Chapter

Applications of Cadmium Telluride (CdTe) in Nanotechnology

Akeel M. Kadim

Abstract

Cadmium telluride quantum dots (CdTe QDs) were prepared by chemical reaction and used to fabricate electroluminescence quantum dot hybrid junction device. QD-LED was fabricated using TPD: PMMA/CdTe/Alq_3 device which synthesized by phase segregation method. The hybrid white light-emitting devices consist of three layers deposited successively on the ITO glass substrate; the first layer was of tetra-phenyl diaminobiphenyl (TPD) polymer mixed with polymethyl methacrylate (PMMA) polymers, while the second layer was 0.5 wt% of the (CdTe) QDs for hybrid device, whereas the third layer was tris (8-hydroxyquinoline) aluminum (Alq_3). The organic light-emitting device (OLED) was considered by room temperature photoluminescence (PL) and electroluminescence (EL). Current-voltage (I-V) characteristics indicate that the output current is good compared to the few voltage (6 V) used which gives good results to generate white light. The electroluminescence (EL) spectrum of hybrid device shows a wide emission band covering the range 350–700 nm. The emissions causing this white luminescence were identified depending on the chromaticity coordinates (CIE 1931): x = 0.32, y = 0.33. The correlated color temperature (CCT) was found to be about 5886 K. Fabrication of EL devices from semiconductor material (CdTe QDs) between two layers, organic polymer (TPD) and organic molecules (Alq_3), was effective in white light generation. The recombination processes and I-V characteristics give rise to the output current which is good compared to the few voltages used which give good results to generate light.

Keywords: CdTe, quantum dots, organic device, quantum hybrid device

1. Introduction

For the past several years, CdTe quantum dots (QDs) have been reconsidered extensively because of their potential for optoelectronic and biological nanoapplications. The unique advantage of colloidal QDs is their size-dependent physical and optical properties such as the energy band gap, narrow emission with small full width at half maximum, broad spectral photo response from ultraviolet to infrared regions, and their compatibility with solution processing [1].

QDs success more significance now a day due to their indicating of nanotechnology applications in the field of laser, bio-imaging, LED, and sensors [1, 2]. QDs materials can illustrate tunable photoluminescent property by changing the particle

size. In particular, QDs-based light-emitting diodes (QD-LEDs) have been below the global attention as a developing technology for next-generation displays or solid-state lighting. A huge improvement has been created in the enhancement of high-performance QD-LEDs of which brightness and efficiency are comparable to those of OLEDs [2].

Among several QDs, cadmium telluride (CdTe) QDs have been significantly used in work and biomedical applications owing to their tunable photoluminescence inside the visible range once excited by a single excitation wavelength. For evidence, CdTe QDs are expected to be possible probes in the bio-imaging of living cells as of their many benefits for example higher photo stability, more controllable and narrower emission bands, and higher quantum fabricate in relationship with conformist fluorescent dyes [3].

The fast enhancement in synthetic techniques has certified producing semiconductor nanoparticles of narrow sizes and of more than a few shapes. The phenomenon of attractive has a great influence of nano materials of the construction of these materials and their optical properties [4]. For existence, magic-sized CdTe has a very broad so-called white light emission with extensive emission quantum produce, which is very different from the very narrow band gap emission detected from typical semiconductor QDs [3, 4].

A leading difference to OLEDs is that the active layer covers ionic components in addition to the light-emitting species (polymers or transition metal complexes). These ionic kinds start moving under applied voltage and so enable charge injection into the light-emitting component [5, 6].

So, the charge transporter injection and transport in this type of devices is ongoing by the movement of the ionic types, the response and turn-on time of OLEDs which is acceptably long, ranging usually from subseconds to hours, depending on the ionic conductivity of the light-emitting layer [7, 8].

The hybrid device was fabricated from three layers: the first layer is the TPD polymer, the second is CdTe QDs, and the third is Alq_3; all these layers are on ITO substrate. It has a significant effect in application of nanotechnology to getting a clear and efficient high-intensity of white light generation [8, 9]. The emission of EL of the hybrid devices showed luminescence of white light with high intensity and good efficiency, using a few voltages [9].

