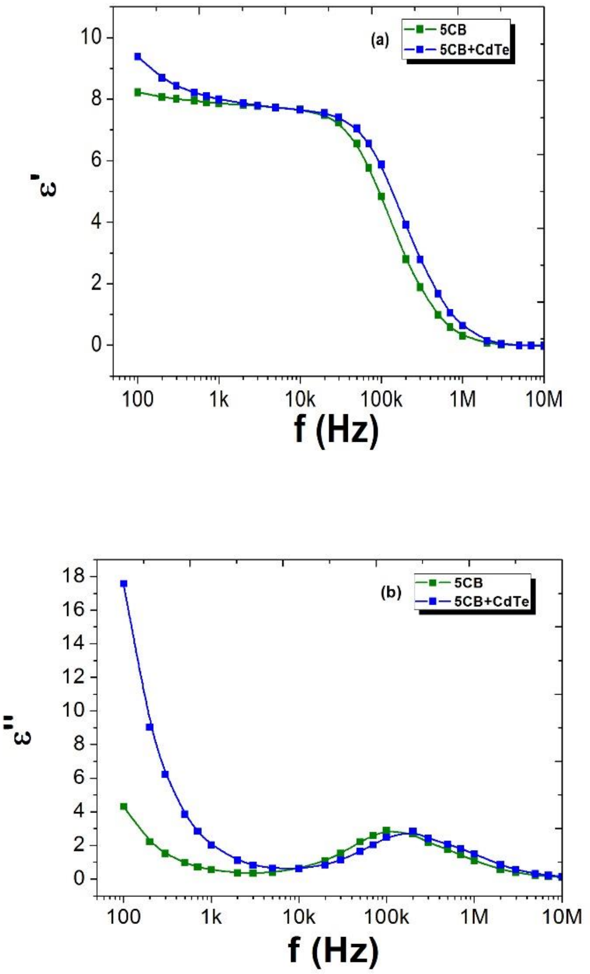

Figure 2. (a) *ε'–f and* ***(b)*** *ε"–f plots of the pure 5CB and doped with CdTe QDs*

By considering the Figure 2(b), ε" increases with frequency at lower frequency regions; however, the values of ε" decrease after passing a critical frequency ($f_{critical}$) for pure and doped samples. The critical frequency value is found using the maximum peak points of the curves. The $f_{critical}$ values of the samples are given in Table 1. As shown in this table, CdTe QDs leads to increase in critical frequency value. When the results obtained for undoped and doped LC samples are compared, it is obvious that QDs dispersal causes an increase in ε' and ε", both, in the low frequency region. The effect of dispersing nano-sized particles in a liquid crystalline sample on dielectric constant is not straight forward. Therefore, it is possible to encounter that polarization ability of the samples is increased and decreased depending on the structure of the LC materials which is in agreement in the literature [1,6,7,9-15].

Table 1. *Some dielectric parameters of the LC samples.*

Sample	$f_{crossover}$ *(kHz)*	$f_{critical}$ *(kHz)*
5CB	826	103
5CB+CdTe	768	191

Dielectric anisotropy ($\Delta\varepsilon$) defined as $\Delta\varepsilon=\varepsilon_{\parallel}-\varepsilon_{\perp}$ is a measure of how effectively LC molecules are reoriented as a result of an external field. In the definition of $\Delta\varepsilon$, $\varepsilon_{\parallel}$ and $\varepsilon_{\perp}$ are components of permittivity and these are parallel and perpendicular to the director, respectively [6]. Figure 3 shows the frequency dependence of dielectric anisotropy. Since permittivity is frequency dependent, dielectric anisotropy is also frequency dependent. Both of the samples have a high $\Delta\varepsilon$ value in the low frequency region. Moreover, $\Delta\varepsilon$ changes sign in this region such that the liquid crystalline samples start to show n-type anisotropy after a frequency value which is referred as crossover frequency ($f_{crossover}$). Hence, the samples exhibit p-type anisotropy up to $f_{crossover}$. It is seen that QDs dispersal also affected the $f_{crossover}$ of the samples, such that $f_{crossover}$ of 5CB is 826 kHz whereas that of 5CB doped with CdTe QDs is 768 kHz as can be seen in Figure 3.

