

Preparation of CdSe Quantum Dots using Laser Ablation Technique for Dye-Sensitized Solar Cell

Zainab H. Omran¹, Odai N. Salman^{1*} and A. K. Ali²

¹Department of Applied Sciences, University of Technology, Iraq

Received 1 November 2020, Revised 28 November 2020, Accepted 2 December 2020

ABSTRACT

Organic dyes are known to be widely used in the manufacture of dye-sensitized solar cells. However, theoretical screening does not play an essential role in dyes design. This work seeks to improve the conversion efficiency of the dye-sensitized solar cells. Clean-laser ablation in ethanol methodology was used for cadmium selenide quantum dots (CdSe QDs) synthesis. The morphological and optical characteristics of the prepared CdSe QDs were investigated by X-ray diffraction, UV-Vis spectra, Fourier Transform infrared spectroscopy; and transmission electron microscopy photographs. The resultant CdSe QDs has a cubic crystal structure of 4 nm averaged particle size. The optimum QDs-sensitized solar cell can be gained by attaching the QDs to a metal oxide nanoparticles (NPs) such as titanium dioxide NPs (TiO₂ NPs) by the laser ablation method as they are non-ligands.

Keywords: CdSe Quantum dots, Dye-Sensitized Solar Cell, Laser ablation, Nanoparticle, Laser ablation technique.

1. Introduction

Quantum dots (QDs) are invested widely in electronic and optoelectronic applications such as dye-sensitized nanocrystalline solar cells that were firstly built in 1991 by Organ and Gratzel [1]. Dye-sensitized solar cells (DSSCs) are considered as one of the most desirable technologies nowadays in most developing countries due to the cheap and non-toxic materials used in their manufacture. In addition, the possibility of designing and manufacturing these cells with different colours and transparency rates makes them more attractive commercially [2]. Several reports discussed the DSSCs performance improvement. Several properties, including novel sensitizers, electrolytes, thickness of TiO₂ and semiconducting behavior were employed in DSSCs power conversion efficiency enhancing point [3]. Also, there are several ways to increase the efficiency of DSSC represented by the enhancement of the absorption of photons [4]. Several researchers have proposed to employ the plasmonic nanostructure to convert the solar cells. The reason for relying on these plasmonic nanostructures is that they are equivalent to optical antennas at the nanometer scale. This, in turn, in a spatially compact form, frees up space for the propagation of the photon energy and turns it into a surface plasmon polarization of electrical energy [5]. The laser ablation in liquid is a practical method for producing a new material. In recent reports, the candidate material Cadmium selenide (CdSe) used as the target to prepare the nanoparticles (NPs) colloidal solution[6]. The world is resorting to nanomaterials because it possess unique superior characteristics and are not available

* Corresponding Author: dr.brq19@gmail.com

in conventional materials [7]. The aim of this work is to improve the conversion efficiency by adding CdSeNPs to sensitizer (dye) to improve the scattering that will lead to increasing the efficiency.

2. Experimental setup

The CdSe NPs were prepared by laser ablation using Nd:Yag laser (type HUAFEI), at energy = 900mJ, no. of pulses = 200 and utilizing the irradiation method; the CdSe sample immersed in ethanol by 1 cm where the distance between the laser and the sample was 10 cm, then added to N719-dye (RuL2 (NCS) 2, 2TBA (L = 2,2'bipyridyl4,4'dicarboxylic, acid TBA = tetrabutylammonium solution with ethanol) to form a mixture of (CdSe-N719 dye) 1:1 Vol. A quantum dot was obtained after several pulses of lasers. After that, a slide of FTO was used, using the method of Screen Printing Technique on the conducting side of FTO glass, then TiO₂ paste is applied (average nanoparticle Size (active): ~20nm) and flatten with a razor on the FTO glass (thickness about 2.3mm) and with this a layer of TiO₂ is formed. The TiO₂/FTO is inserted after drying at the furnace.