2. Synthesis the CdTe quantum dots

All materials used in this work were supplied from Fluka Company without further purification; TPD is a hole-transport molecule, having maximum absorption wavelength at 351 nm and emission wavelength at 391 nm, while Alq_3 is an electron transport molecule, having maximum absorption wavelength at 392 nm and emission wavelength at 519 nm. The cadmium telluride CdTe QDs were made by combination two chemical solutions of molarities 0.02 M. The first solution was arranged by dissolving 0.092 g of $CdCl_2$ in 50 ml distilled water, while the second solution was succeeded by dissolving 0.033 g from sodium telluride Na_2Te in 50 ml distilled water. The two solutions were mixed at 1:1 mole ratio in a three-neck flask and left on magnetic stirrer at temperature of around 80°C; then, ammonium hydroxide (NH_4OH) was added drop by drop to the solution, having three values of pH 10 with continuous flowing of argon gas for about 1 h, till the color changed to light green.

Fabrication process of the hybrid junction devices can be summarized. It consists of three coatings added sequentially on the ITO glass substrate by phase

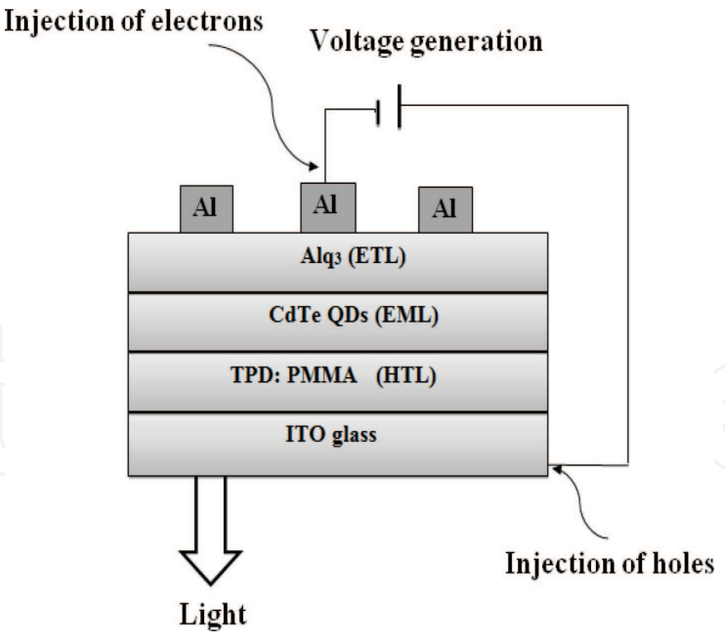

Figure 1.
Structure of TPD: PMMA/CdTe/Alq_3 hybrid junction devices.

segregation method using spin coating at 2000 r.p.m. for about 10–15 s for each coat. The first layer was of TPD mixed with PMMA in ratio 1:1. PMMA was used to prevent cracks in the film, leading to the increased conductivity of TPD, while the second layer was 0.5%wt CdTe QDs. After deposition, each layer is dried at a temperature of 60°C to get a layer well rolled on the film. Completely deposition Alq_3 coat above the CdTe QDs film. The thicknesses of the films have been measured by interference method whereas the thicknesses of TPD: PMMA and Alq_3 layers were 600 and 540 nm, respectively; while the thickness of CdTe QDs layers was 550 nm, whereas the thickness and resistance of ITO coat were 150 nm and 10 Ω individually. Then, aluminum cathode is added on the hybrid film. The hybrid junction device is thus sandwiched between the ITO and aluminum electrodes. The ratio of TPD: PMMA/CdTe QDs/Alq_3 was taken to be 1 ml:1 ml/0.5%wt/1 ml separately (see **Figure 1**).

