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Research Article

Effects of CdTe Quantum Dot Dispersal on Current-Voltage Characteristics in Liquid Crystalline Mediums of E63, E7 and SCLP

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ABSTRACT

The usage of nano-sized quantum dots (QDs) particularly in guest-host based hybrid mediums revealed enhancements in electro-optical properties of the mediums, therefore the focus of considerable amount of contemporary studies has been about dispersal of QDs for improvements in medium. This study investigates the effects of CdTe QD dispersal on current-voltage characteristics of some liquid crystalline materials such as E63, E7 and SCLP. Current is increased for all samples due to QD dispersal, however the best improvement is obtained for E7. Hence, current-voltage characteristics of E7 and QD dispersed E7 mediums were also investigated under UV light exposure. Current values of both mediums were found to increase with increasing UV light power due to generation of electron-hole pairs. Photocurrent's dependence on light power revealed that QD dispersal does not affect recombination mechanism in the medium. On the other hand, UV light responsivity of QD dispersed E7 was obtained approximately twice of that of E7. Thus, it was concluded that CdTe QDs make considerable contribution to current-voltage and photoconductivity characteristics of E7 in dark and under UV light illumination.

Keywords: *Quantum Dots (QDs), Liquid crystals, Current-voltage characteristics, Photoconductivity*

CdTe Kuantum Noktası Katkısının E63, E7 ve SCLP Sıvı Kristal Malzemelerin Akım-Voltaj Karakteristikleri Üzerine Etkisi

ÖZET

Nanometre boyutlarındaki kuantum noktalarının (KN) özellikle de konuk-konak bazlı hibrit yapılarda kullanımı yapıların elektro-optik özelliklerinde iyileşmeler ortaya koymuş, dolayısıyla da güncel çalışmaların hatırı sayılı bir kısmının odak noktası KN katkısı yoluyla yapıda iyileştirmeler sağlama üzerine olmuştur. Bu çalışmada CdTe KN katkısının E63, E7 ve SCLP gibi sıvı kristal malzemelerin akım-voltaj karakteristikleri üzerindeki etkileri incelenmiştir. Akım tüm numuneler için QD katkısıyla birlikte artmış fakat en iyi gelişme E7 için elde edilmiştir. Bu sebeple E7 ve KN katkılı E7 yapılarının akım-voltaj karakteristikleri ayrıca morötesi ışık altında incelenmiştir. Her iki yapı için de elektron-deşik çiftlerinin üretiminden dolayı artan morötesi ışık şiddetiyle birlikte akımın arttığı tespit edilmiştir. Fotoakımın ışık gücüne bağlılığı KN katkısının yapıdaki rekombinasyon mekanizmasını etkilemediğini ortaya koymuştur. Öte yandan KN katkılı E7'nin morötesi ışık duyarlılığı E7'ye kıyasla yaklaşık iki kat fazla elde edilmiştir. Böylece, CdTe KN katkısının E7'nin karanlıkta ve morötesi ışık altındaki akım-voltaj ve fotoiletkenlik karakteristiklerine hatırı sayılır katkıda bulunduğu sonucuna varılmıştır.

Anahtar Kelimeler: *Kuantum noktaları (KN), Sıvı kristaller, Akım-Voltaj karakteristiği, Fotoiletkenlik*

I. INTRODUCTION

Lately, the search for sustainable energy sources has become a major issue due to the environmental harm caused by conventional energy sources. Therefore, tremendous amount of research was conducted by many in the last couple decades and considerable amount of these researches was on solar energy [1]. Quantum dots (QDs) are nano-sized 3-dimensional crystals which constitute important part of third-generation solar energy devices [2]. Therefore, in the last couple decade, QDs were studied a lot for improvements in device characteristics, particularly for current-voltage and electro-optical characteristics. Among the several QD types, CdTe QDs yielded promising results for their utilization in photovoltaic devices, sensors, nano-thermometer devices, X-Ray imaging, electro-optical devices and liquid crystals [3]-[9].