The resulting film was annealed for 1 h at 500 °C. Before the immersion step in the dye solution, the film was cooled down at room temperature. Two TiO₂/FTO films were prepared in the same way. The TiO₂ electrodes were dipped into the dye solutions for 24 h (CdSeNPs-N719 dye and dye only). The platinum was prepared by dropping the oil-based platinum gel on FTO, then, a blade was used for spreading it. After the paste dried, burning process takes place at 450 °C. Uniformly, the results were distributed to platinum, which in turn contributed to the provision of high transparency and catalytic activity. The TiO₂/FTO/dye electrode was taken out from the solutions and washed by ethanol. A small diamond drill (DC12v/0.8A, Pros kit PK-500) was used to make two holes in counter electrode to inject the Iodine and Tri-iodide electrolyte as a redox couple. Inorganic iodide salt (I⁻/I₃⁻), organic iodide salt, imidazole compound and 3methoxypropionitrile were added. The next step including placing of the hot melt tape on TiO₂/dye electrode to paste with platinum electrodes utilizing a heating tool for 10 min at 150 °C. Then, some drops of iodide salt, organic iodide salt, and imidazole compound and the solvent 3methoxypropionitrile were dropped into one of the holes to get the bubbles out of the other hole.

The DSSC properties were measured by using UV-Vis beam spectrophotometer, SP-3000 puls, optima Tokyo, Japan; X-ray analysis measured in (lab XRD-6000, ADVANCEX-RAYSOLUTIONS-D8) and Transmission Electron Microscopy images TEM, Zeta potential and Fourier Transform Infrared Spectroscopy (FTIR).

3. Results and Discussion

XRD data of the CdSe Quantum Dots measured in 20° to 80° angle range (See Fig. 1) reveals two peaks at angles (2θ) 25.3° and 42° which correspond to (111) and (220) planes respectively. The measured interplanar spacing (d_{hkl}) correspond to peak (111) found (3.51 Å) compatible with those of bulk cubic zinc blende (ZB) CdSe (d₁₁₁ = 3.51Å for ZB CdSe, ICDD 00-019-0191) [8]. The averaged crystallite size of CdSe QDs obtained about 1.35nm estimated from the Scherrer formula [9]:

$$D = \frac{0.9\lambda}{\beta \cos\theta} \quad (1)$$

where D, λ, β and θ are the particle size of quantum dots, the wavelength of Cu-Kα radiation (0.15418 nm), full width at half maximum (FWHM) and angle corresponding to the peak respectively.

