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COMPARISON OF PHOTOVOLTAIC PARAMETERS OF CDSE QD AND SAFRANIN DYE BASED SOLAR CELL

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Abstract

In the present investigation, comparison between photovoltaic parameters of FTO/TiO_2/CdSe.QDs/Pt/FTO and FTO/TiO_2/Safaranin Dye/Pt/FTO are presented. Photo electrodes are prepared on FTO coated glass with three layers; titanium isopropoxide with spin coating, TiO_2 nano-crystalline paste using doctor-blade technique, and a thin layer of titanium chloride with spin coating. Counter electrodes are prepared with sputtering on FTO. CdSe quantum dots are synthesized in three neck flask using trioctylphosphine oxide. Higher photovoltages V_{oc} in QDSSC has been observed whereas higher photocurrents have been measured in DSSC solar cell. At 100 mW/cm^{-2} power density, maximum power is achieved in Safranin dye based solar cell. The capacitance-voltage characteristics of the cell were measured in a wide range of frequencies. It shows a behavior from positive to negative capacitance due to injection of electrons from FTO electrode into TiO_2.

Key words: *Quantum dots, Solar cells, Photo electrode, Electrolyte, Impedance spectroscopy*

1. INTRODUCTION

Dye-sensitized solar cell (DSSC) is a promising alternative to conventional silicon solar cells due to its low cost, low energy consumption, simple fabrication process, and high power conversion efficiency after the breakthrough work by Grätzel, M (2001), Grätzel, M, and O'Regan, B (1991), Yella, A. et al (2011). Commonly a DSSC is made of a sensitizing dye, transparent conducting substrates (fluorine-doped tin oxide (FTO)), nanometer sized TiO_2 thick film, iodide electrolyte, and counter electrode (Pt or carbon/FTO). The light absorbed by a dye molecule leads to the excitation of electrons on the HOMO orbital to an electronically excited LUMO orbital. As this dye molecule is excited it injects an electron to the conducting band of the TiO_2 film. By electron donation from the reducing ions in the electrolyte (organic solvent containing a redox system) the oxidized dye is restored. The recreation of donated electron leads to the reduction of conjugated ions in electrolytes and the circuit competence using electron migration via external load. Details are given in the research work of Grätzel, M, (2005), Lan, Z. et al (2012), Chen, C.M et al (2010), Suzuki, K et al (2003), Tjoa, V. et al (2012), Zakeeruddin, S. M. and Grätzel, M. (2009) Nozik, A.J, (2002). Dyes don't provide tuning capability in DSSC. Researchers have introduced quantum dots (QDs) in order to tune the absorbed light in solar cell to enhance the efficiency.

Currently researcher's main area of interest using QDs is its potential use and applications in photovoltaics, light-emitting diodes (LEDs), single-electron transistorsand fluorescent tags for biological imaging because of its tunable property by changing size of the QDs. For instance, this work was done by different researchers such as: Nozik, A.J., (2002), Medintz, I. L. et al. (2005), Kongkanand, A. et al (2008) and Lee, H.J.et al (2008). The common area of interest in the present investigation also includes unique size-dependent optical and electronic properties, mainly a size-tunable optical absorption and emission spectra. Due to these unique properties recent interest is developed for utilizing semiconductor nano-crystals (or quantum dots) to harvest light energy toward metal-chalcogenide-based system. Particularly, CdX and PbX (X = S, Se, and Te) QDs having relatively small bandgaps and are capable of harvesting photons in the visible and infrared region. Quantum dots are used in quantum dot-sensitized solar cells (QDSCs), metal junction solar cells and polymer hybrid solar cells.