An advantage of QDs is that they allow researchers to tune electrical, dielectric and optical properties of the medium they are dispersed in. Due to charge carrier transfer and creation of electric dipoles between guest (QDs) and host materials, QDs were found to enhance some properties for the colloidal mixture. Liquid crystalline materials form a suitable medium for QD dispersal, hence researchers have focused on characterizing the colloidal mixture formed by QD dispersal. In their studies [9]-[13], they found that incorporation of QDs in the liquid crystal affects orientation and anchoring of liquid crystal molecules, threshold voltage, elastic constants and anisotropy. For obtaining liquid crystalline materials having required features, one could mix several liquid crystal molecules together or mix them with polymeric materials. The previous way forms a new liquid crystal which has different properties than its constituents whereas the latter way forms a side-chain liquid crystalline polymer (SCLP). The liquid crystalline materials of this study, i.e. E63, E7 and SCLP, are the materials that are obtained through these ways.

Another way of obtaining liquid crystalline materials that attain requested properties is incorporation of doping agents in the medium. QDs' ability in modifying electrical, dielectric and optical properties of liquid crystalline materials brings great advantage which could save time and effort spent for synthesis of a liquid crystal material attaining demanded properties. However, there is a need for characterization studies which provide emerging effects after QD dispersal. Several research groups have conducted studies for this purposes. Doke et al. [14] managed to lower saturation voltage along with an enhancement in optical contrast, optical tilt angle and photoluminescence intensity by dispersing CsPbBr₃ QDs in ferroelectric liquid crystals. Rastogi et al. [15] observed memory effect memory due to storage of charge on CdZnS/ZnS QDs dispersed in fluorinated 4'-alkylphenyl-4-isothiocyanatotolane liquid crystal mixtures. Praseetha et al. [16] found that CdSe QD doped LC can be considered as a good candidate for the optical limiting application. Wang et al. [17] achieved a fast response time in 5CB LC holographic display through using ZnS/InP QD dispersal. Kocakulah et al. [18] yielded decreased response time and threshold voltage in polymer stabilized LCs by dispersal of CdSeS/ZnS QDs. These studies of the last two years show how promising QDs can be when they are dispersed in liquid crystalline materials in terms of material characteristics.

Therefore, in this study, the studied liquid crystalline materials, i.e. E63, E7 and SCLP, were dispersed with CdTe QDs so that the effect of QD dispersal on current-voltage and photoconductivity characteristics of the studied mediums are investigated between 0 V and 10 V, at room temperature, and in dark and under UV light illumination.

II. EXPERIMENTAL

CdTe QDs (COOH functionalized, fluorescence λ_{em} 520 nm) were purchased from Sigma-Aldrich. E63 and E7 were purchased from Merck, and SCLP was obtained by radical polymerization of Poly (methyl methacrylate) comprising a 4-cyanophenyl benzoate side group. E63 is a mixture of 5CB, 7CB, 5CT, PCH3, BCH5 and DB71, with significant amounts of 5CB and 7CB while lesser amounts of the others, and E7 is a mixture of 5CB, 7CB, 80 CB and 5CT having w/w value of 51, 25, 16 and 8, respectively

[19]. CdTe QDs were fully dissolved in deionized water using magnetic stirrer. Later, the QD solution was separately mixed with E63, E7 and SCLP in order to obtain E63, E7 and SCLP mediums with trace amount of QDs and the QD dispersed mediums were treated with ultrasonic bath for an hour at room temperature. Throughout the paper, these mediums will be referred as E63+QD, E7+QD and SCLP+QD. Once the liquid crystalline mediums are ready, they were filled into ITO coated planarly aligned homogenous liquid crystal cells (purchased from AWAT) having thickness of 9.5 μm using capillary action. Later the cells were connected to a Keithley 2400 sourcemeter for current-voltage measurements at room temperature. The measurements were carried in dark and under UV light for which an Omron ZUV-C20H UV ($\lambda=365\text{ nm}$) was used.

III. RESULTS AND DISCUSSION

Current-voltage plots of E63, E7 and SCLP are given in Figs. 1(a)-1(c), respectively. Dashed line stands for QD dispersed samples. It is seen that higher current value (on the order of mA) is obtained for SCLP (Fig. 1(c)) whereas current value is on the order of 10^{-8} A for liquid crystal samples.