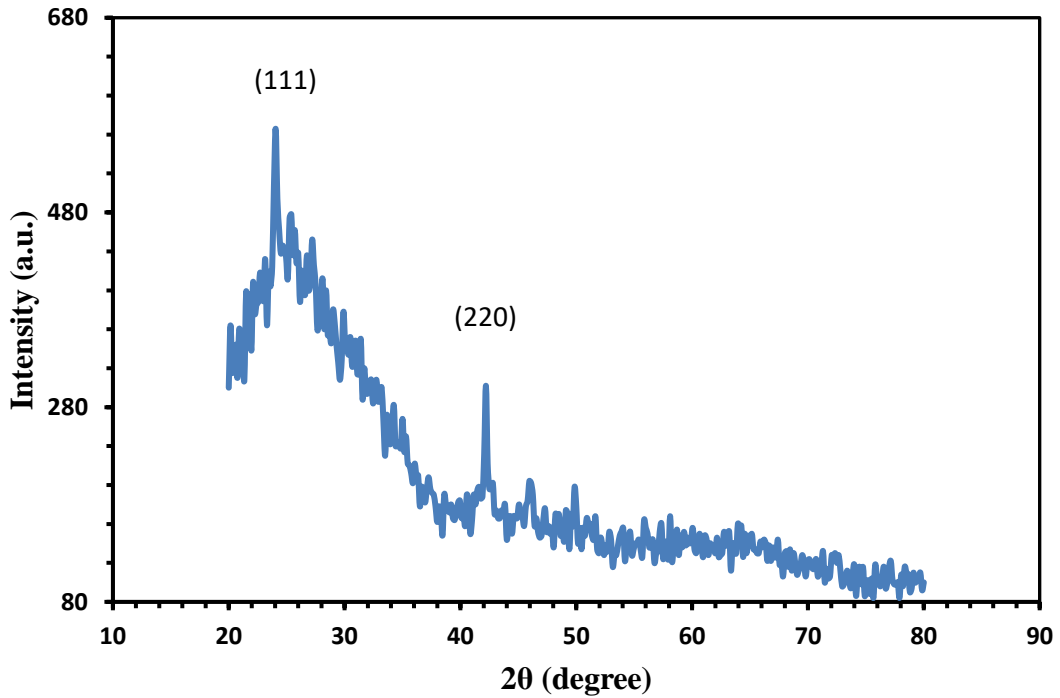
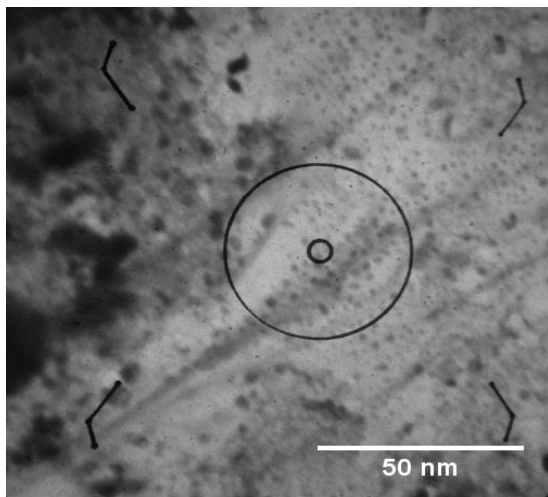
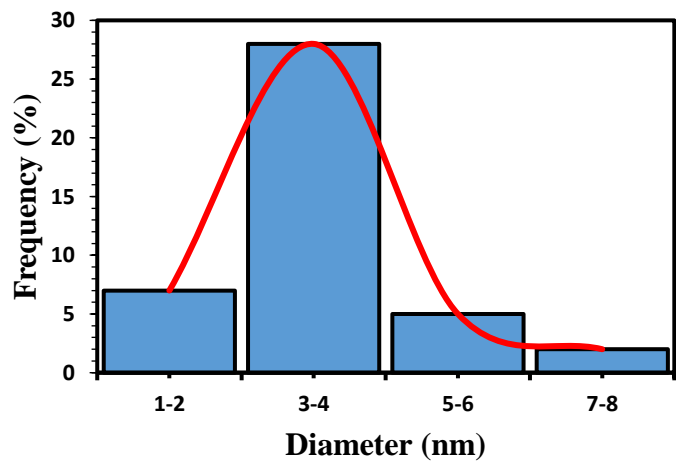


Figure 1. XRD diffraction pattern of CdSe Quantum Dots

Fig. 2 (-a) shows the TEM image of CdSe quantum dots prepared by laser ablation in ethanol with (100000X) magnification. The image reveals formation of CdSe QDs with spherical shape with no aggregation. The corresponding size distribution has been displayed in size distribution chart, where the average particle diameter is about 4 nm. Fig. 2(-b) shows the size distributions of CdSe Quantum dots which is fitted by Gaussian curve; it is clearer from the figure that the highest distribution is at 3-4 nm.



(a)



(b)

Figure 2. (a) TEM image and (b) size distribution of the CdSe QDs synthesized by Pulse Laser Ablation.