In the first case of the QDSCs, excited electrons of semiconductor nano-crystals are inserted into a large band gap semiconductor of TiO_2 or ZnO, and holes are scavenged by a redox couple. The polymer hybrid solar cells are utilizing blends of conducting polymers (e.g., poly(3-hexylthiophene)) and QDs to obtain charge separation and charge transport. In the metal junction solar cells, charge separation is created at metal semiconductor

interface using visible laser excitation. The related research work is given in the refs Klein, D.L. et al (1997), Rosenthal, S.J (2002), El-Sayed, M.A., (2004), Baker D.R. and Kamat, P.V., (2009), Bowers, M.J et al. (2005), Mingyuan, G. et al. (2000), Bang J.H. and Kamat, P.V., (2009).

2. CELL PREPARATION

TiO_2 working electrodes have been prepared on FTO glass substrates. Two separate TiO_2 electrodes were dipped overnight in CdSe QD solution and Safranin dye solution in order to prepare CdSe-QDSSC and Safranin-DSSC cells. Prior to QD deposition, the working electrode was dipped in mercaptoalkanoic acid (MAA) solution which was acting as a linker between QDs and TiO_2. For depositing dye on the electrode, the electrode was first heated above 350 ^oC and cooled to 100 ^oC. At 100 ^oC, the electrode was suddenly dipped in safranin dye solution and kept overnight for effective adsorption.

Two sandwich-type cells were fabricated by clamping the QDs sensitized and dye sensitized working electrodes with Pt/FTO counter electrodes. A good quality tape (~100 μm thickness) was used as a spacer. Prior to cell assembly, an Iodine based electrolyte was prepared using iodine, potassium iodide and acetonitrile solution which was then dropped in droplets onto the surface of the electrodes until the TiO_2 working electrode was fully covered with the electrolyte. The effective working area used was 0.126 cm^2.

3. RESULTS AND DISCUSSIONS

The light-current-voltage characteristics of the FTO/TiO_2 + syfranin dye/Pt/FTO (DSSC) and FTO/TiO_2 + CdSe QDs/Pt/FTO (QDSSC) solar cell were measured using a standard solar simulator. The fourth quadrant of light-current-voltage characteristics for DSSC and QDSSC are shown in Figs.1 (a,b). The photocurrent is defined as an increase of the current under light exposure. This is an indication of the generated free carriers by absorbed light photons. The phenomenon of photocurrent involves the process of absorption of light photons within the depletion layer and the photo generation of charge carriers. As seen in Figs.1 (a,b), the values of photocurrent and photovoltage are increased with the increasing illumination intensities for DSSC and QDSSC. The short circuit current I_{sc} and open circuit voltage V_{oc} were found to be 393 μA and 0.58 V for DSSC and 111 μA and 0.71 V for QDSSC under 100 mW/cm^2 illuminations, respectively. When the dye and QDs is added to form the heterojunction, the heterojunction induces the separation and transfer of charge carriers and promoted the production of photocurrent, which improves the photoelectric conversion efficiency of the solar cell.

Figs. 1–5 show the photovoltaic performance parameters (output power, open circuit voltage, short circuit current) versus the incident light intensity of sensitized TiO_2 coated with safranin dye and QDs sensitized solar cell. The power–voltage curve gives the more information about the delivered power to this device. The plot of the electric power versus voltage for DSSC and QDSSC are shown in Figs.2 (a,b). The electric power increases with the increasing of the bias voltage and reaches its maximum power and then, decreases until reaches zero values with the further increase of the applied voltage. The maximum power is defined as $P_{max} = I_M \times V_M$, where I_M is the maximum current and V_M is the maximum voltage at each illumination intensities. The maximum power value indicates how much the sensitized solar cell can deliver its maximum power to an external load. The maximum power point is shifted to the higher voltages with the increasing incident light.

Fig. 3 shows the dependence of V_{oc} on the intensity of the incident light. It can be seen that V_{oc} increases with the light intensity for DSSC and QDSSC, which indicates that the photovoltaic voltage is only proportional to the light intensity. Comparing the open circuit values of the sensitized TiO_2 without safranin dye and CdSe QDs, one can notice that the values of V_{oc} for the coated TiO_2 with the CdSe are higher than the safranin dye which may be due to the more harvesting of light by QD-CdSe.

