J Nanostruct 8(2): 159-167, Spring 2018

RESEARCH PAPER

Simple Synthesis of In_2S_3 Nanoparticles and their Application as Co-sensitizer to Improve Energy Conversion of DSSCs

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ARTICLE INFO

Article History:
Received 01 February 2018
Accepted 18 March 2018
Published 01 April 2018

Keywords:
Co-sensitizer
Nanoparticles
Semiconductor
Solar Cell

ABSTRACT

This paper describes synthesis of In_2S_3 nanoparticles by sonochemistry method and their application to enhance solar cells performance which In_2S_3 nanoparticles work as co-sensitizer for the first time. In_2S_3 is a narrow band gap semiconductor (2 eV) with conduction band higher than TiO_2. Therefore it can transfer electron to the conduction band of TiO_2. The effect of different parameters such as power and time on size of products were investigated. The fabricated solar cells made by different samples in the same conditions shown different Jsc, Voc, FF and efficiency. Modified dye sensitized solar cells (DSSC) exhibits the best performance with the power conversion efficiency of 8 % which is superior to that of the free–modified DSSC with the photoelectric conversion efficiency (PCE) of 5.1%. Modified solar cell shows 56.7% improvement in the efficiency. The prepared Nanoparticles and fabricated solar cells were characterized by X-ray diffraction (XRD), energy dispersive X-ray spectroscopy (EDX), scanning electron microscopy (SEM) and I-V measurement.

How to cite this article
Shabani nia K, Madani M. Simple Synthesis of In_2S_3 Nanoparticles and their Application as Co-sensitizer to Improve Energy Conversion of DSSCs. J Nanostruct, 2018; 8(2):159-167. DOI: 10.22052/JNS.2018.02.006

INTRODUCTION

Dye-sensitized solar cells are currently attracting world-wide scientific and technological interest because of its low cost and simple fabrication process [1–3]. Titanium dioxide (TiO_2) with a wide band-gap of 3.0–3.2 eV is one of the most prominent oxide materials for performing various kinds of industrial applications such as photonic crystals [4], photovoltaic [2], photochromic [5,6], photocatalytic [7,8]. The wide band gap of TiO_2 (3.2 eV) limits its absorption to the ultraviolet region of the solar spectrum while only about 3 percentage of solar spectrum is UV light [9]. Also, the electron mobility of TiO_2 is low and limited the conversion efficiency of solar cells [10,11]. Till now many efforts have been made to enhance light harvesting in the visible light region by focusing on the development of high performance sensitizers [12–15]. It is still a challenge to obtain an ideal organic dye as sensitizer to absorb photons in the full sunlight spectra. For this reason, various semiconductors such as CdS, CdSe, Bi_2S_3, $CuInS_2$, and so on, which absorb light in the visible, can serve as sensitizers because they are able to transfer electrons to large bandgap semiconductors such as TiO_2 or ZnO [9].

Herein we use In_2S_3 as co-sensitizer to improve efficiency of dye sensitized solar cells. In_2S_3 is a narrow band gap semiconductor (2 eV) with conduction band higher than TiO_2. Therefore it can transfer electron to the conduction band of TiO_2.

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MATERIALS AND METHODS

Preparation of TiO_2/In_2S_3

Firstly, 1.173 g of $InCl_3$•$4H_2O$ and 0.451 g of thioacetamide were dissolved into 60 mL of distilled water. Then the mixture was stirred under sonication and heated to 70 ◦C for 45 min. The samples were collected after being filtered and washed with distilled water and finally dried at 60 ◦C in air.

Preparation of Working Electrodes

TiO_2 films was prepared according to the previous works [7,8, 15–17]. Briefly, this deposited by Electrophoretic Deposition (EPD) methods .Power was supplied by a Megatek Program-Mable DC Power Supply (MP-3005D).The applied voltage was 10V.The optimal concentrations of additives in the electrolyte solution as follows:I_2 120mg/l, acetone 48 ml/l, and water20ml/l.