Fig. 3 reveals the optical absorption spectrum of suspended particles of CdSe Quantum Dots in the 300–1000 nm wavelength range. The absorption spectrum is in good agreement with the absorbance as a function of wavelength of the CdSe Quantum Dots prepared using femtosecond laser ablation [10]. The optical energy gap (E_g^{op}) of the semiconductor Quantum Dots materials can be determined by Tauc plot which is based on the following Tauc relationship [11]:

$$\alpha E = A(E - E_g)^{\frac{1}{2}} \quad (2)$$

where (E) is the photon energy, (α) is the absorption coefficient, (A) is a constant.

The inset of Fig. 3 shows the Tauc plot for the colloidal CdSe Quantum Dots, using the same absorption spectrum data. The optical energy gap (E_g^{op}) for the colloidal CdSe Quantum Dots estimated from the intercept with the $h\nu$ -axis is 2.8 eV, which is in good agreement with Surana [12] and much higher than that for the CdSe bulk material ($E_g = 1.7$ eV) [13]. This blue shift make the CdSe Quantum Dots suitable for solar cell applications [14].

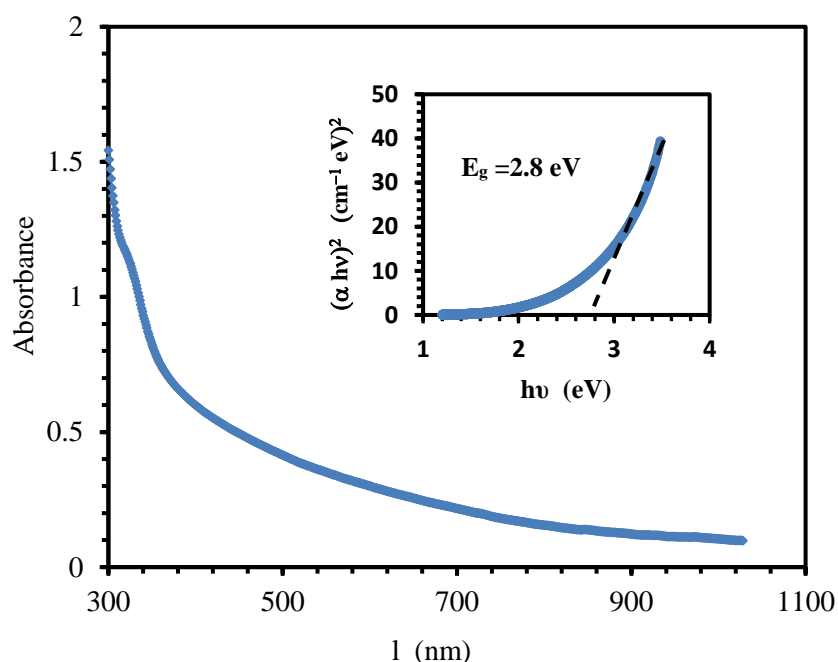


Figure 3. Absorption spectra of colloidal CdSe Quantum Dots and the inset shows the optical energy gap.

Fig. 4 shows the absorption coefficient (α) as a function of wavelength of CdSe Quantum Dots. The absorption coefficient was calculated using the following equation:

$$\alpha = \frac{2.303}{t} A \quad (3)$$

where A is the absorbance and t is the optical path.

