

RESEARCH PAPER

Fabrication of Inorganic Sensitized Solar Cells by Drop Casting Deposition of PbSe and PbTe on the TiO₂ Surface

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ABSTRACT

In this work, PbSe and PbTe sensitized TiO₂ solar cells were fabricated. PbSe and PbTe nanostructure was deposited on the TiO₂ surface via a drop cast method. The fabricated surfaces were examined by atomic force microscopy (AFM). Also the optical properties of the layers were studied by diffuse reflectance spectroscopy (DRS) spectra. The morphology of the surfaces was obtained by scanning electron microscopy (SEM) images. The structure and phase of the obtained materials were studied by X-ray diffraction pattern (XRD). Furthermore chemical elements of the fabricated layers were examined by energy dispersive X-ray analysis (EDX) spectra. The solar cells were made by the fabricated layers, Pt as a counter electrode, I₃⁻/I⁻ electrolyte, surlyn as a sealer and silver paste to enhance collection of the produced current.

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INTRODUCTION

TiO₂ is an n-type wide band-gap oxide semiconductor used for variety of applications such as dyesensitized solar cell, environmental purification, nanodevices, gas sensors, and photocatalysts [1-9]. Also TiO₂ is a promising candidate for using in dye sensitized solar cells. TiO₂ is a low cost semiconductor and has a wide band gap that can use in different kinds of solar cells. One of the key factors determining the efficiency of DSSC is the light-harvesting [10, 11]. Inorganic semiconductors such as CdS [12, 13], CdSe [14, 15], CdTe [16], PbS [17, 18, 19, 20], and InP [21], which have extraordinary optical and electrical properties, could be the viable alternatives to ruthenium complexes or organic dyes in sensitized solar cell applications [22]. These materials due

to their band gap value can absorb light in the visible range and therefore can harvest more sun light range. In this work we fabricated PbSe and PbTe sensitized TiO₂ solar cell. PbSe and PbTe nanostructures were deposited on the TiO₂ surface by a drop cast method. It was found these layers expand absorption light range to the visible one and hence more electron-hole pairs are created. Therefore sensitization of TiO₂ with PbSe and PbTe is good for using in the solar cell application. Based on our knowledge this is the first work that deal with sensitization of TiO₂ with PbSe and PbTe for using in inorganic dye sensitized solar cells.

MATERIALS AND METHODS

GC-2550TG (Teif Gostar Faraz Company, Iran) were used for all chemical analyses. To deposit

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of TiO₂ on the FTO surface, the cleaned FTO glass remained at a positive potential (anode) while a pure steel mesh was used as the counter (cathode) electrode. The linear distance between the two electrodes was about 3 cm. Power was supplied by a Megatek Programmable DC Power Supply (MP-3005D). The applied voltage was 10 V. The deposition cycle was 4 and 8 times with each time of 15 s, and the temperature of the electrolyte solution was 25 °C. The coated substrates were dried in air. The apparent area of the film was 1×1 cm². The process was done at TiO₂ electrolyte that can be obtained by adding 0.4 g TiO₂ in the absolute ethanol and then add the 60 mg I₂, 24 ml acetone and 20 ml deionized water. The resulting layer was annealed under an air flow at 325 °C for 5 min, at 375 °C for 5 min, at 450 °C for 15 min and 500 °C for 15 min °C. To deposit PbSe on the TiO₂ surface via drop cast method, first PbSe nanostructures were prepared via simple solvothermal method by dissolving equal mole of Pb(NO₃)₂·4H₂O and SeCl₄ in the propylene glycol separately. Two prepared solutions were mixed together under vigorous stirring. After that certain amount of hydrazine as reducing agent and polyethylene glycol (PEG) as surfactant was added to the final solution. The beaker was then transferred to the autoclave and placed in the oven at 180 °C for 3 h. The obtained powder was washed with absolute ethanol and deionized water for several times and then dried in the oven at 80 °C for 12 h. To deposit the obtained PbSe nanostructures on the TiO₂ surface, a dilute suspension of PbSe was prepared from dispersing certain amount of PbSe on the ethanol with ultrasonic bath. After that one drop of the suspension was placed on the TiO₂ surface and the surface was placed in the oven to evaporate the ethanol. The deposition process of PbTe on the TiO₂ surface was similar to PbSe one with the difference that instead of SeCl₄, TeCl₄ was used.