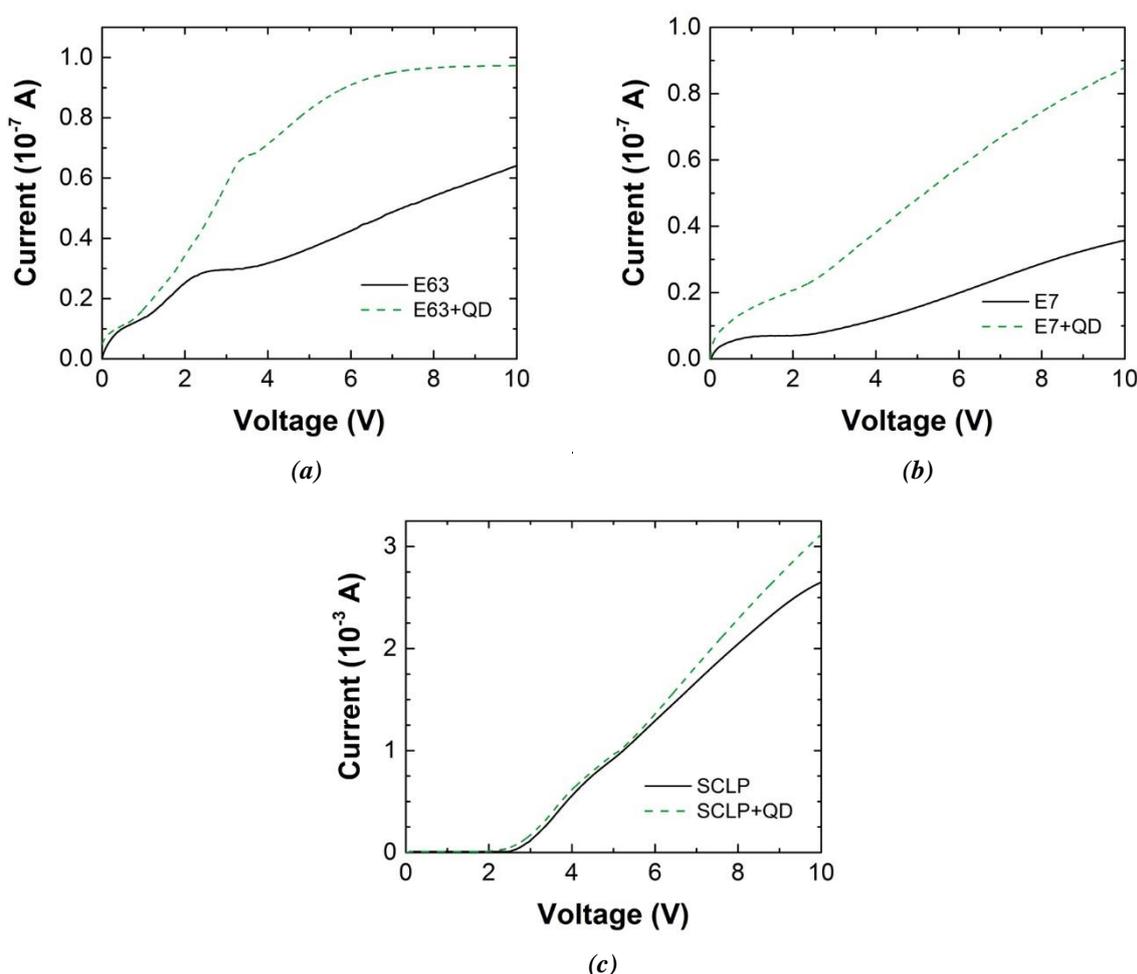


Figure 1. Current-voltage plots of (a) E63 and E63+QD, (b) E7 and E7+QD and (c) SCLP and SCLP+QD mediums in dark.