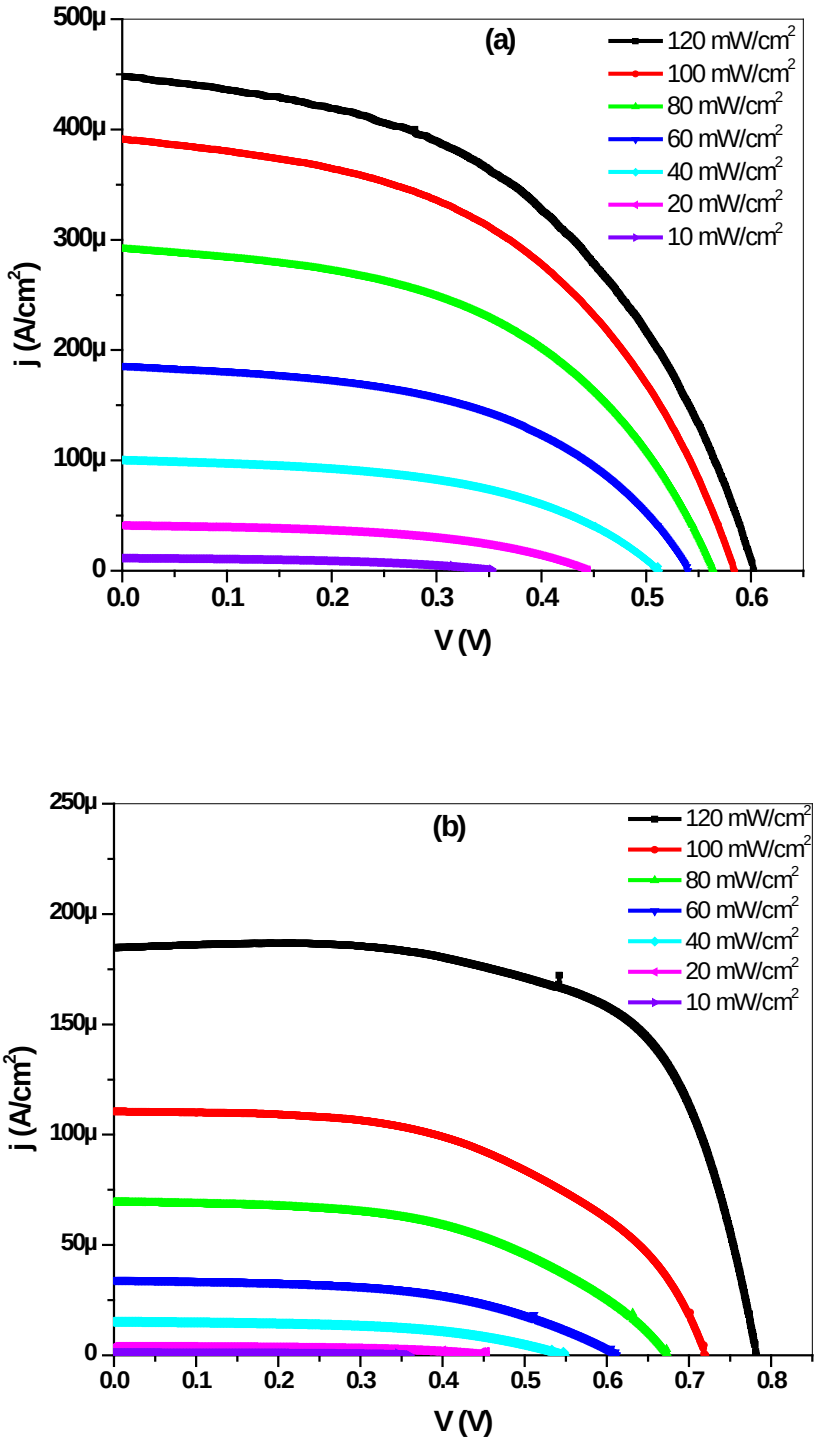


Figure 1: The light–current–voltage curves of nanostructure (a) FTO/TiO_2 + safranin dye/ Pt/FTO, (b) FTO/TiO_2 + CdSe QDs/Pt/FTO solar cell.