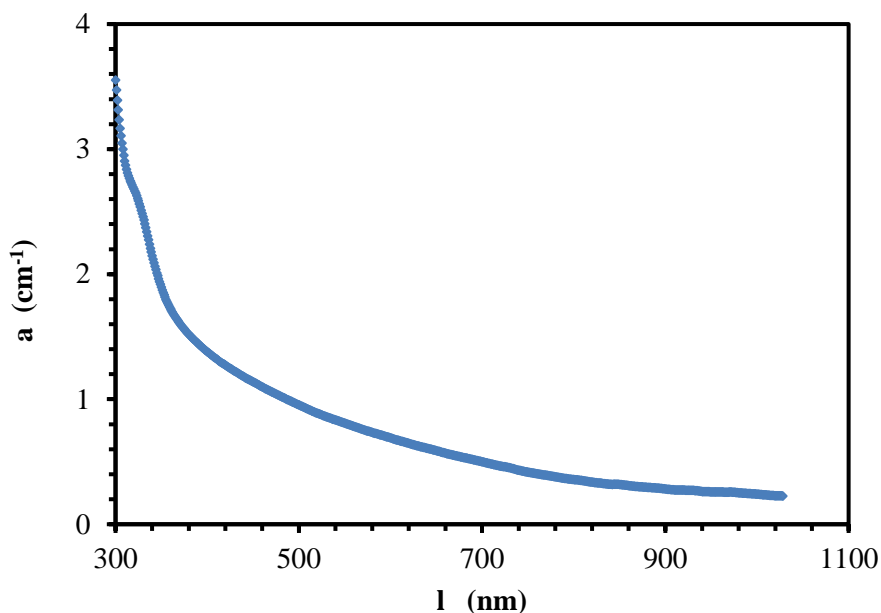


Figure 4. Absorption coefficient (α) as a function of wavelength of CdSe Quantum Dots.

Fig. 5 Shows the FTIR spectra of Cadmium Selenide compound containing Cd and Se atoms were bonded and formed CdSe molecule. In a Quantum Dot, there were number of molecules. When the CdSe molecule gets energy from IR radiation, the CdSe molecule vibrates in stretching mode vibrations only. Generally, the metal atoms stretching vibrations are observed in the region of 500-3000 cm^{-1} [15], as shown in Fig. 5. Fig. 6 shows the Zeta potential of Colloidal CdSe Quantum Dots and the figure reveals the peak at -21 mV which suggests relatively stable Colloidal [16].