Prepare working electrode including In_2S_3/ TiO_2

TiO_2 films was prepared by a method described in section 2.2. Next, as synthesizes In_2S_3 were dispersed in ethanol by bath ultrasonic. 0.1 g of In_2S_3 was dispersed in 30 ml ethanol for 40 min. Then the electrode was immersed in this solution for 2 min. Finally, this electrode was dried at 125 C for 15 min.

Cell assembly

The fabricated electrodes were separately immersed into an ethanol solution of N-719 (Dyesol) and kept at48 C for 24 h to complete the Sensitizer up take. Then the dye-adsorbed TiO_2 electrodes were rinsed with acetonitrile and dried. A Pt coated FTO glass electrode was prepared as a counter electrode. The Pt electrode was placed over the dye-adsorbed composite electrode. Sealing was accomplished by pressing the two electrodes together on a double hot-plate at a temperature of about 110 C.

RESULTS AND DISCUSSIONS

The XRD patterns and EDX of the In_2S_3 nanoparticles are shown in Fig. 1, it can be seen

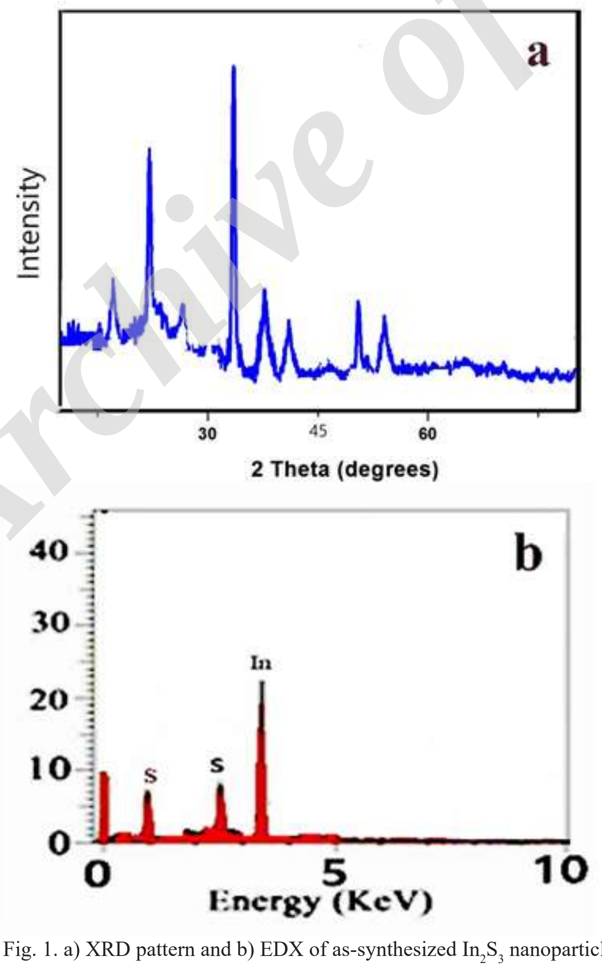

Fig. 1. a) XRD pattern and b) EDX of as-synthesized In_2S_3 nanoparticles

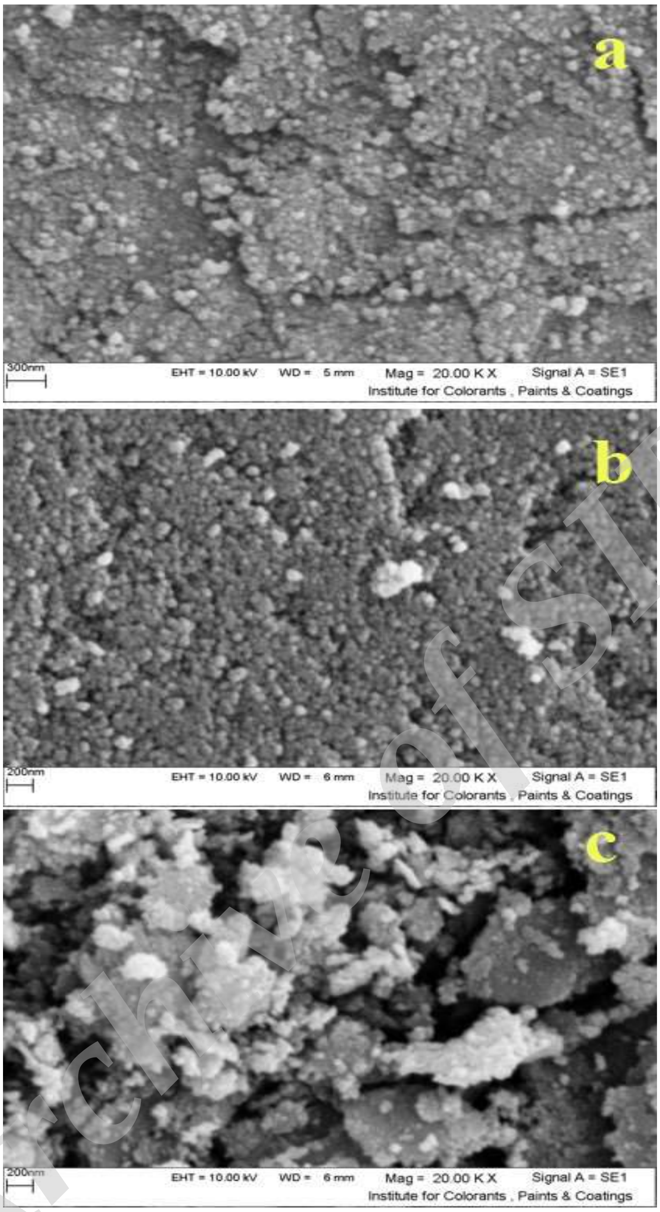