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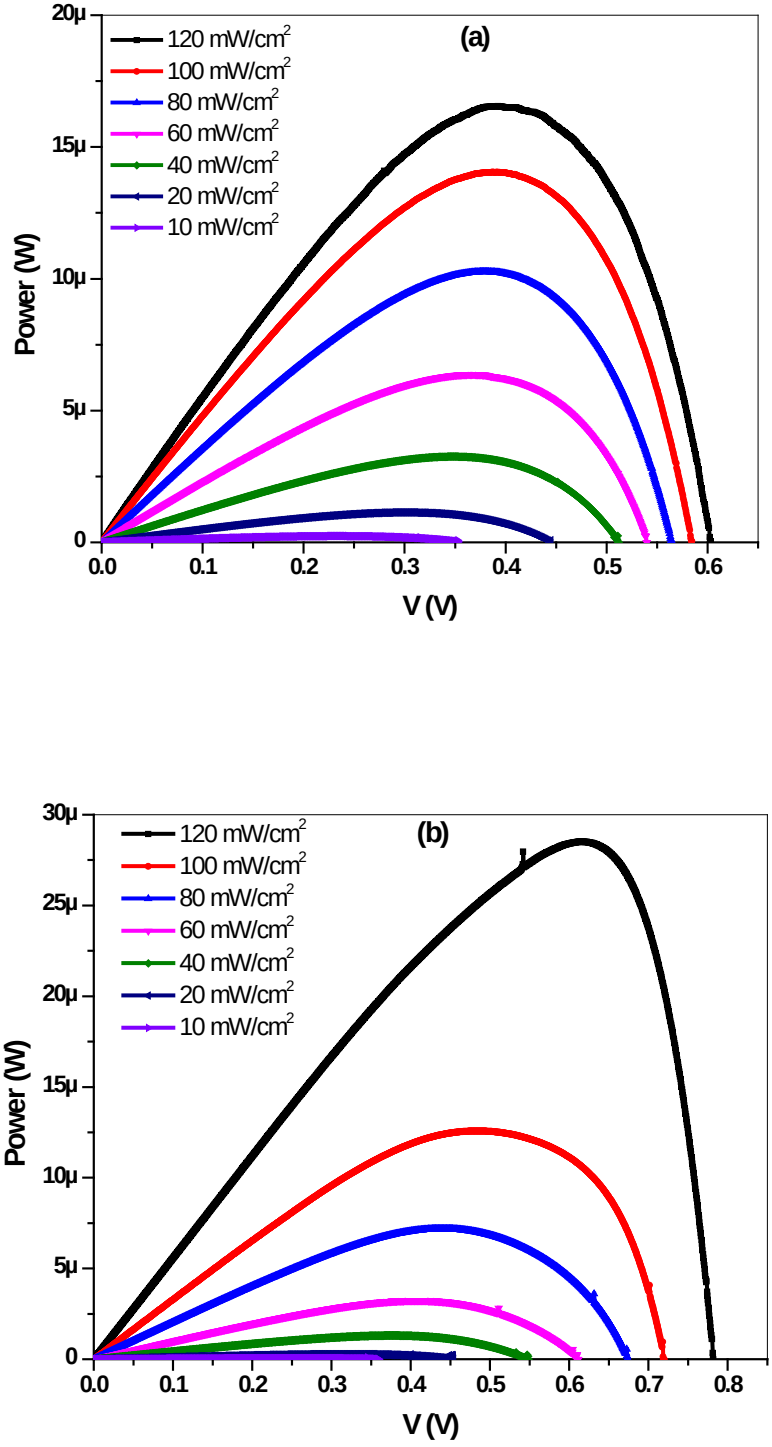


Figure 2: Plotting of the output power versus voltage for (a) FTO/TiO_2 + safranin dye/Pt/FTO (b) FTO/TiO_2 + CdSe QDs/Pt/FTO solar cell.