Fig. 1 shows the fabricated surface schematic. After preparation the work electrode, the cell was made as follow: A Pt coated FTO glass electrode was prepared as a counter electrode. The Pt electrode was placed over the inorganic adsorbed TiO₂ electrode and the edges of the cell were sealed with 50 um thick sealing sheet (Surlyn 50, Dyesol). Sealing was accomplished by pressing the two electrodes together on a double hot-plate at a temperature of about 110 °C. The I₃⁻/I⁻ electrolyte (Dyesol) was introduced into the cell through one of two small holes drilled in the counter electrode. Finally, these two holes were sealed by a small square of sealing sheet. After that DSSCs were characterized by I-V spectra. Fig. 2 shows a schematic of the fabricated solar cell device.

RESULT AND DISCUSSION

Fig. 3 shows XRD pattern of the TiO₂-PbSe surface. As shown in this figure, there are two TiO₂ phases namely anatase and rutile that is belong to TiO₂ P25 used as first layer. Beside that TiO₂ phases there is also PbSe with cubic phase that is due to PbSe deposition on TiO₂ surface. Beside the mentioned peaks there are some other peaks that are belong to SnO₂ of FTO layer. From the XRD pattern it can be concluded that PbSe was deposited successfully on the TiO₂ surface. The XRD pattern of PbTe deposited on the TiO₂ surface is shown in Fig. 4. It can be seen that the thin film is composed of PbTe with cubic phase, TiO₂ with rutile and anatase phases and SnO₂ related to the FTO substrate. As shown in this pattern, PbTe is successfully deposited on the TiO₂ surface. Fig. 5 shows EDS spectra of the created surface to approve deposition of PbSe on the TiO₂ surface. It can be seen that beside Ti and O peaks there are Pb, Se peaks that can be attributed to deposited PbSe. There are also Si and Sn peaks beside the mentioned ones that belong to glass and FTO

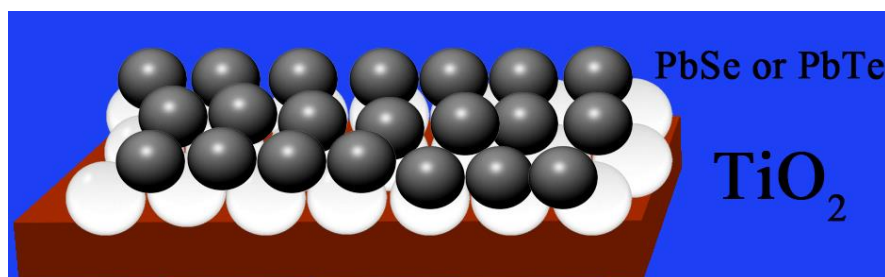


Fig. 1. Schematic of the fabricated surface.

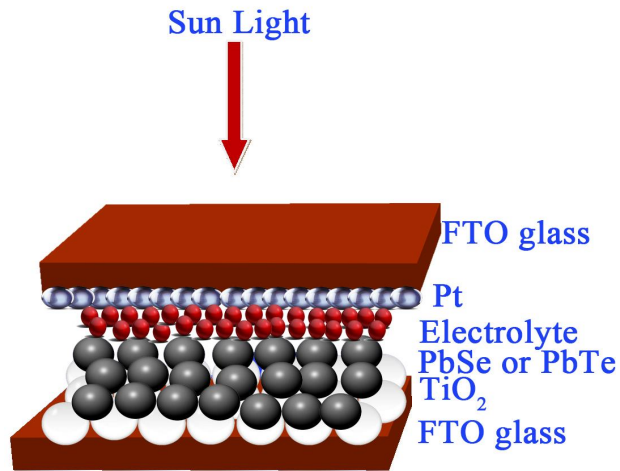


Fig. 2. Schematic of the fabricated solar device.