Fig. 2. SEM images of as-synthesized In_2S_3 nanoparticles under different ultrasonic power a) 50 W, b) 60 W, and c) 70 W.

that the In_2S_3 is β-In_2S_3 structure (JCPDS No. 65-0459) with no impurity.

There are important parameters in the sonochemistry method such as the ultrasonic power and time whose effects on the In_2S_3 nanoparticles were investigated by SEM images. Fig. 2 and 3 show the effect of power and time of ultrasonic on the size and morphology of products. According to the Fig. 2, when the power was 50 w, the particle size was about 100 nm (Fig. 2 a). Increasing the power to 60 W led to the production of uniform particles with small size of about 60 nm (Fig. 2 b). Further increase in the power led to the produced bubbles with more energy, and the products were agglomerated (Fig. 2 c) [18-20]. Thus, optimal power was recorded at 60 W.

The reaction was carried out for 20 min, 30 min and 40 min to investigate the effect of sonication time on the morphology of the products (Fig. 3 a-c). As seen from Fig. 3 a, when reaction time was chosen as 20 min small nanoparticles were

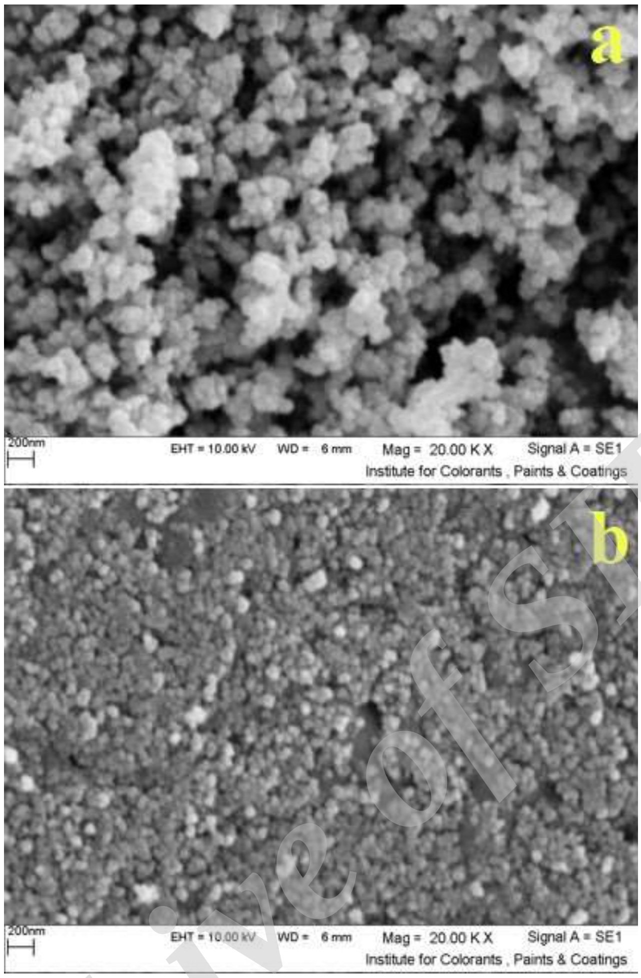

Fig. 3. The effect of time reaction on size of In_2S_3 nanoparticles a) 20 min and b) 40 min.