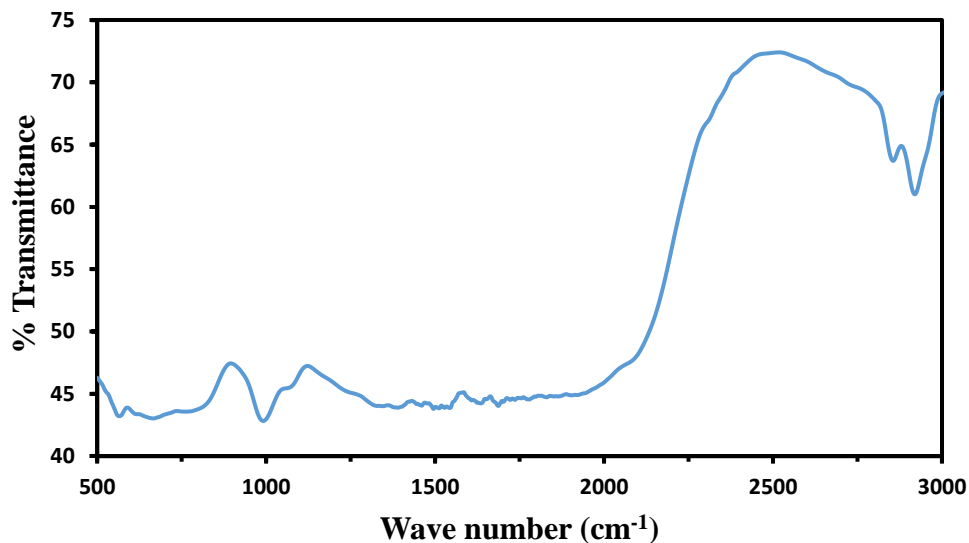


Figure 5. FTIR analysis of CdSe Quantum Dots

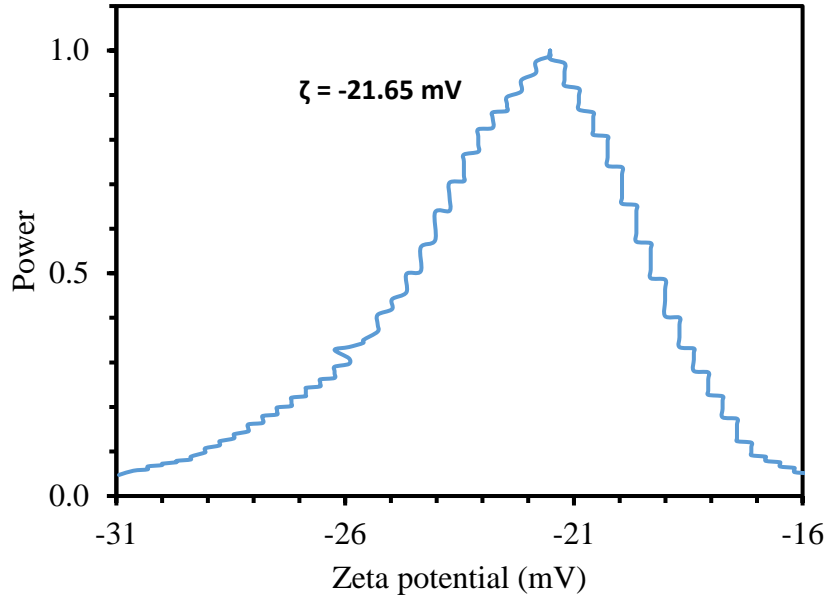


Figure 6. Zeta potential curve of the prepared colloidal CdSe

CdSe QDs synthesized by laser ablation in the ethanol solution to prepare the Dye-Sensitized photovoltaic solar cell with a successful procedure. Fig. 7 shows J-V characteristics and power as a function of voltage. Table 1 includes a CdSe QDs Dye-Sensitized Solar Cell parameters, where the fill factor and efficiency were calculated from Eq. (4) and (5) respectively [11].

$$FF = \frac{V_m J_m}{V_{oc} J_{sc}} \quad (4)$$

$$\eta = \frac{(FF \times J_{sc} V_{oc})}{P_{in}} \times 100 \quad (5)$$

Table 1. Solar cell parameters for Dye-Sensitized Solar Cell based CdSe Quantum Dots.