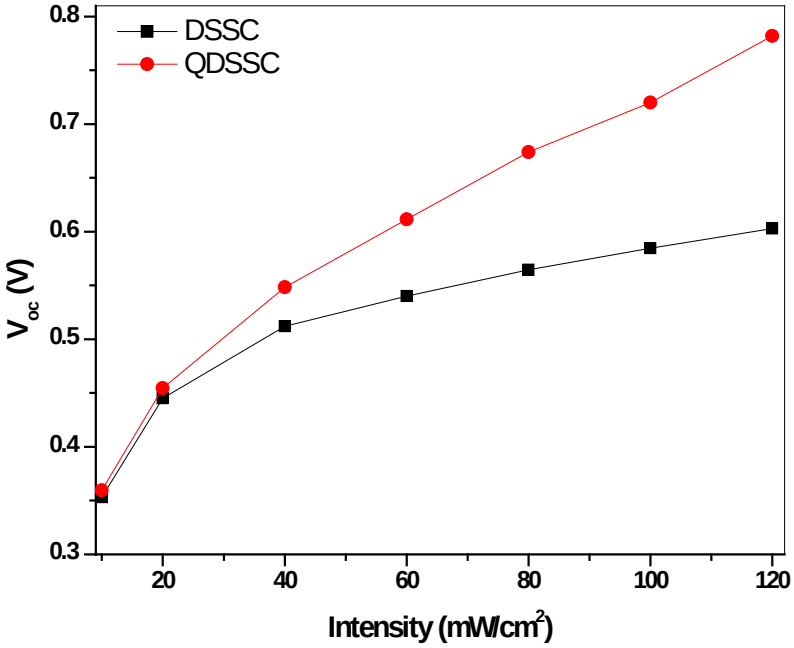


Figure 3: Illumination dependence of the open circuit voltage V_{oc}.

Generation of a photocurrent in the sensitize solar cell is occurred, when sensitizer dye absorbed the incident light photons, resulting in ultra-fast electron injection into the conduction band of the TiO_2. This has been demonstrated by Peter, L. M., (2007), Moser, J.E.et al. (1999), Burfeindt, B. et al (1999) and Tachibana, Y. et al. (1996). The injected electrons move through the network of interconnected oxide particles by a random path process until they reach the conducting glass substrate. Details can be found in the work of Wang, Y. et. al (200). The dye is regenerated by rapid electron transfer from the iodide ions in the electrolyte before it has time to undergo irreversible bleaching. The I^{3-} ions produced in the regeneration step diffuse the short distance to the platinum-coated cathode, where they are reduced to iodide ions to complete the regenerative cycle. The dye regeneration step is similar to the super-sensitization process that is used in photography to allow the dye molecules to inject electrons repeatedly without bleaching. The process is explained in by Nelson, J. and Chandler, R.E., (2004), Wang, P. et al (2005) and Huang, S.Y., (1997).

The short circuit current I_{sc} of the solar cell were obtained from *I–V* curves under illuminations and it is seen that it increases almost linearly with increasing illumination intensity especially at the higher intensities as shown in Fig. 4. This indicates that both the photo-oxidization and regeneration (by the I^-/I^{3-} ions) of the adsorbed safranin dye CdSe QDs are very efficient. Comparing the results of I_{sc} for the safranin dye sensitized TiO_2 and the CdSe QDs sensitized TiO_2 nanostructure devices, one can find that the present safranin dye sensitized TiO_2 cell has greater value of I_{sc} than the QDSSC. At about 120 mW/cm^2, the value of I_{sc} become equal.