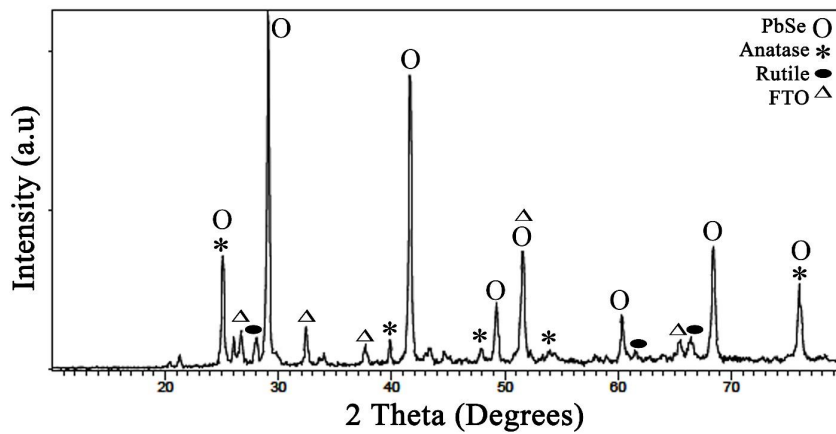


Fig. 3. XRD pattern of PbSe nanostructures deposited on the TiO₂/FTO surface.

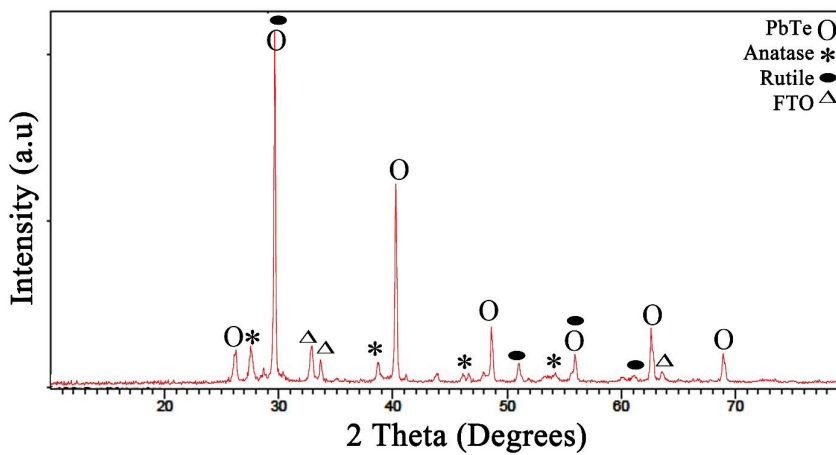


Fig. 4. XRD pattern of PbTe nanostructures deposited on the TiO₂/FTO surface.

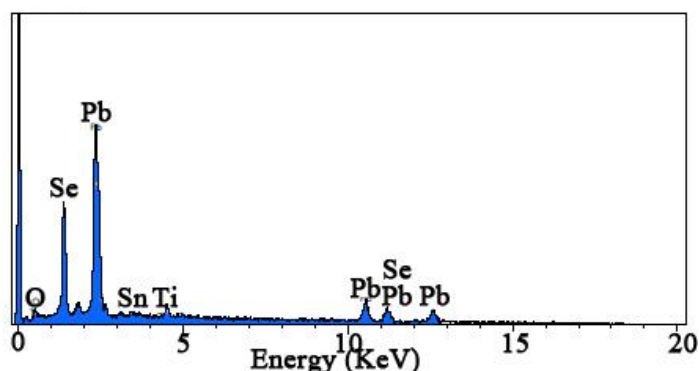


Fig. 5. EDS spectra of the TiO₂-PbSe surface.

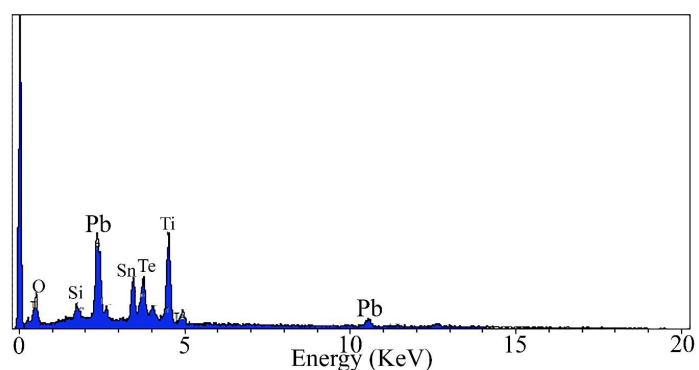


Fig. 6. EDS spectra of the TiO₂-PbTe surface.