Jsc (mA/cm²)	Voc (V)	FF	η
1.38	0.44	0.35	4.2 x 10 ⁻³

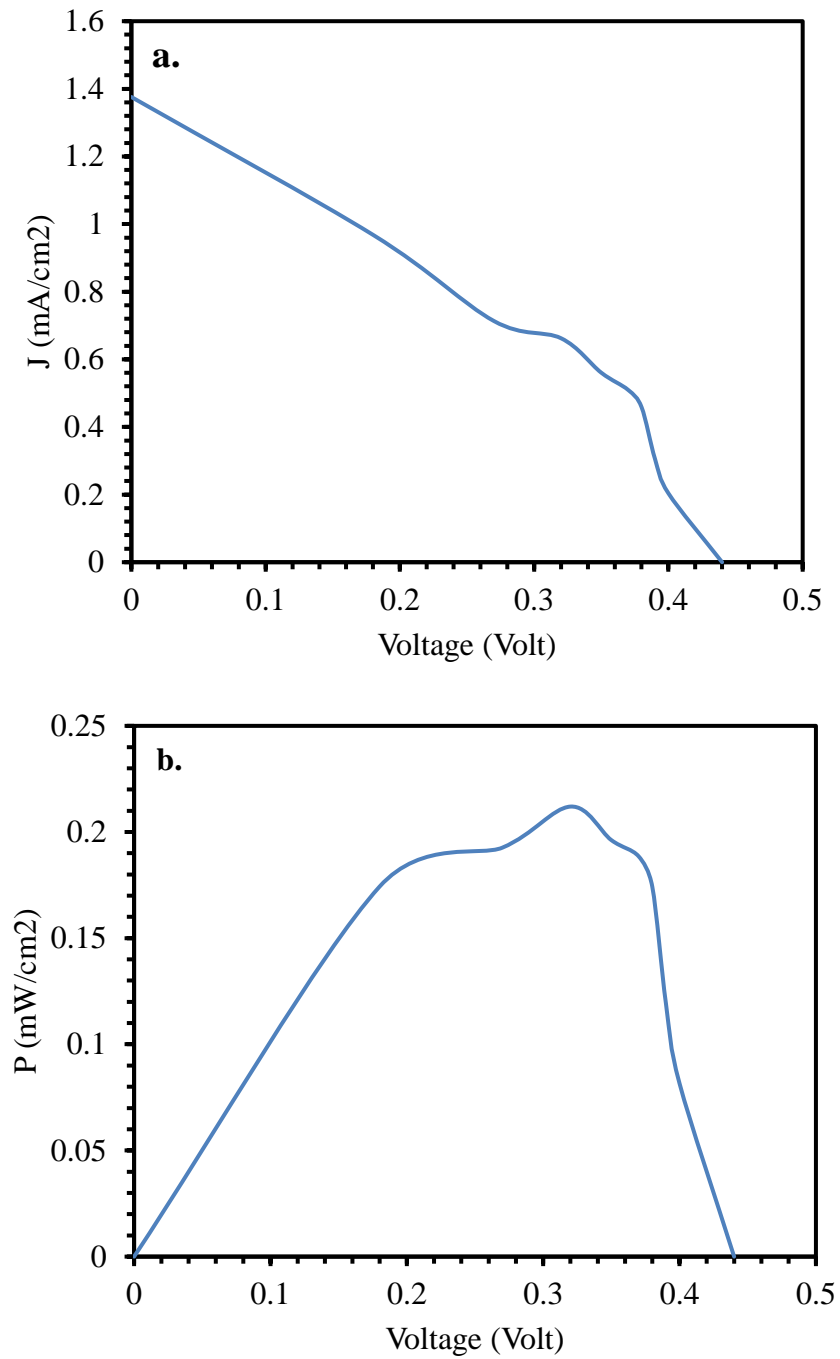


Figure 7. (a) J-V curve for Dye-Sensitized photovoltaic device based CdSe Quantum Dots, **(b)** the solar cell power response with voltage variation.

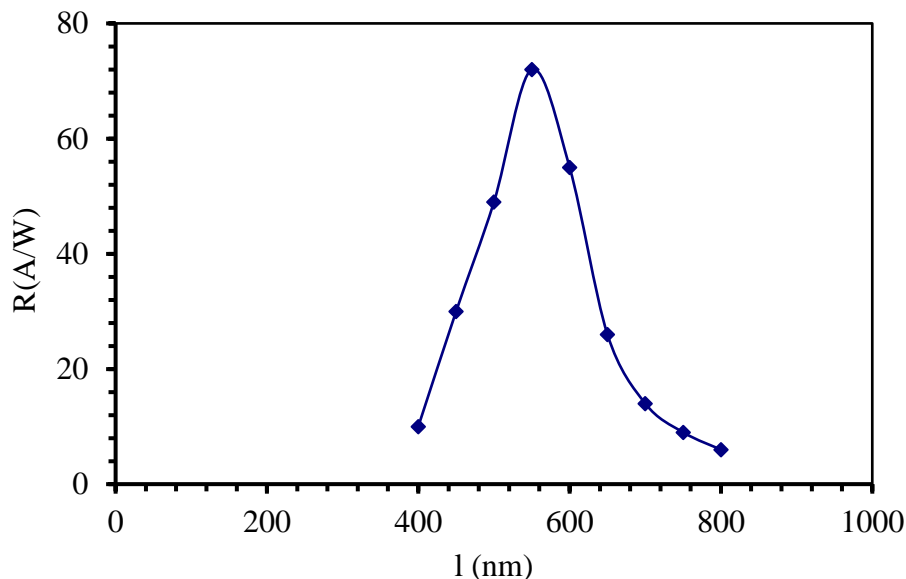


Figure 8. Relative Spectral Response of Dye-Sensitized Solar Cell.