Conducting layer deposit is an organic contain of TPD indicate a hole- carrying layer (HTL), while the emissive cover of QDs be an electron-injected layer (EML) then Alq_3 illustrate an electron transporting layer (ETL). The Alq_3 molecular orbitals experienced position on states surfaces of semiconductors materials. These molecules orbitals are trapped to the Fermi level in QDs materials because of that injunction of electrons charge assignment and substrate work function main to trapped level (TL) placement within the high occupied molecular orbital (HOMO) and low un occupied molecular orbital (LUMO) gap. Successively a potential is applied, the injected positive and negative carrier's charges recombine process in the emissive layer to produce an electroluminescence light. The transport electrons from the cathode (Al) and produces light in reaction to an electric current as appear in **Figure 1**. Recognizable anode films are thin films of optically transparent and electrically conductive material.

3. Characterization

Cadmium telluride QDs were characterized by OPTIMA SP- 3000 UV-Vis spectrometer in the spectral range 200–1100 nm and photoluminescence spectrum was

measured by SL 174 spectrofluorometer covering a range 300–900 nm. The scanning electron microscope (SEM) was recorded by VEGA3 TESCAN, mode SE from TESCAN ORSAY HOLDING. The I-V measurements for the TPD: PMMA/CdTe/Alq_3 hybrid device hybrid junction was approved out by Keithley digital electrometer 616 and D.C. power supply to estimate the EL device. The EL spectrum of the EL devices was measured at room temperature using fiber optic spectrometer CCS Series by THORLABS Company (Germany) with a covering range of 200–1000 nm and resolution of 1 nm.

4. Optical properties of CdTe QDs

The absorption spectrum of the CdTe QDs is shown in **Figure 2**.

It is can be noticed from **Figure 2** that the absorbance spectrum of CdTe QDs illustrates high absorbance in the visible range 350–450 nm and extremely decreases till about 470 nm where there is no absorbance [10]. The spectrum shows high absorbance of CdTe QDs in the ultraviolet region, where the absorption spectrum of the CdTe is characterized by convexity or peaks resulting from a nanostructure formation of the material.

The photoluminescence (PL) spectrum of the CdTe QDs is revealed in **Figure 3**.

Figure 3 shows the PL of the colloidal CdTe QDs, which shows that the band edge transmission is centered at 550 nm and other peaks represent the surface states

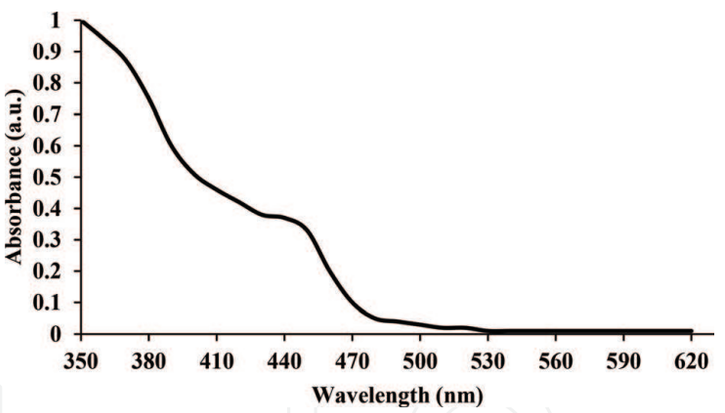

Figure 2.
Absorption spectrum of CdTe QDs.

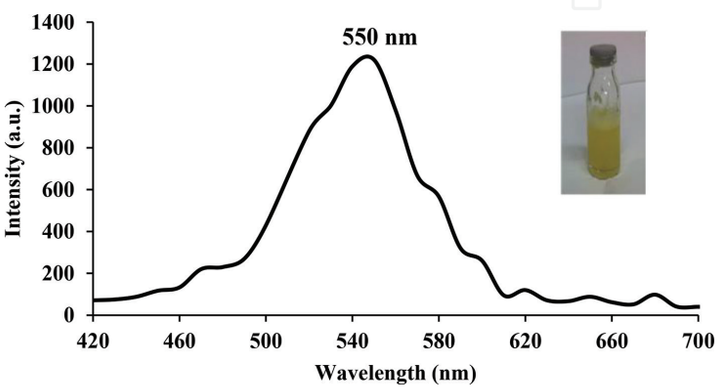

Figure 3.
Photoluminescence (PL) spectrum of CdTe QDs.