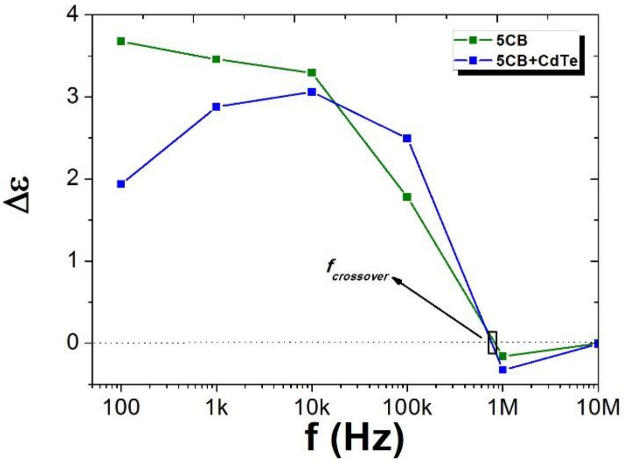

Figure 3. *Δε–f plots of the pure 5CB and doped with CdTe QDs*

The frequency variation of threshold voltage (V_{th}) in the nematic phase for pure and nanocomposites doped with CdTe QDs of 5CB is shown in Figure 4. In planar aligned cells, V_{th} is the voltage at which the liquid crystal molecules start to reorient along the direction of applied electric field. The threshold voltage was determined by measuring light intensity change between crossed polarizer and analyzer. By applying voltage with 100 Hz-10 MHz sinusoidal frequency and then detecting the change in the transmitted light intensity, we have obtained the threshold voltage which is transmitted light intensity changed by the 10 % (upper or bottom value). It is seen that the threshold voltage has reduced with addition of CdTe QDs in the pure nematic liquid crystal. Due to increased charge density of the CdTe QDs in hybrid structure energy barrier of LC composite is reduced. The doping of CdTe QDs in the LC generates free electrons which enter into the LC structure and therefore charge density increases near the interface. This effect requires less electric field for polarization and thus a smaller threshold voltage is obtained for QDs doped LC which is a desirable results regarding the usage of liquid crystalline sample in device applications. Besides, lower values V_{th} might be due to lowered anchoring energy of liquid crystalline molecules with QDs dispersal. Moreover, according to Figure 4, the threshold voltage of both samples increases with increasing frequency.

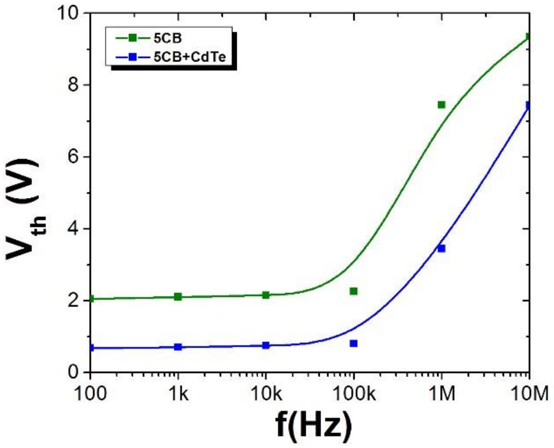

Figure 4. *V_{th}–f plots of the pure 5CB and doped with CdTe QDs*

V_{th} values were utilized to calculated splay elastic constant (K_{11}) of the samples. The splay elastic constant (K_{11}) is determined using the following relation [3,6,16],

$$V_{th} = \pi\sqrt{\frac{K_{11}}{\varepsilon_0|\Delta\varepsilon|}} \qquad (2)$$

The splay elastic constant is given a function of frequency for both samples in Figure 5. The value of K_{11} increases or decreases in proportion to the square of V_{th} value. The K_{11} value is reduced due to the reduction of the V_{th}. And it is also thought that the elastic constant decreases due to the increase in the pretilt angle with the quantum dot doping [17]. K_{11} of the samples are nearly same in the high frequency limit, however QDs dispersal yields much lower K_{11} values in the low frequency regime. Similar results were also obtained for other LC samples dispersed with QDs [1,9]. Current dependent voltage graphs of the samples is given in Figure 6. Current values at 10 V are $1.1\text{x}10^{-6}$ A and $3.7\text{x}10^{-6}$ A for 5CB and 5CB doped with CdTe QDs samples, respectively.

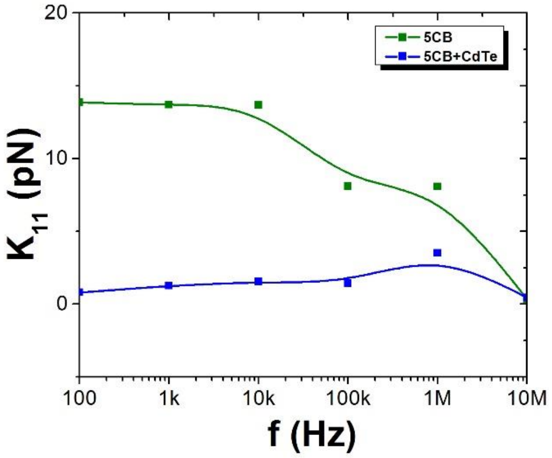

Figure 5. *K_{11}–f plots of the pure 5CB and doped with CdTe QD.*

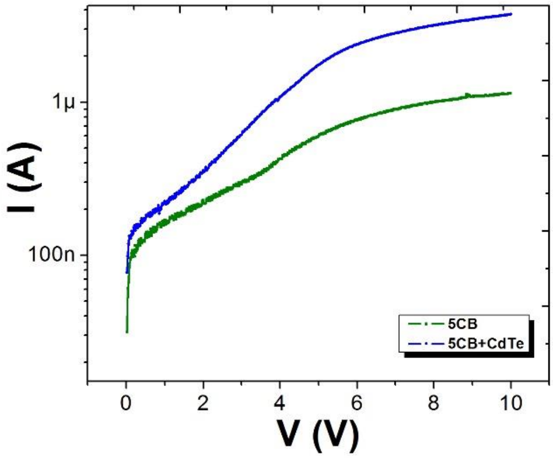

Figure 6. *I-V plots of the pure 5CB and doped with CdTe QDs.*

IV. CONCLUSION

In this study, the effect of CdTe QDs on the dielectric and electrical properties of 5CB nematic liquid crystal has been investigated. Dielectric parameters such as dielectric anisotropy, threshold voltage, splay elastic constant were obtained in the frequency range of 100 Hz - 10 MHz. For undoped and CdTe QDs doped samples, $\Delta\varepsilon$ has high values in the low frequency region which is preferred for device applications for less energy requirement. The reduction of the threshold voltage and the splay elastic constant with the doping of quantum dots is very important for easy orientation in liquid crystals. It was found that splay elastic constant of LC samples decreases with QDs doping. The splay elastic constant of pure 5CB is 17 times larger than that of QDs dispersed 5CB at 100 Hz. Similarly, threshold voltage is decreased from 2.05 V to 0.68 V with dispersal of QDs in LC composite structure. The results show that CdTe QDs contribution cause the significant changes in LC based device applications.

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