Substrate Temperature Effect on Photovoltaic Performance of Lead Sulfide (PbS) Nanostructures Deposited by Chemical Vapor Deposition (CVD) method

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ABSTRACT:
PbS nanostructures for solar cell application, deposited in different substrate temperatures by CVD method. FESEM images show nanostructures with rod and spherical volumes and porous surface for samples. XRD analysis verified formation of cubic crystalline nanostructures. Photovoltaic measurements also shown that with increasing in substrate temperature, efficiency conversion of cells was increased.

KEYWORDS: PbS Nanostructures, Chemical Vapor Deposition, Photovoltaic, Solar Cells, Quality Parameters.

1. INTRODUCTION
At the moment, inescapable depletion of fossil fuels and the increasing energy demand to support the current model of economic growth, mankind is facing a global energy problem. On the other hand, the use of fossil fuels leads to infection problems, which is very important today. Among a number of alternative resources, renewable energies are rapidly becoming the leading solution to fulfill the growing needs of power sources. And in the renewable energy sources, solar energy is considered the most promising renewable resource. Every day, the sun shines on the earth, thus providing around 3×10^{24} J of green energy per year [1].

This is the energy equivalent that the 4.9×10^{14} barrels of crude oil can be produced. Solar cells can be easily installed anywhere and pay to the producing of electrical energy. For example, they can easily be providing the electric power of telecommunication towers that installed in the desert and arduous areas. Today's solar cells are made mainly of semiconductor materials. Therefore, research on the characteristics of the semiconductors used in solar cells plays a prominent role. PbS is an amazing, favourite material that has recently received great attention as a potential for the material of photovoltaic cells (PVCs) as a result of its near-optimal energy band gap and high optical absorption coefficient [2-4]. To the best of our knowledge, the study of photovoltaic properties of PbS thin films by modify chemical vapour deposition methods have not been reported yet. Therefore, in the current study, we investigate and present the effect of substrate temperatures on photovoltaic properties of PbS thin films.

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2. EXPERIMENTAL SECTION

2.1. Synthesis
Deposition details completely described in our previous work [5]. Here is a comparison between of samples that synthesized with Ar/H_2 as carrier gas but they have different substrate temperatures. Their substrate temperatures are 300 °C, 330 °C and 360 °C, respectively.

2.2. Device fabrications and characterizations
Primary characterizations method description in previous work, too [5]. Photovoltaic device fabrication is like to the other pervious work for PbTe nanostructures [6]. The solar cell measurement was carried out under 100 mW/cm^2 (1.5 Air Mass)

illumination from a solar simulator (Solar cell simulator IIIS-200+, Nanosat Co. Iran). A 100-W xenon lamp served as a light source, and the intensity of the light was calibrated using a standard silicon solar cell. The effective surface of the samples exposed to the light is 0.25 cm^2.

3. RESULTS AND DISCUSIONS

Figure 1 show FESEM image of PbS thin films at different substrate temperatures. As we seen in this image, in 300 °C (Fig. 1a) we have a rod and spherical volumes with average diameter of 28±5 nm and 52±5

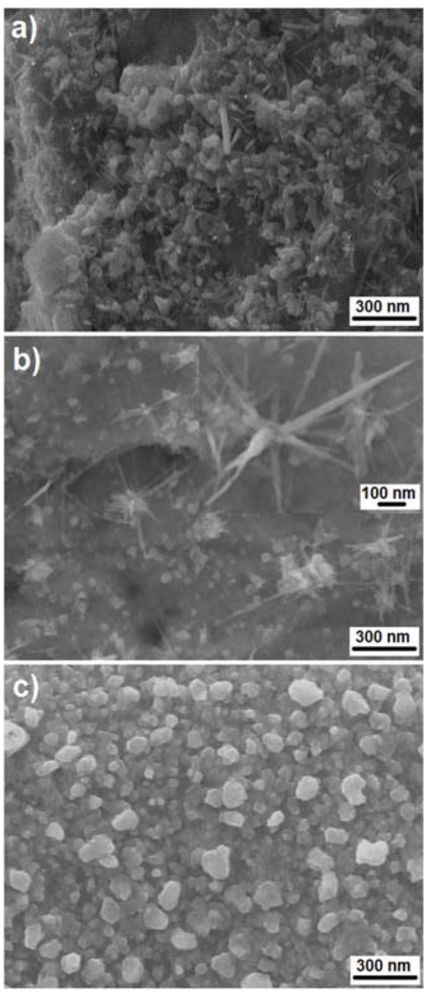

Fig. 1. FESEM image of PbS thin films synthesized at substrate temperature of a) 300 °C, b) 330 °C and c) 360 °C.