[10, 11]. This value refers to the band-to-band transition in CdTe QDs, where the emission spectrum of the CdTe is characterized by high intensity due to the presence of surface states that cause an increase in the intensity and efficiency of the material that has wide applications in nanotechnology applications [11]. The energy gap calculated from PL according to the relation (E = 1240/λ (nm)) was found to be about 2.25 eV for CdTe QDs.

5. Morphological properties of CdTe QDs

5.1 Scanning electron microscope (SEM)

The surface morphology of the arranged CdTe QDs was considered by the SEM of 60K× magnifications, as revealed in **Figure 4**. The SEM images of the QDs films give a good sign for construction of the CdTe QDs. The average grain size governed from SEM is about 10 nm by knowing the diameter of the QD and dividing it by the amount of magnification used. **Figure 4** reveals that the shape of formed QDs is approximately spherical, while the image shows aggregation of QDs in the range of 100 nm.

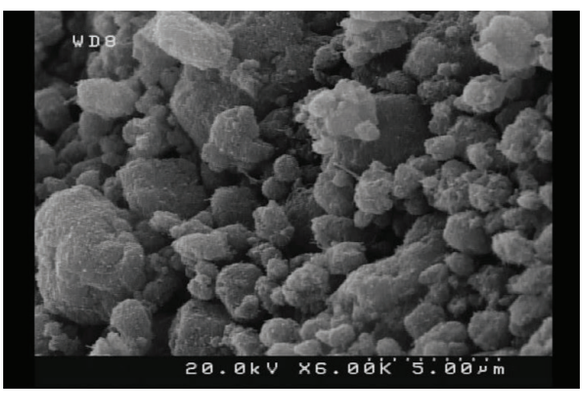

Figure 4.
Scanning electron microscope (SEM) of CdTe QDs.

6. Electrical properties of CdTe QDs

Figure 5 shows the I-V characteristics of the hybrid junction devices obtained using the TPD: PMMA/CdTe/Alq_3. **Figure 5** reveals that the rectification behavior with a turn-on voltage in general at bias voltage at 6 V, while light emissions was found at current levels of near 0.02–0.7 mA.

The I-V appearances of the hybrid device indication exponential increase in current because of reduction in the depletion layer width at the border. In the forward bias, the conduction band barrier will shrunk due to the exponential distribution of electrons and holes in the conduction and valence bands and thus the diffusion current running through the hybrid junction increases exponentially with increasing forward bias. The drift current curving in the opposite direction does not depend on the potential barrier height and will improve the electron flow from the Alq_3 to n-(QDs) and holes from the p-(TPD) to the n-(QDs) [12]. The succeeding recombination would contribute to increase in the forward bias current flow with few voltages at 6 V for TPD: PMMA/CdTe/Alq_3.

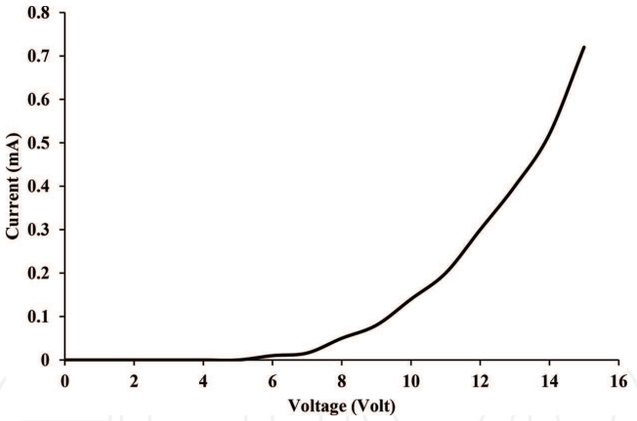

Figure 5.
Current-Voltage (I-V)characteristics of TPD:PMMA/CdTe/Alq_3 hybrid EL devices.

