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Studies of Power Conversion Efficiency and Optical Properties of $Ni_3Pb_2S_2$ Thin Films

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Abstract

$Ni_3Pb_2S_2$ thin films were prepared by using a chemical bath deposition method. In this work, solar cells were fabricated using these materials as absorber layers. Power conversion efficiency testing will be carried out. The results show that these absorbent materials exhibit an open circuit voltage of 0.61 V, a short circuit current density of 9.9 mA/cm^2, a fill factor of 0.47 and a power conversion efficiency of 2.7%.

Abstrak

Kajian Efisiensi Konversi Tenaga dan Sifat Optik dari Lapisan Tipis $Ni_3Pb_2S_2$. Lapisan tipis $Ni_3Pb_2S_2$ dibuat dengan menggunakan metode deposisi bak kimia (CBD). Dalam penelitian ini, sel solar diproduksi dengan menggunakan material-material ini sebagai lapisan penyerap. Uji efisiensi konversi tenaga juga dilakukan. Hasil menunjukkan bahwa material absorben ini menghasilkan *open circuit voltage* sebesar 0,6V, *short circuit current density* 9,9 mA/cm^2*, fill factor 0,47,* dan efisiensi konversi tenaga sebesar 2,7%.

Keywords: *chemical bath deposition, power conversion efficiency, short circuit current density, thin films*

Introduction

Currently, the photovoltaic market is dominated by silicon technologies due to their reliability and cost-efficiency. However, silicon-based solar cells are much more expensive than thin film-based solar cells. When a solar cell is naturally illuminated with sunlight, it converts the solar energy into electrical energy. Many researchers have reported using metal chalcogenide thin films as a photovoltaic absorber material [1-12]. Its power conversion efficiency is assessed using the ratio of electrical power produced to the energy of the incident solar radiation. This value depends on the quality of the photovoltaic absorber material used to fabricate the solar cells as described by several scientists [13-17]. Thin film-based solar cells were classified as second generation solar cells. Cadmium telluride [18-21] and copper indium gallium diselenide thin films [22-25] have been intensively investigated by many researchers and are commercially successful, being used in several technologies. The thickness of these films may vary between a few nanometers and a few tens of micrometers, much thinner than silicon-based technology.

Table 1. Power Conversion Efficiency of Thin Films

Thin films	Power conversion efficiency (%)	References
SnS	4.4	[26]
InSe	0.5	[27]
CdSe	0.7	[28]
PbS	0.04	[29]
MnCdSe	0.37	[28]
Cu_2SnS_3	4.3	[30]
Cu_2SnS_3	1.4	[31]
Cu_2SnS_3	2.4	[32]
Cu_2ZnSnS_4	5.7	[33]
Cu_2ZnSnS_4	2.6	[34]
Cu_2ZnSnS_4	6.8	[35]
Cu_2ZnSnS_4	4.1	[36]
Cu_2ZnSnS_4	0.2	[37]
Cu_2ZnSnS_4	3.2	[38]
Cu_2ZnSnS_4	3.4	[39]
Cu_2ZnSnS_4	0.4	[40]
Cu_2ZnSnS_4	6.0	[41]
Cu_2ZnSnS_4	0.1	[42]

Here, $Ni_3Pb_2S_2$ films were prepared onto soda lime glass substrate via chemical bath deposition. The photovoltaic characteristics were investigated for the first time by using these materials as an absorber. The power conversion efficiency of various types of thin films has been reported by many researchers, as shown in Table 1. The obtained films were studied under one sun, AM 1.5 illuminations. The solar cell device was designed with fluorine doped tin oxide (FTO) coated glass, cadmium sulfide, a titanium dioxide (TiO_2) buffer layer and an absorber layer.

Materials and Methods

$Ni_3Pb_2S_2$ thin films were grown on soda lime glass by using a chemical bath deposition method. Before depositing the films, the glasses were ultrasonically washed with ethanol and finally with deionized water. During the deposition process, the soda lime glass was placed vertically at the bottom of the beaker. The composition of the beaker contained some precursors such as 0.08 M nickel (II) sulfate, 0.08 M lead (II) nitrate, and 0.08 M sodium thiosulfate, which were used as sources of Ni^{2+}, Pb^{2+} and S^{2-} ions, respectively. The chemical reaction was carried out at a pH of 1.6 and bath temperature of 65 °C. After 75 minutes, the deposited films were removed, washed with distilled water, and dried in a desiccator.

In terms of study photovoltaic characteristics, current voltage measurements were carried out under a simulated AM1.5 Global spectrums. Open voltage potential, short circuit current, fill factor and power conversion efficiency were studied at one sun (1000 W/m^2 irradiation). Optical absorption study was also carried out using the Perkin Elmer UV/Vis Lambda 20 Spectrophotometer.