layer, respectively. It can be said that PbSe was deposited successfully on the TiO₂ surface and these layers are on the FTO glass substrate. The chemical composition of the PbTe deposited on the TiO₂ surface was investigated by EDS analysis (Fig. 6) and it was found the thin film is composed of Pb, Te, Ti, O and Sn elements that is in good agreement with the XRD pattern. To investigation of the fabricated surface quality and morphology SEM images were taken from the surface (Fig. 7). As shown in this figure the surface is mainly made from the nanoparticles and the surface is almost uniform. But beside these uniformly there are some issues that affect on the surface quality and solar cell efficiency. Other factor that can restrict the solar cell performance is grain boundaries. These sites act as a trap site and catch the electrons. As shown in the Fig. 6, there are some chunk-like structures that act as trapping site too. These structures were made from aggregation the nanoparticles with high energetic surface. The surface quality of PbTe-TiO₂ was studied by SEM image (Fig. 8a) and it was found when PbTe was deposited on the TiO₂ surface, some crack states

were created on the TiO₂ surface that can restrict the electron transfer and solar cell performance. Also, The morphology of PbTe nanoparticles were studied by SEM image (Fig. 8b) and it was found it was composed of very tiny particles that aggregated together. In fact due to high surface activity of the prepared nanoparticles, they aggregated together and larger particles were achieved. Fig. 9 shows AFM image of the surface of PbSe deposited on the TiO₂. It can be seen that the surface is uniform and PbSe nanoparticles was deposited on the TiO₂ surface uniformly. This is good for solar cell efficiency. In fact when the surface is uniform, produced electrons are transferred across the surface and hence recombination is restricted. The surface morphology of the PbTe-TiO₂ thin film was examined by AFM image (Fig. 10). The results showed by deposition PbTe on the TiO₂ surface, the uniformity of the TiO₂ surface was increased that can increase the recombination centers and limit electron transfer through the electrode. The UV-Vis diffuse reflectance spectroscopy (DRS) was served for investigation of optical property of the fabricated samples. As shown in Fig. 11a

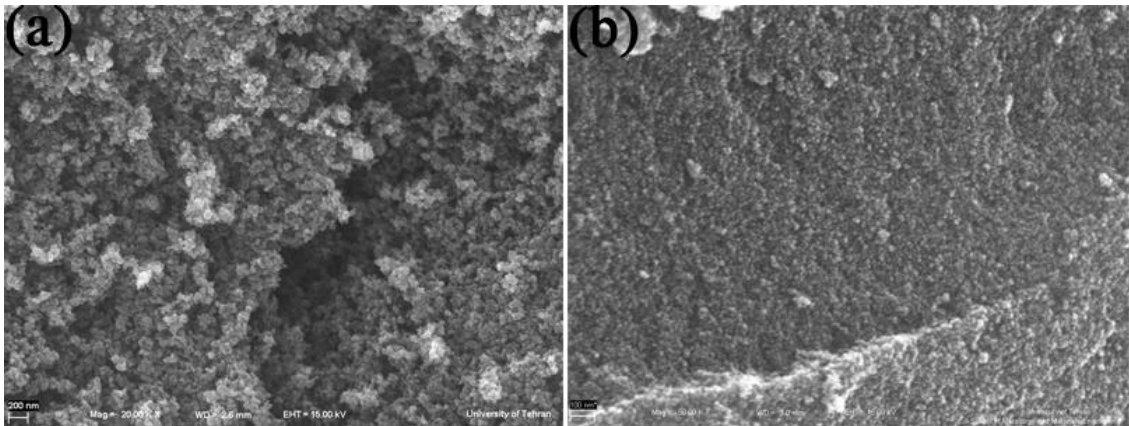


Fig. 7. SEM image of (a) PbSe surface deposited on TiO₂/FTO and (b) PbSe nanoparticles.