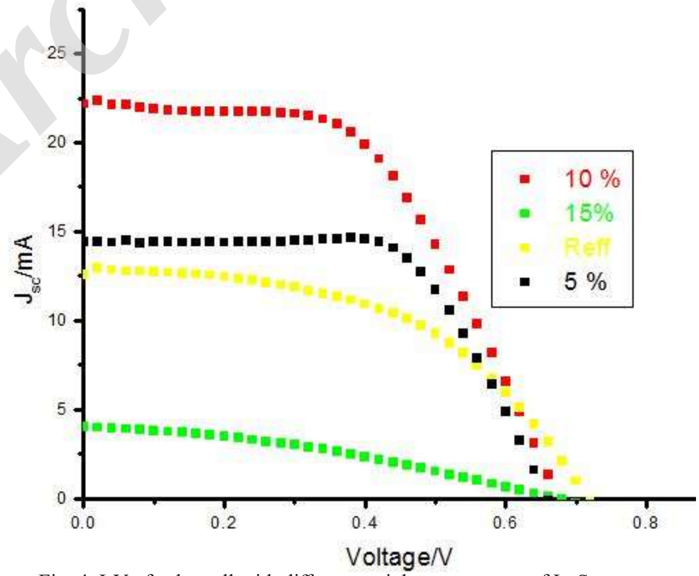

Fig. 4. I-V of solar cell with different weight percentages of In_2S_3.

Table 1. Solar cell performance parameters of devices including different weight of In_2S_3 under AM 1.5.

DSCs	Voc	Jsc	FF	η %
Reff.	0.69	12.5	0.50 ±0.02	5.1
5% In_2S_3	0.66	14	0.54± 0.02	7.48
10% In_2S_3	0.67	22	0.30± 0.01	8.01
15% In_2S_3	0.68	6	0.52±0.01	4