Results and Discussion

The structure and morphology of the obtained films were investigated using an X-ray diffraction technique, atomic force microscopy and scanning electron microscopy, as described in earlier works [43,44]. Figure 1 shows the X-ray diffraction (XRD) pattern of obtained films prepared using chemical bath deposition. These films indicate a strong preferred orientation along the (012) plane of the rhombohedral phase of $Ni_3Pb_2S_2$. The other diffraction peaks, such as (042) and (1010) can also be seen in Figure 1. The obtained XRD data agrees with standard JCPDS patterns (00-006-0459). Figure 2 shows the two-dimensional representation of a 10 µm x 10 µm area of the $Ni_3Pb_2S_2$ thin films. The topography of thin films was studied using atomic force microscopy (AFM). Initial visual investigations of the deposited films suggested that they have good adherence to the substrate. The obtained films are uniform, densely packed and pinhole free. The grains are made of different sizes varying from 0.5-1 µm The ultraviolet-visible absorption spectrum of $Ni_3Pb_2S_2$ films is shown in Figure 3. The films' absorption range covers 300 to 900 nm, as indicated in the figure. The absorption of the films was found to be high in the ultraviolet region, but the films displayed low absorbance in the visible or near-infrared region of up to 900 nm. On the other hand, the optical

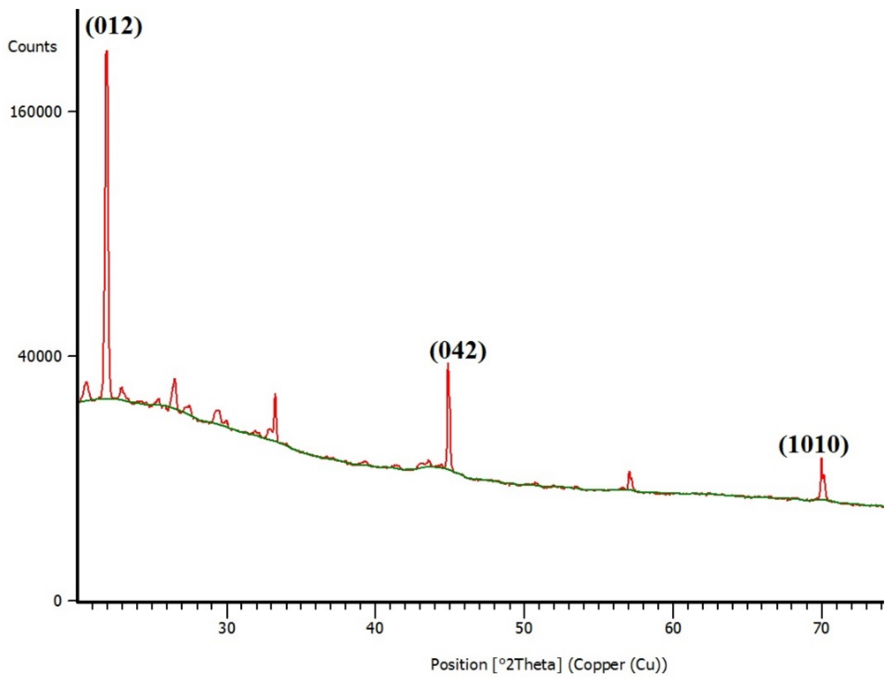

Figure 1. The Typical x-ray Diffraction Pattern of $Ni_3Pb_2S_2$ Thin Films

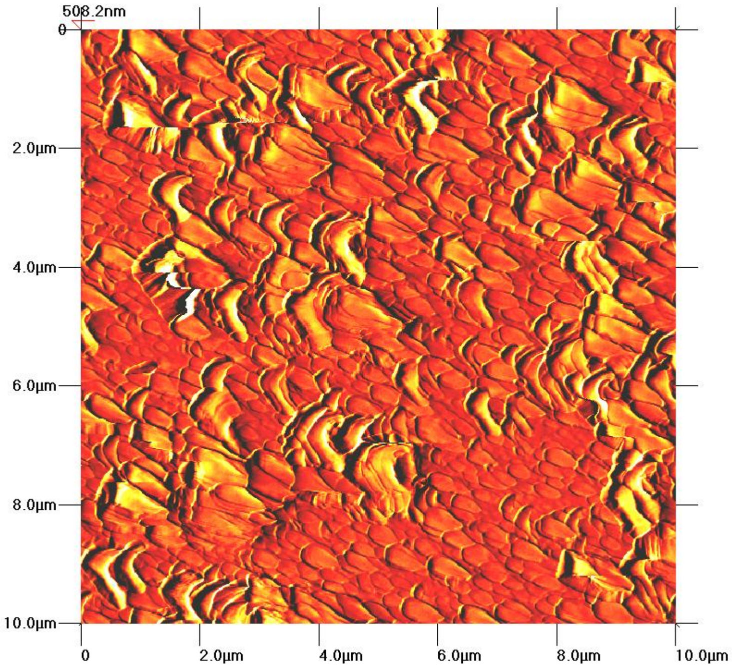

Figure 2. Atomic Force Microscopy Image of $Ni_3Pb_2S_2$ Thin Films

band gap energy value of the films deposited in a chemical bath was studied from the absorption spectrum using the following relationship (Eq. 1):

$$A = \frac{[k(hv - E_g)^{n/2}}{hv} \quad (1)$$

Where v is frequency, h is Planck's constant and k is a constant value. In this study, n=1 for direct transition and n=4 for indirect transition. The graph of $(Ahv)^2$ versus photon energy was plotted in Figure 4. The band gap energy was found to be 1.4 eV after plotting an extra linear line, indicating that these films absorb a broad range of the light spectrum, such as infrared, ultraviolet and visible light.