7. Electroluminesces properties of CdTe QDs

The EL measurements under forward bias voltages of 6 V represent the upper limit for the light which has been obtained experimentally from the TPD: PMMA/0.5%wt CdTe QDs/Alq_3 hybrid junction devices; light emission was carried out using a photomultiplier detector at room temperature.

Figure 6 represents the emission spectrum studied by CIE 1931 chromaticity diagram, which indicates the white light generated at forward bias voltage of 6 V. It is clear from the figure that the peaks at 460, 540, and 610 nm of TPD: PMMA/ CdTe/Alq_3 and the other peaks are due to defect states. The mechanism transport of carrier in the hybrid junction device (QDs-OLEDs) is that the TPD performs as the hole transporting material and it contributes to increase the intensity emission of OLEDs [13]. Holes are injected from the ITO anode into the high occupied molecular orbital (HOMO) of the TPD material and carried to the valance band; electrons are injected from the aluminum (Al) cathode into the conduction band. These electrons are injected once more in Alq3 layer, which is used as an electron transfer material and emitting layer. The number and the mobility of electrons will be improved and consequently are receiving high mobility of electrons affecting the CdTe QDs layer [14].

Therefore, holes and electrons from the excitons in the QDs that recombine radiatively are called band-to-band recombination. The holes and electrons recombination achieved defects sates to emission light in changed wavelengths, this recombination processes complete defects names the Shockley-Read-Hall recombination. The maximum emission intensity increases were creating in the case of layers covering 0.5wt%

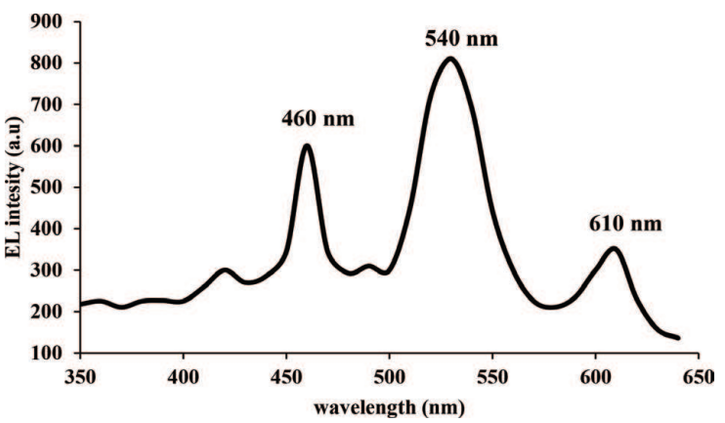

Figure 6.
Electroluminescence of TPD: PMMA/CdTe/Alq_3 hybrid EL device.

of QDs and Alq_3 layer when compared with that without Alq_3 layer. Addition of Alq_3 organic molecules layer causes in generation of Förster energy between the LUMO epitomized by (Alq_3) and HOMO signified by (ITO), which indicates increase in the efficiency of hybrid devices [15]. From **Figure 6**, it can be perceived the occurrence of peaks spectrum at blue, green, and red, which in turn contributes to white light when mixed. The energy unconfined from the recombination of the charge transfer excitons being resonantly transported to the proximal electrons in conduction band of the QDs concluded an Auger process to produce electrons with sufficiently high energy to inject into the lower unoccupied molecular orbital (LUMO) of Alq_3. These electrons then radioactively recombine with holes in the HOMO of the polymer, causing emission of photons with energy equal to the HOMO-LUMO gap of the TPD [15, 16].

The white light generated by hybrid devices, or several other light sources for general lighting, should have a good white color in stability to show all the colors of illuminated objects suitably. As the color of light is expressed by the CIE colorimetry system [17], the spectrum of a given light is weighted by the XYZ color matching functions. The x and y on CIE system are located from X, Y, and Z:

$$x = \frac{X + Y + Z}{X} \tag{1}$$

$$y = \frac{X + Y + Z}{Y}$$

The correlated color temperature (CCT) for any white light can be analyzed by using McCamy's approximation algorithm to estimate the CCT from the x, y chromaticity coordinates as in Eq. (2):

$$CCT = -449\,n^3 + 3525\,n^2 - 6823n + 5520.3..... \tag{2}$$

where $n = \frac{x - 0.3320}{y - 0.1858}$.