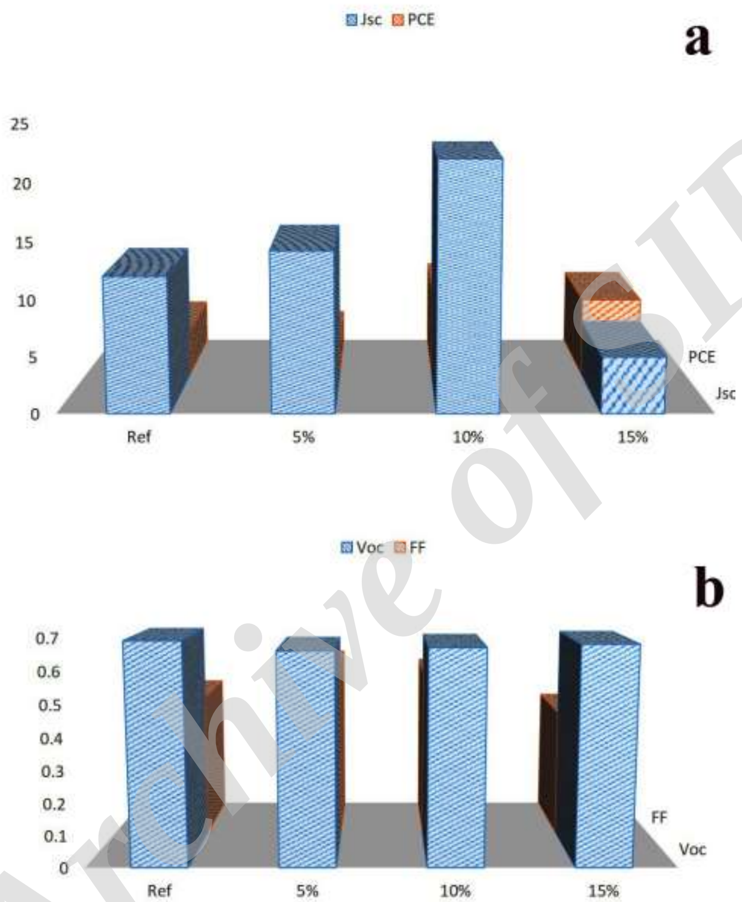

Fig. 5. The effect of weight percentages of In_2S_3 on a) Jsc and PCE and b) Voc and FF.

obtained. By increasing the reaction time to 30 min smaller nanoparticles were achieved (Fig. 2b). Finally by choosing the reaction time to 40 min aggregated particles were obtained due to high energy surfaces of nanoparticles.

To carry out optimization studies on the incorporation of In_2S_3 nanoparticles into DSSCs, 5, 10, and 15% W/V of In_2S_3 nanoparticles dispersed in ethanol were chosen. The efficiency enhancement of the device in the presence of In_2S_3 nanoparticles can be seen to arise chiefly from an increase in Jsc. For proper comparison of the respective effects, dye synthesized solar cells with 5, 10, and 15% W/V of In_2S_3 nanoparticles dispersed in ethanol were produced and thoroughly examined.

The devices were assembled with different weight percent of of In_2S_3 nanoparticles from 5 % to 15%. These devices were fabricated and measured under AM 1.5 illuminations at 100 mW/cm^2. Corresponding current density versus voltage (J–V) curve and details of DSCs based on the different weight percent of In_2S_3 nanoparticles are reported in Fig. 4 and Table 1.

The best efficiency of cells which immersed in 5 % of In_2S_3 nanoparticles for 2 min was 7.1% (average efficiency was 7.0%). It shows 39% improvement compared to reference cells (5.1%). 8.0% efficiency (average 7.7) was achieved by increasing In_2S_3 concentration into 10 % for 2 min. When photoanodes immersed in 15% of In_2S_3, efficiency decreased to 3.2%. At first, by increasing the concentration of co-sensitizer to 10%, efficiency increased sufficiently while high concentrations of co-sensitizer can act as trap center and decrease the efficiency. Therefore, efficiency decreased to 4.2 (average 3.4) in the present of 15% co-sensitizer. Fig. 5 shows how Jsc, V_{OC}, FF and efficiency are changed by increasing weight percentage of co-sensitizer.

The possible mechanism for increasing the efficiency of dye sensitized solar cell including In_2S_3 nanoparticles schematically illustrated in Fig. 6. As seen from the figure, In_2S_3 nanoparticles can transfer electrons to the conduction band of TiO_2 and improve Jsc. The treatment time for immersing photoanode in In_2S_3 solution was optimized. Three treatment time (1, 2, and 3 min) were investigated. As seen in Fig. 7, optimum treatment

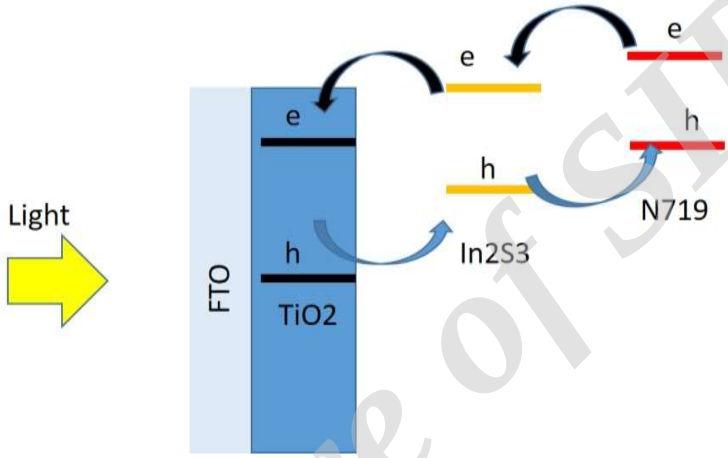

Fig. 6. The possible mechanism for improve efficiency of DSSCs by using In_2S_3 as co-sensitizer.