Fig. 8 presents a relative spectral response of Dye-Sensitized Solar Cell based CdSe Quantum Dots. This response was measured for spectrum range (400-800) nm. Note that the responsivity curve comprised of one peak, where the responsivity increase with wavelength, attains the maximum value at wavelength equal to 550 nm.

3. Conclusion

The CdSe Quantum Dots were synthesized successfully at room temperature using pulse laser ablation. The average particle size for preparing the CdSe QDs is approximately 4 nm. The optical energy gap (E_g^{op}) according to Tauc's plot is 2.8 eV. XRD indicated that the CdSe Quantum Dots had a cubic phase with blende structure. The synthesized QDs based Dye Sensitized solar cell shows 4.2×10^{-3} % efficiency, 0.44 V open circuit voltage and 1.38 mA/cm² current density short circuit at 1 Sun condition.

References

- [1] Nazeeruddin, M. K., Baranoff, E., and Gratzel, M., *Solar Energy*, Vol **85** (2011) pp. 1172–1178.
- [2] Cheng, W., Deka, J., Chiang, Y., Rogeau, A., and Lu, S., *Chem. Mater*, Vol **24** (2012) pp. 3255-3262.
- [3] Hou, W., Pavaskar, P., Liu, Z., Theiss, J., Aykol, M., and Cronin, S.B., *Energy Environ. Sci.*, Vol **4** (2011) pp.4650.
- [4] Deepa, K.G., Lekha, P., and Sindhu, S., *Solar Energy*, Vol **86** (2012) pp. 326–330.
- [5] Ng, S., Lu, X., Ding, N., Wu, C. L., and Lee, C., *Solar Energy*, Vol **99** (2014) pp. 115–125.
- [6] Abbass, S. A., Abdullah, A. H. and Ali, A. K., *Eng. & Tech. Journal*, Vol **30** (2012) pp.16.
- [7] Ali, A. K. and Raouf, D. N., *Eng. & Tech. Journal*, Vol **29** (2011) pp.15.
- [8] Junjie, H., Liu, H., Miao, J., Rui, L., Ziming, Z., Bingxin, Z., Bin, X., Jiaji, C., Kai, W., and Marie-Helene, D., *Scientific Reports* Vol **9** (2019) 12048.
- [9] Salman, O. N., Ahmed, D. S., Abed, A. L., and Dawood, M. O., *IOP Conf. Series: Materials Science and Engineering*, Vol **518** (2019) 032012.

- [10] Gondal, M. A., Talal, F. Q., Dastageer, M. A., Yamani, Z. H., and Anjum, D. H., *J. Nanosci. Nanotechnol.*, Vol **16**, issue 1 (2016).
- [11] Al-Jawad, S. M. H., Odai, N. S., and Nwar A. Y., *Surface Review and Letters*, Vol **26**, issue 03 (2019) 1850155.
- [12] Karan, S., Pramod, K. S., Hee-Woo, R., Bhattachary, B., Vol **20**, issue 6 (2014) pp. 4188-4193.
- [13] Soloviev, V. N., Eichhoffer, A., Fenske, D., and Banin, U., *J. Am. Chem. Soc.*, Vol **122** (2000) pp. 2673-2674.
- [14] Ke, F., Li, R., Junnian, C., Wenye, S., and Tianyou P., *Sci Adv Mat.*, Vol **5** (2013) pp. 1596-1626.
- [15] Sahuban, B., Chandramohan, R., Vijayan, T. A., Saravana, K. S., Sri, S. R., Ayeshamariam, A., and Jayachandran, M., *J Material Sci Eng*, Vol **5**, issue 6 (2016).
- [16] Minho, N., Taehoon, K., Hosub, L., Chang-Koo, K., Sang-Woo, J., Kangtaek L., *Colloids and Surfaces A: Physicochem. Eng. Aspects*, Vol **359** (2010) pp. 39-44.