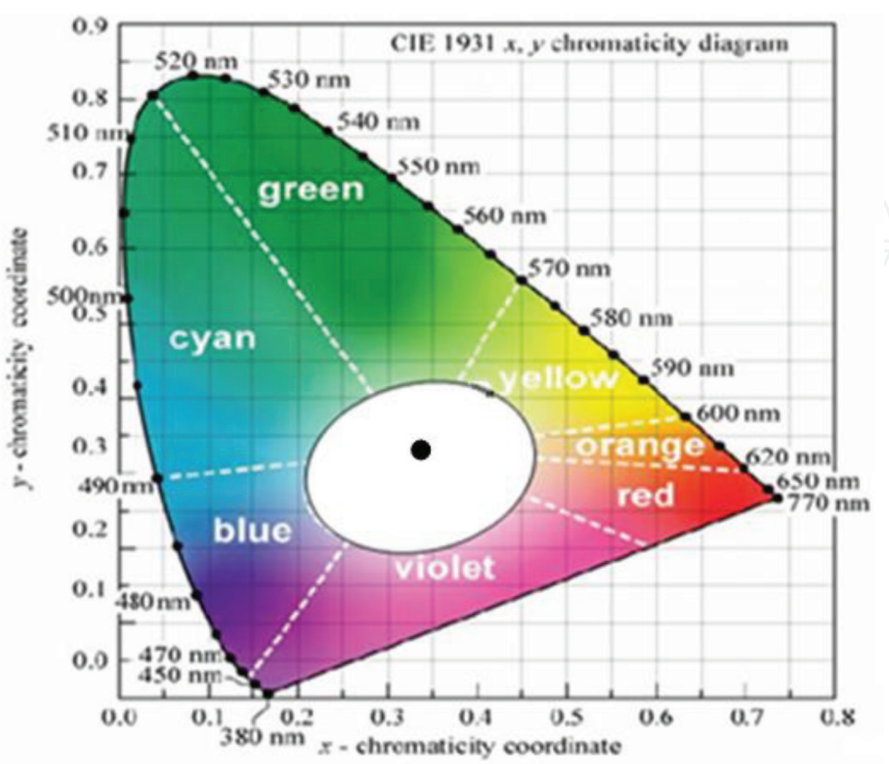

Figure 7.
Tristimulus coordinates of hybrid device on the chromaticity diagram.

Figure 8.
A photographic plate of the white light generation of TPD: PMMA/CdTe/Alq_3.

Figure 7 shows the CIE 1931 chromaticity diagram (x = 0.32, y = 0.33). The output light of the emission lines registered in the EL spectrum is in the white light region confirmed by the photograph of the white light emitted from the hybrid devices in **Figure 8**. It is clear that the intensity of the output light is very high and clear.

The cause of emission of this white light was identified depending on chromaticity coordinates. The values of chromaticity coordinates show that the hybrid device of TPD: PMMA/0.5%wtCdTe/Alq_3 has a high correlated color temperature of about 5886 K. This means that during high temperature, the light site will be heading toward the center of the white light, which in turn gives a high efficiency of the devices.

8. Summary

Limited confinement size of CdTe QDs is considered by chemical effect which was very beneficial since they have many defects. These defects sates can be used in many applications for occurrence of white light generation in QDs-OLEDs. The producer of white light properties with high efficiency using confinement effect makes a large energy gap and hence, the direction of the light sites be toward the center of white light color. The succeeding recombination processes would give rise to the forward bias current flow. So growth in the forward current under high bias could be the amplification of the good contact between the Al electrode and QDs layer. The output current from I-V forms is good compared to the few voltages used which give good results to develop a production of white light. Fabrication of EL device from semiconductors material (CdTe QDs) with hole injection organic polymer (TPD) and electron injection (Alq3) was effective in the intensity and efficiency of white light generated and can be the color of emerged clear light.

DOI: http://dx.doi.org/10.5772/intechopen.85506

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