nm. In temperature of 330 °C (Fig. 1b) we seen rods that are tapered, with tip diameters of 20±5 nm and base diameters of 100±5 nm and finally in 360 °C (Fig. 1c) we have a dense porous morphology with a particle like morphology on surface of them that average diameter of 83±5 nm. So we can claim that we growth PbS nanostructures. With increasing in substrate temperature, the size of nanostructures increased and morphology varied to the porous. Usually, anion concentration is the most important factor to obtain different morphology in metal-chalcogenide nanostructures [7].

For all samples, XRD analysis verified formation of cubic PbS structures according to the standard card of bulk PbS (JCPDS Card No. 05-0592).

Figure 2 shows the *J–V* curves of solar cells fabricated form the PbS nanostructures. Quality parameter (QP) of solar cell can be calculated form below equations [8]

$$FF = \frac{V_{max} I_{max}}{V_{oc} I_{sc}} \quad (1)$$

$$\eta = \frac{V_{oc} I_{sc} FF}{P_{in}} \quad (2)$$

The quality parameters are given in Table 2. Results show that the solar cell synthesized at 360 °C, had the efficiency and lowest fill factor (FF).

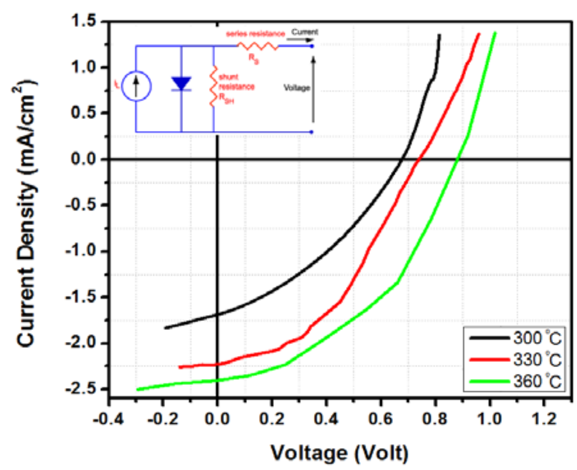

Fig. 2. J-V curve of PbS thin films synthesized at different substrate temperatures. Inset shows equivalent circuit of a solar cell.

FF for silicon and dye-sensitized solar cell was 0.8 and 0.7, respectively. However, if FF is less than 0.6, indicates that recombination has happened in the solar cells and electron-hole pairs are recombination after generation and not transmitted to the external circuit [9]. Based on the results in Table 1, with increasing in substrate temperature, FF factor increased. For binary p-type semiconductors such as PbS, FF value affected by the light absorption and effective hole carrier density of the absorber [10]. The light absorption is strongly dependent on the band gap of absorbers. So it seems that with increasing in substrate temperature, optical energy band gap and carrier concentration of PbS thin films increases, too. A UV-Visible and Mott-Schottky analysis for probing about variations of the optical energy band gap and carrier concentration can be helpful, respectively.

Table 1. QP parameters of PbS thin films synthesized at different substrate temperatures.

Sample/QP	FF	Efficiency (%)
300 °C	0.36	0.40
330 °C	0.42	0.70
360 °C	0.43	0.89

The efficiency of PbS thin film solar cells increased with increasing in substrate temperatures like FF. it seems that porous morphology that can be obtain with increases in temperature in this work, is better for PbS thin films based solar cell. The other important points to be considered in order to improve PbS solar cell efficiency are include band alignment and density of defect states at PbS/buffer interface, PbS bulk defects and secondary phases formation, short minority carrier lifetime and diffusion length and PbS-back contact and solar cell configuration [11].

4. CONCLUSIOS

A study on QPs of PbS thin film based solar cell provided. Morphological studies shows PbS thin films have a nano-dimonsion surface morphology. FF and efficiency of solar cell increased, with increasing in substrate temperature. This increase is related to the the increased of light absorption and effective hole carrier density of the absorber layer (PbS thin films) that has been by an porous morphology.

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