Fig. 5 shows the variation of the short circuit current I_{sc} as a function of open circuit voltage V_{oc}. It is clear that V_{oc} increases exponentially with the increase of I_{sc}. This curve was fitted and it is seen that the variation of V_{oc} with J_{sc} (current density) obey the following relation which is explained by Rosenblut, M.L., Lewis, N.S., (1989) and Hagfeldt, A., et al (1995) Sheng, X., (2007):

$$V_{oc} = \frac{nkT}{q}\left(\frac{Jsc}{J_0} + 1\right) \quad (1)$$

where n is the diode ideality factor, k is the Boltzmann's constant, q is the electric charge, and J_0 is the reverse saturation current density. According to Eq.(1), V_{oc} is proportional to the log of I_{sc}, and it increases with the increasing of light intensity which can be observed in Figs.(3,4).

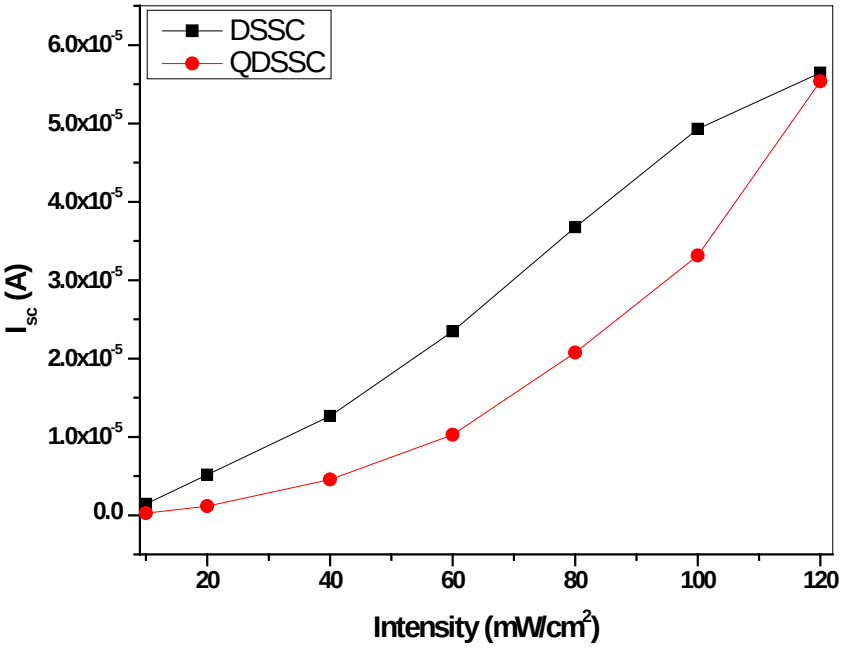


Figure 4: Illumination dependence of the short circuit current I_{SC}

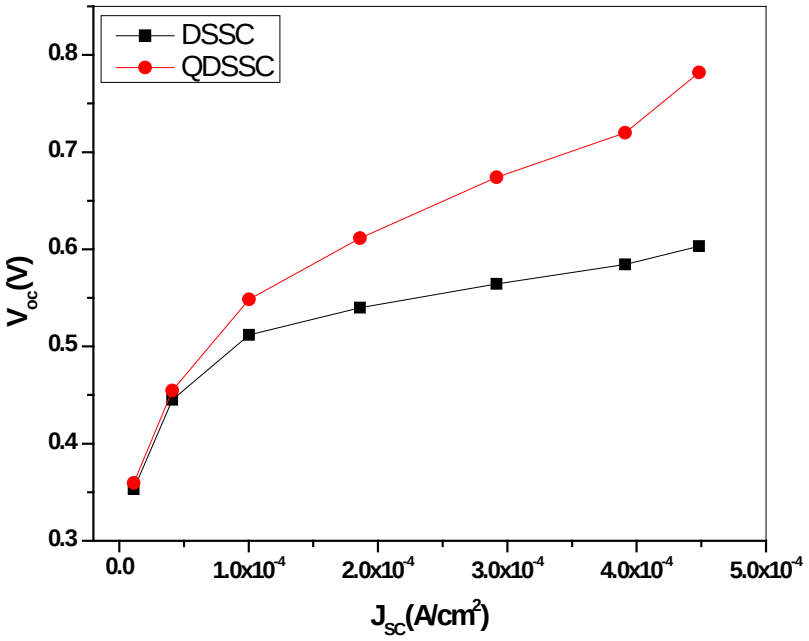


Figure 5: The plotting of short circuit current density J_{sc} as a function of open circuit voltageV_{oc}.