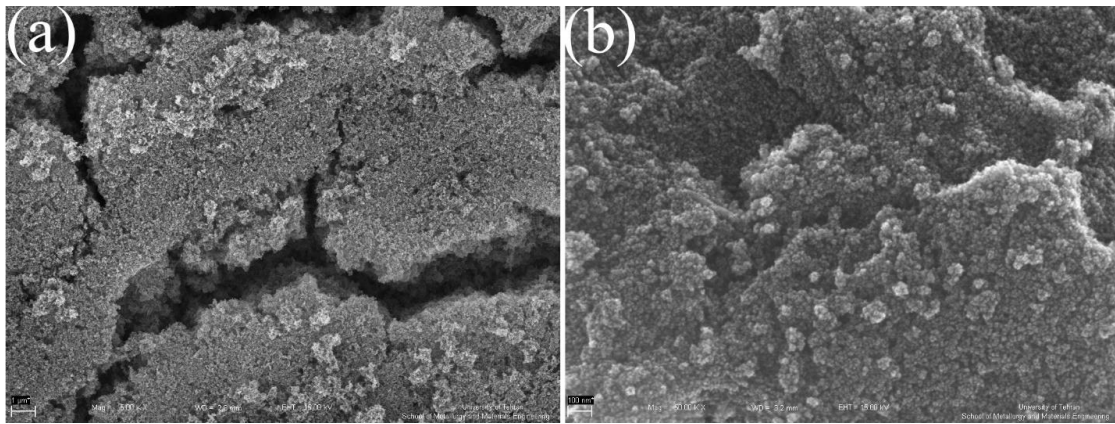


Fig. 8. SEM image of (a) PbTe surface deposited on TiO₂/FTO and (b) PbTe nanoparticles.

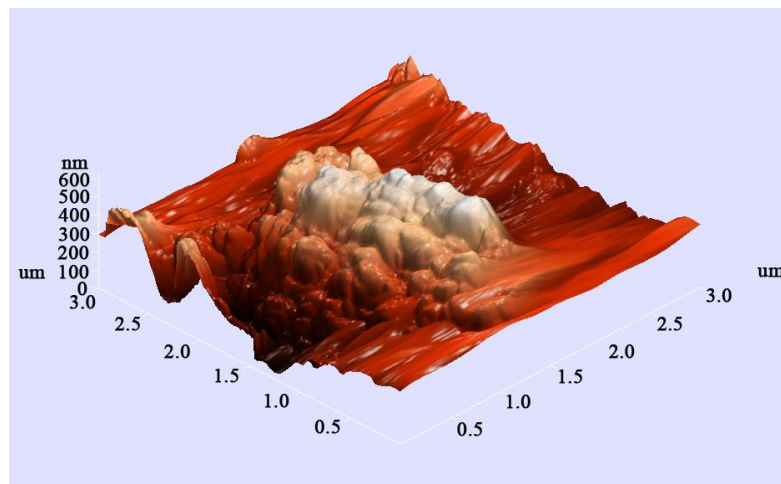


Fig. 9. AFM image of PbSe surface deposited on the TiO₂/FTO surface.

using PbSe was led to shift TiO₂ spectrum to the red region that is needed for solar cell application. It can be said that using PbSe on the top of the

TiO₂ surface expand visible spectrum range. The fundamental absorption edge in the most semiconductors follows the exponential law. Using

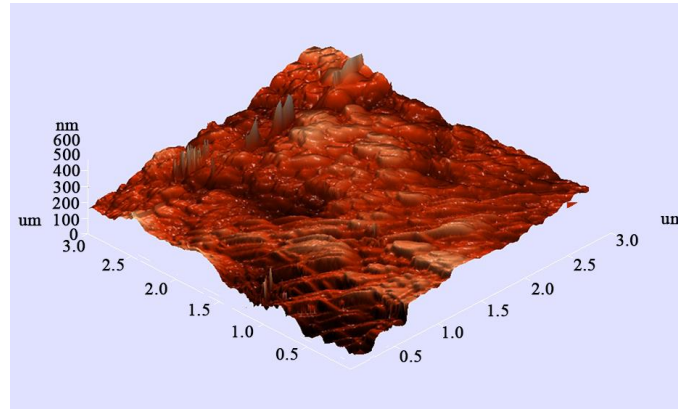


Fig. 10. AFM image of PbTe surface deposited on the TiO₂/FTO surface.