Many scientists describe the preparation of metal chalcogenide thin films by using different deposition techniques, including vacuum-based methods [45-48] and solution-based methods [49-57]. According to their experimental results, some of them have successfully designed thin film solar cells with power conversion efficiency between 0.12 % and 5.74%, as reported in Table 1.

In this study, heterojunction photovoltaic cells based on $Ni_3Pb_2S_2$ films were fabricated as shown in Figure 5. The FTO glass will be used for its transparency, better conductivity and stability when heated compared to other glasses. The TiO_2 buffer layer was used to enhance the solar cells' photovoltaic performance. Generally, charge recombination at an electrode/electrolyte interface is the main factor to limit solar cells' power conversion efficiency. Thin films solar cells have become one of the most promising methods for tackling modern energy

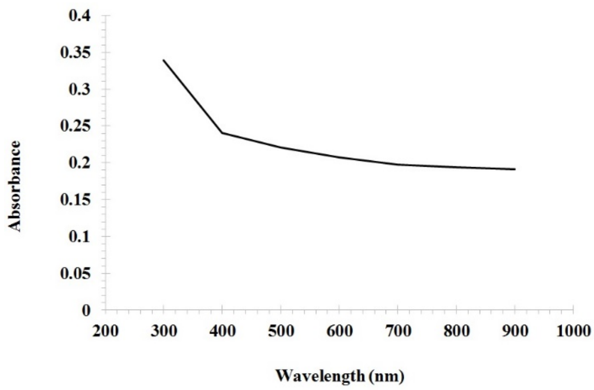

Figure 3. Absorption Spectrum of $Ni_3Pb_2S_2$ Thin Films

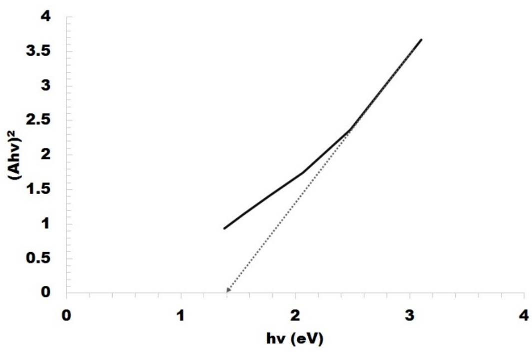

Figure 4. $(Ahv)^2$ Versus hv Plot of $Ni_3Pb_2S_2$ Thin Films

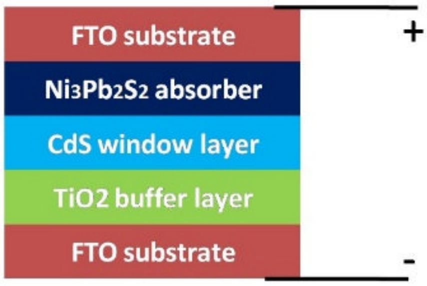

Figure 5. Schematic of Solar Cell Device

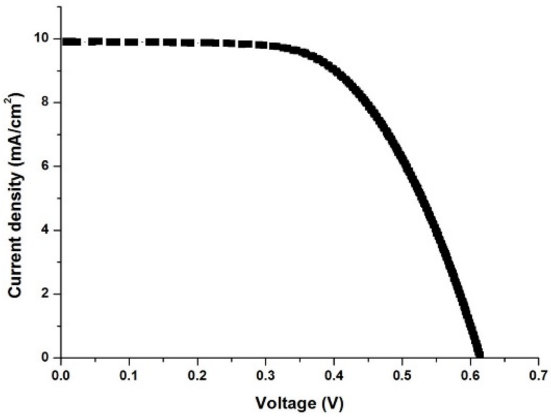

Figure 6. I-V Characteristics of Solar Cell Device

issues by boasting a low production cost, low material cost and large area fabrication. Simulation was performed to investigate the photovoltaic characteristics of obtained films, and the I-V characteristics of the solar cell device are shown in Figure 6. The device indicated an open circuit voltage (V_{OC}) of 0.61 eV and short circuit current (J_{CS}) of 9.9 $mAcm^{-2}$. These absorbers demonstrate a 2.7% conversion efficiency with a fill factor (FF) of 0.47.

Conclusions

$Ni_3Pb_2S_2$ photovoltaic materials were synthesized using a chemical bath deposition technique. Their power conversion efficiency and optical properties were investigated. The power conversion efficiency of the obtained films is 2.7%.

Acknowledgments

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