As to the effect of QD dispersal on current in the liquid crystalline mediums, it is clear that QD dispersal increased the current. Current ratio (QD dispersed medium/Neat medium) values at 10 V for E63, E7 and SCLP were calculated as 1.52, 2.46 and 1.18 respectively. Despite the higher current yield in SCLP, QD dispersal does not seem to cause a significant increase in current (Fig. 1(c)). On the other hand, there is a considerable increase in current of E63 and E7. However current ratio of E7 is higher compared to

E63. It is likely that such difference among E63 and E7 mediums is due to the fact that current-voltage plot of E63+QD is nearly saturated after 8 V. Thus, among the studied liquid crystalline mediums, E7 is the most suitable one for CdTe QD dispersal in terms of improvement in current conduction in the sample. Therefore, UV illumination dependent current-voltage measurements were carried and given for only E7 and E7+QD samples.

Figs. 2(a) and 2(b) show current-voltage plots of E7 and E7+QD samples, respectively, in dark and under UV light illumination. It is clear in these figures that both LC mediums show dependence on UV light such that higher current is obtained as the UV light power is increased. When the mediums are exposed to UV light, electron-hole pairs are created and these charge carriers are swept by the applied voltage, thus high current values are obtained. An interesting results of QD dispersal becomes prominent under UV light illumination; there is a small amount of current at zero bias (inset of Fig. 2(b)) which is basically observed for photovoltaic devices. Thus, it is seen that E7+QD sample exhibits weak photovoltaic behavior when it is exposed to UV light. Better photovoltaic behavior is observed when UV light power is 60 mW/cm². It can be seen in the inset of Fig. 2(b) that open-circuit voltage and short-circuit current of E7+QD are 0.42 V and 16 nA. CdTe QD is known to reveal photovoltaic behavior in organic materials such as polymers [3]. It is believed that similar effect is governed when it is dispersed in liquid crystalline mediums as well.

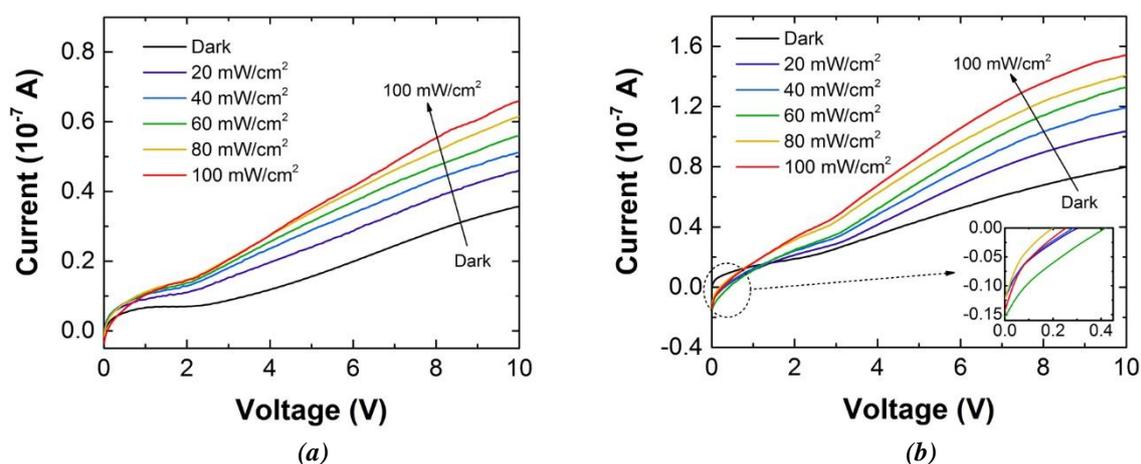


Figure 2. Current-voltage plots of (a) E7 and (b) E7+QD mediums in dark and under various UV light power.

Current values under UV light illumination; i.e. photocurrent values (I_{ph}), were also drawn against UV light power and given in Fig. 5 in double logarithmic form. It is seen that data points in Fig. 3 show linearity. Such linearity is interpreted through the equation below which gives light power dependence of photocurrent [20];

$$I_{ph} = BP^\alpha \quad (1)$$

where B is a constant, P is light power and α is an exponent; which is obtained from the slope of Fig. 3. The exponent α is obtained for describing recombination mechanisms governing in the sample when it is exposed to illumination. For any crystalline form, α values of 0.5 and 1 stand for bimolecular recombination and monomolecular recombination, respectively [20].