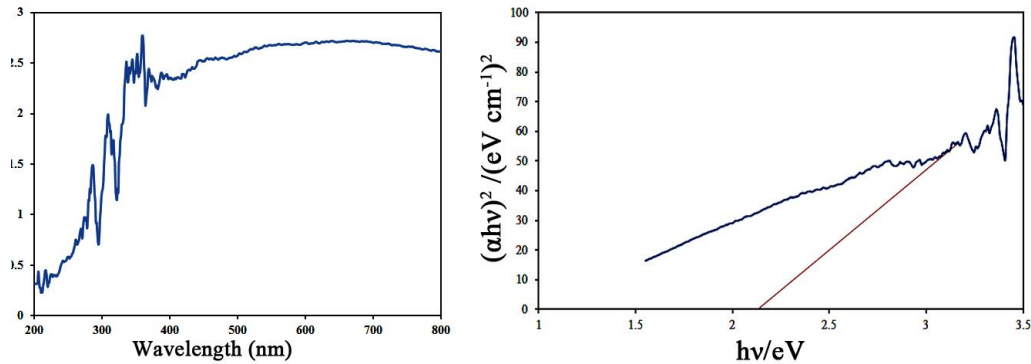


Fig. 11. DRS (left) and $(\alpha hv)^2$ versus $h\nu$ (right) of PbSe surface deposited on the TiO₂/FTO surface.

the absorption data the band gap was estimated by Tauc's relationship:

$$(\alpha hv) = B (hv - E_g)^m$$

Where B is characteristic disorder parameter and m depends on the type of electronic transition and can be any value between 0.5 and 3 [2]. For direct transition between valance band and conduction band $m = 0.5$. A rapid rise in absorption coefficient (α) near the fundamental absorption edge indicates direct energy transition in the forbidden gap. The energy band gap of the sample has been estimated by extrapolating the linear portion of the plots of $(\alpha hv)^2$ against $h\nu$ to the energy axis (Fig. 11b). As shown in this plot, TiO₂ bandgap are decreased using PbSe. It can be concluded that PbSe is able to decrease TiO₂ bandgap and expand the visible-light spectrum that is useful for solar cell application. The UV-Vis spectra of the PbTe-TiO₂ is shown in Fig. 12a. it can be seen when PbTe was deposited on the TiO₂, the thin film can absorb more light than the bare TiO₂. In other words by deposition PbTe

on the TiO₂ surface, the band gap is decreased (Fig. 12b) that is suitable for light harvesting materials in the solar cells. Fig. 13 shows J-V curve of the fabricated solar cell. When PbSe deposited on the TiO₂ and create a uniform surface, the produced electrons can transfer across the electrode to the external circuit. The obtained short circuit current, open circuit voltage and fill factor were 96 $\mu A/Cm^2$, 0.42 V, 0.59 respectively. In fact when sun light expose to the PbSe surface, electron and hole pairs are created and the electrons transfer to the TiO₂ conduction band and therefore these electrons transfer to the external circuit and hence the short circuit current is obtained. J-V curve of the solar cells made by PbTe deposited on TiO₂ surface is shown in Fig 14. It was found the PbTe-TiO₂ solar cell showed weaker performance respect to the PbSe-TiO₂ that is mainly due to the lower quality of the PbTe-TiO₂ surface respect to the PbSe-TiO₂. In fact, due to the existence of crack sites in the PbTe-TiO₂ surface, electron cant well transfer through the electrodes and hence short current circuit density is decreased.