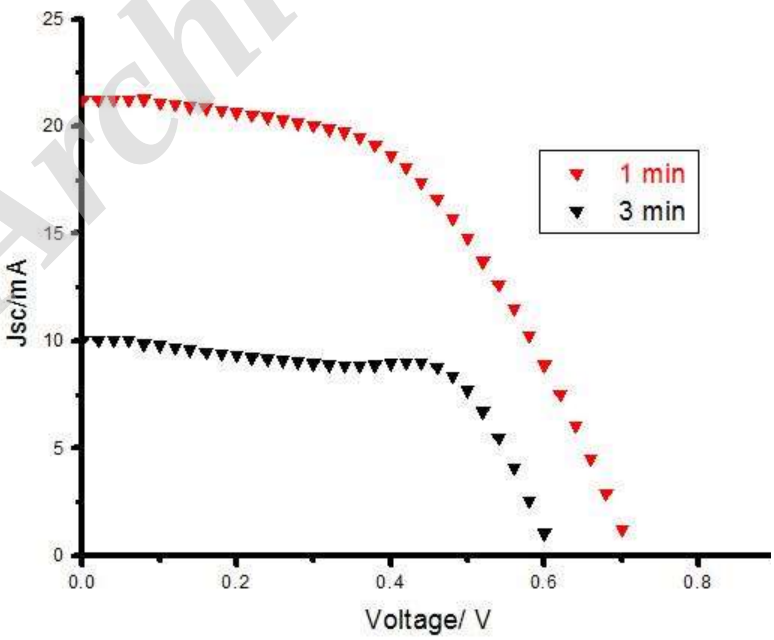

Fig. 7. Solar cell performance parameters of devices with different time treatment of In_2S_3 under AM 1.5.

time is 2 min. Treatment time has the same effect as concentration of In_2S_3. The efficiency of the devices with 1 min treatment was 6% (average 5.9%) which shows better performance compared to reference cells and efficiency of cells with 2 min treatment was 7.1% while increasing time treatment to 3 min showed the reverse effect on performance of DSSCs (Fig. 7 and Table 1). Fig. 8 shows how Jsc, V_{OC}, FF and efficiency are changed by increasing time treatment of co-sensitizer.

In addition, we investigated the effect of In_2S_3 nanoparticles prepared under different ultrasonic power and time on the performance of DSSCs. Fig. 9 shows the results. According to the Fig. 9, solar cell including sample 2 has the best efficiency. This may happens because sample 2 has uniform size.

CONCLUSION

In summary, In_2S_3 nanoparticles successfully prepared by sonochemistry method. The effect of different parameters such as power and time on size of products were investigated. For the first time, In_2S_3 nanoparticles was successfully used as co-sensitizer in DSSCs. The fabricated solar cells made by different samples in the same conditions shown different Jsc, Voc, FF and efficiency. It was