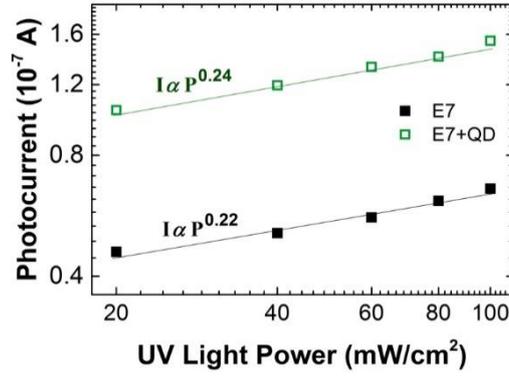


Figure 3. UV light power dependence of photocurrent in E7 and E7+QD mediums at 10 V.

As seen in Fig. 4, α values of E7 and E7+QD are extracted as 0.22 and 0.24, respectively. This result of $\alpha < 0.5$ indicates sublinear behavior in photocurrent [21]. The slight difference between α values suggests QD dispersal does not alter recombination mechanism in the medium. For a further exploration of effect of QD dispersal on UV light illumination dependence of current-voltage characteristics in the samples, responsivity and photosensitivity values of the samples are calculated using the following equations [20];

$$\text{Responsivity} = \frac{I_{ph}}{PA} \quad (2)$$

$$\text{Photosensitivity} = \frac{I_{ph}}{I_{dark}} \quad (3)$$

Here A is area of the mediums exposed to UV light and I_{dark} is the current value in dark which is also called as dark current. Responsivity is a measure of optical power conversion to photocurrent whereas photosensitivity reflects the strength of photocurrent compared to dark current. Obtained responsivity and photosensitivity values were plotted against UV light power and given in Fig. 4.

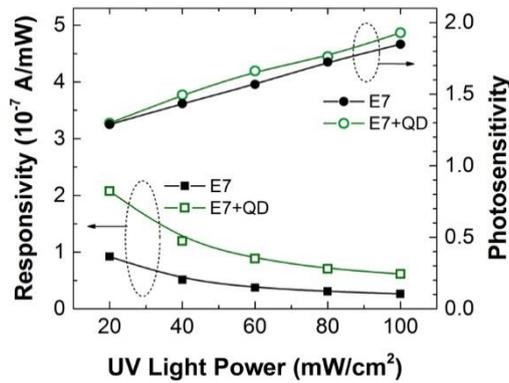


Figure 4. UV light power dependence of responsivity and photosensitivity in E7 and E7+QD mediums at 10 V.

It is seen that QD dispersal causes slight increase in photosensitivity while there is considerable increase in responsivity such that responsivity of E7+QD to UV light is almost twice of that of E7. Therefore, obtained results not only point out an increase in current value with QD dispersal, but also they clearly show that the liquid crystalline medium becomes more responsive to UV light exposure thanks to QDs. Nevertheless, it needs to be noted that QD dispersal does not affect photosensitivity of liquid crystalline medium significantly. However, appearance of photovoltaic behavior in E7+QD medium is an interesting outcome that would motivate researchers to conduct studies about QD dispersed liquid crystalline mediums.

IV. CONCLUSION

When the liquid crystalline mediums; E63, E7 and SCLP, were dispersed with CdTe QDs, their current-voltage characteristics were enhanced such that the least progress occurred for SCLP whereas the highest progress is observed for E7. Thus, E7 was found the suitable medium for CdTe QDs in terms of contribution to current. As a result, measurements under UV light exposure were carried for E7 and E7+QD and both samples were found to show dependence on UV light illumination. An interesting finding is that E7+QD exhibited photovoltaic behavior due to CdTe QDs. The evolution of photocurrent with UV light power revealed a slight difference between α values therefore it was said that QD dispersal did not change recombination mechanism in the liquid crystalline medium significantly. On the other hand, QD dispersal caused an increase in photosensitivity and particularly in responsivity under UV light. As a conclusion, CdTe QDs make considerable contribution to current-voltage characteristics of E7 liquid crystalline medium both in dark and under UV light illumination.

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