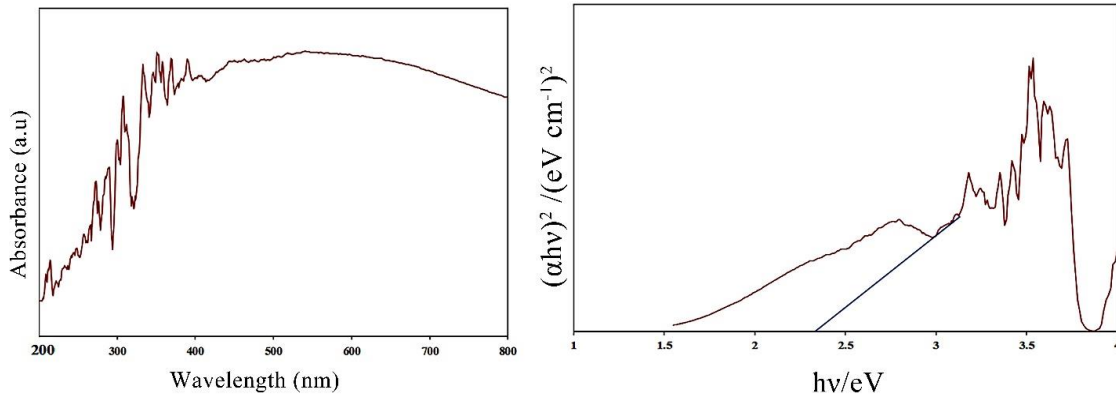


Fig. 12. DRS (left) and $(\alpha h\nu)^2$ versus $h\nu$ (right) of PbTe surface deposited on the TiO₂/FTO surface.

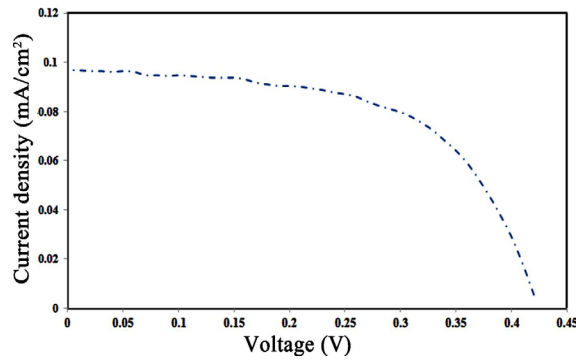


Fig. 13. J-V curve of the solar cell fabricated from PbSe-TiO₂ surface.

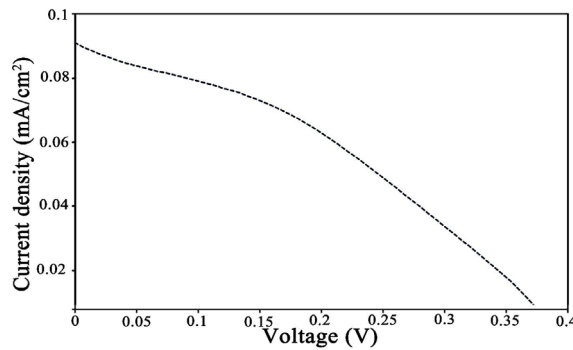


Fig. 14. J-V curve of the solar cell fabricated from PbTe-TiO₂ surface

CONCLUSION

In summary, PbSe and PbTe sensitized TiO₂ solar cells were made. The solar cells were fabricated via deposition of PbSe and PbTe nanostructures via a drop cast method. XRD patterns and EDS spectra were shown that PbSe and PbTe were deposited on the FTO/TiO₂ surface. Also AFM images showed the dropcasting of the PbSe nanostructures on the TiO₂ create the more uniform surface than PbTe

nanostructures. Also, SEM images showed the surface made by PbTe had more track sites respect to the PbSe one that was a limiting factor for the solar cell performance. Optical properties of the products were examined by DRS spectra and it was seen that deposition of PbSe and PbTe on the TiO₂ surface increase the ability of the TiO₂ to absorb sun light. Finally the solar cell performance was studied by J-V curve and the results showed that

deposition of PbSe on the TiO₂ surface shows an acceptable solar cell parameters. In fact when PbSe was deposited on the TiO₂ surface, electron can transfer across the electrode and hence this solar cell shows an acceptable short circuit current. Also it was found PbTe sensitized solar cell shows a weaker performance respect to PbSe one that is mainly due to the lower surface quality of PbTe surface than PbSe surface. In fact due to existence of crack sites on the PbTe-TiO₂ surface, the electrons can't transfer across the electrodes and hence the solar efficiency is dropped.

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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