Impedance spectroscopy was used to study the cell capacitance (C) as a function of the applied biasing voltage (V) at different frequencies for DSC based safranin dye. The capacitance–voltage plots at different frequencies for safranin DSSC is shown in Fig. 6. This figure that the positive capacitance at 500 kHz and studied to have

negative capacitance at 700 kHz. Kron et al. and Yahia, I.S, et al (2011) concluded that the appearing of the negative capacitance (i.e., inductive) in DSSC is generally discussed on the basic of the electrons injected from the front electrode (FTO) into the TiO_2 thick layer films. These electrons modulate the number of holes in the hole conductor and thus the resistance is decreased within the pores. The time delay between electron injection and the modulation of the hole concentration leads to the observed inductive behavior.

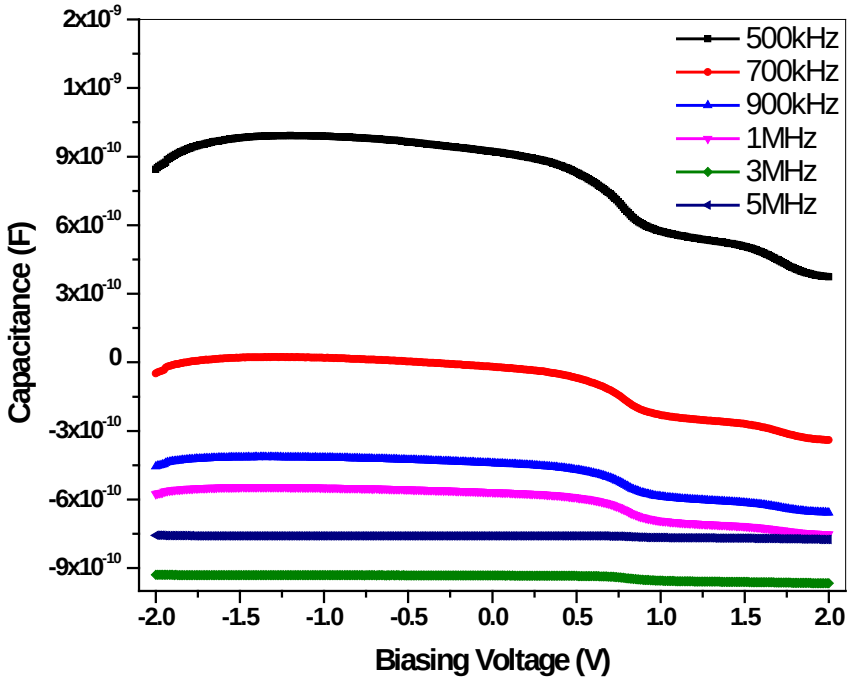


Figure 6: Capacitance-voltage characteristics as a function of biasing voltage V for DSSC with safranin Dye

4. CONCLUSION

In this study, two cells were fabricated as follows: FTO/TiO_2/CdSe.QDs/pt/FTO and FTO/TiO_2/Safaranin Dye/Pt/FTO. Photovoltaic parameters and constants were deduced and analyzed on the basis of Grätzel. Both cells showed good photovoltaic response. The short circuit current I_{sc} and open circuit voltage V_{oc} were found to be 393 µA and 0.58 V for DSSC and 111 µA and 0.71 V for QDSSC under 100 mW/cm^2 illuminations, respectively. Also, It is was observed that V_{oc} increases with the light intensity for both cells DSSC and QDSSC, which indicates that the photovoltaic voltage is only proportional to the light intensity. The open circuit voltage of the coated TiO_2 with the QD-CdSe are higher than the safranin dye which may be due to the more harvesting of light by QD-CdSe. The capacitance–voltage shows a behavior from the positive to negative capacitance at the higher frequencies due to injection of electrons from the FTO electrode into TiO_2.

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