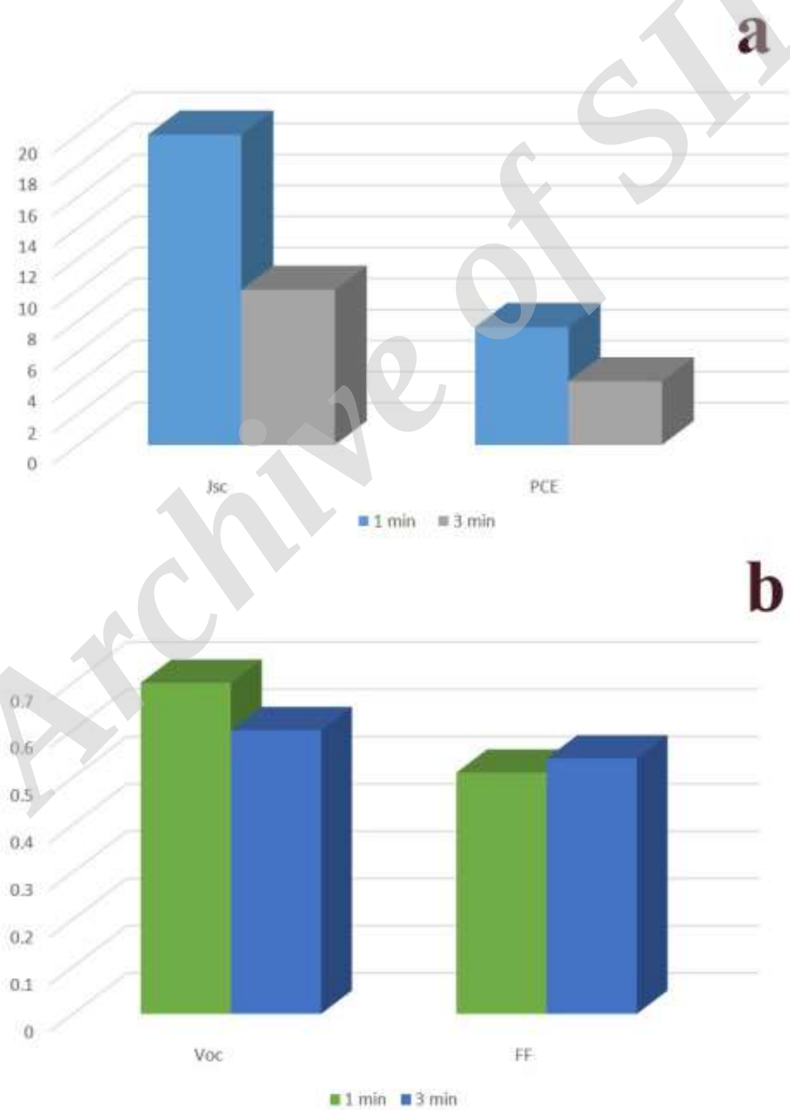

Fig. 8. The effect of time treatment of In_2S_3 on a) Jsc and PCE and b) Voc and FF.

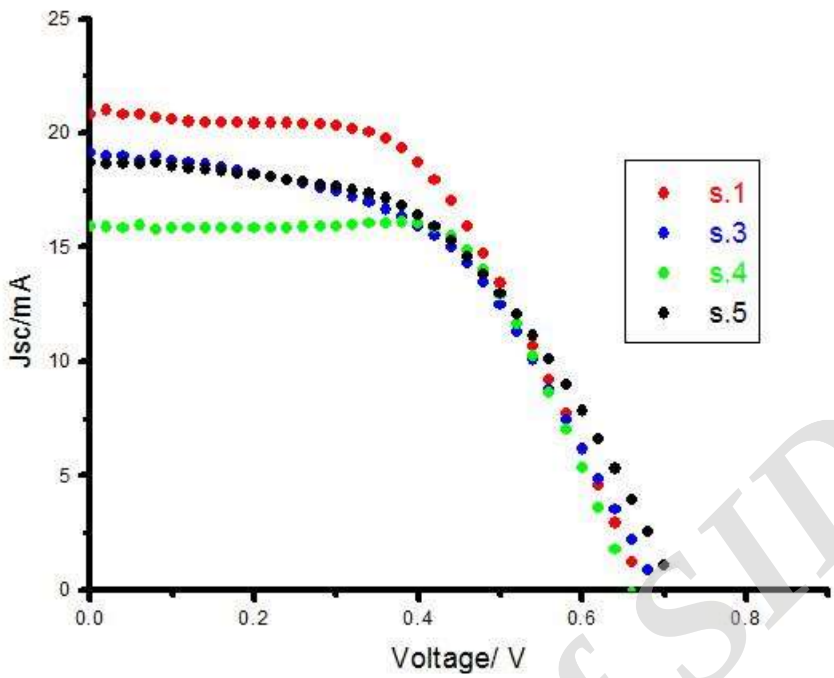

Fig. 9. Solar cell performance parameters of devices made by different In_2S_3 samples.

found that 10% of In_2S_3 nanoparticles and 2 min treatment is the best condition for fabrication DSSC with the best performance.

ACKNOWLEDGEMENT

The authors express gratitude and thanks to Kashan University and the Iranian Nanotechnology Initiative for supporting this study.

CONFLICT OF INTEREST

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

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