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# The Characterizations and Studies of Chemical Bath Deposited $Ni_3Pb_2S_2$ Thin Films for Solar Cell

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## Abstract

Currently, thin films have high potential for use in optoelectronic and solar cell applications due to appropriate band gap value. There are many deposition techniques have been used to prepare thin films including physical and chemical method. Chemical bath deposition technique was used to produce thin films. This technique has many advantages such as can control film thickness, quality of sample, and deposition rate. In this work, $Ni_3Pb_2S_2$ films were deposited onto glass slide from aqueous solutions. Characterization of obtained films were investigated by using various tools. X-ray diffraction, atomic force microscopy and UV-visible spectrophotometer were employed to investigate the structure, topography and optical properties of films. Photovoltaic parameters were studied using a simulated AM1.5 Global spectrums. The obtained nanostructured thin films indicated band gap of 1.4 eV. Optical properties exhibited higher absorption in ultraviolet region, while lower absorption could be observed in infrared region. These ternary compounds indicated efficiency of 2.7 % based on power conversion efficiency testing.


**Keywords**
Thin film, Solar cell, Band gap, Power conversion efficiency

## Introduction

Thin films have received a great attention because of high potential to be used in solar cell applications [Lee & Luo 2019; Subhash & Mahendra 2019]. Nowadays, silicon technology [Di et al., 2019; Zhuang et al., 2019] and thin film based technologies contributed into solar cell market. Silicon based solar cell has many advantages [Jong et al., 2019; Yang et al., 2019] such as high power conversion efficiency [Jan et al., 2018] and displayed better performance in low light conditions. Therefore, successfully dominated global photovoltaic shares [Cham et al., 2018]. However, the big issue is more expensive [Takuya et al., 2018; Florian et al., 2018] if compared to thin film technologies. Researchers have described that thin film based solar cell as second generation photovoltaic cell [Zhu et al., 2019; Liang et al., 2019; Victoria et al., 2019]. For example, cadmium telluride [Kazi et al., 2019; Amit et al., 2018; Hossain et al., 2019; Patel et al., 2019] and copper indium gallium diselenide [Tobias & Marika 2009; Chung & Chuan 2012; Craig et al., 2017; Pierre et al., 2017] thin films have been prepared using

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various deposition methods. These films with thickness (few nanometers to few tens of micrometers) were employed in solar cell applications. Following that, there are many researchers have synthesized various thin films such as MnS [Dhandayuthapani et al., 2017], FeS [Anuar et al., 2010], $MnS_2$ [Abdullah et al., 2010], $Sb_2Se_3$ [Yu et al., 2019], CdZnSe [Ham et al., 2008], NiSe [Ho et al., 2011], PbSe [Kassim et al., 2010], PbTe [Ibrahim et al., 2009], ZnTe [Klapetek et al., 2003] as a photovoltaic absorber material. Metal chalcogenide thin films are low-cost and easy fabrication. Researchers have highlighted that the best band gap energy of metal chalcogenide is about 1.5 eV, indicating these films absorb a very broad range of the light spectrum. Literature showed that synthesis of nickel sulfide [Yue et al., 2014; Christine et al., 2017; Nan et al., 2014; Ko et al., 2018; Mgabi et al., 2014] and lead sulfide films [Ikhioya et al., 2017; Nair et al., 1992; Moe et al., 2017; Veena et al., 2017] have been deposited onto various substrates. For this reason, these elements were used to produce ternary compound in my project.

In this work, ternary compound such as $Ni_3Pb_2S_2$ films were deposited onto cleaned glass substrate (soda lime glass) by using chemical bath deposition. The optimized experimental conditions were described in order to obtain good quality of films. Power conversion and band gap of obtained films were investigated.

## Methodology

$Ni_3Pb_2S_2$ films were grown onto soda lime glass during the chemical bath deposition process. It was washed with ethanol and deionized water in order to remove undesired matter on the surface of glass. All chemicals used were analytical reagents and purchased from Fisher Scientific. Chemical bath contains 25 mL of 0.08 M nickel (II) sulfate, 25 mL of 0.08 M lead (II) nitrate, and 25 mL of 0.08 M sodium thiosulfate solutions. Glass slide was put vertically into bath during the deposition process at pH 1.6, at 65 °C. The sample was removed from bath after 75 minutes, washed with water and put in oven.

Structure, optical and morphology of films were studied by using X-ray diffraction, UV-visible spectrophotometer (Lambda 35) and atomic force microscopy (Q-Scope 250 in contact mode with commercial $Si_3N_4$ cantilever), respectively. The PANalytical X-Pert PW 3040 diffractometer equipped with a CuKα (λ=0.15418 nm) radiation source. Data were collected by step scanning from 10° to 90° with a step size of 0.026° (2θ). Photovoltaic parameters were studied using a simulated AM1.5 Global spectrums.

## Results and Discussion

In this work, atomic force microscopy and x-ray diffraction technique were used to study the morphology and structure of obtained films. Figure 1 indicates atomic force microscopy image, which scan area was 10 µm X 10 µm. The observation was excellent adherence to the surface of substrate. Furthermore, pinhole free, uniform surface with various sizes (0.5-1 µm) could be seen. Figure 2 shows the XRD pattern of chemical bath deposited films. The major peak was (012) plane because has higher intensity if compared to (042) and (1010) planes. The XRD data supported the existence of rhombohedral phase of $Ni_3Pb_2S_2$. The obtained d-spacing values are match well with standard JCPDS patterns (00-006-0459).

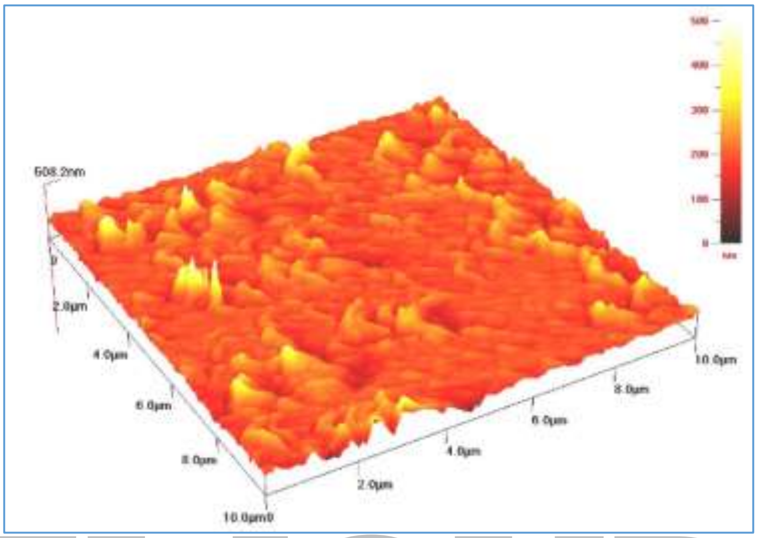


Figure 1. Atomic force microscopy image of chemical bath deposited $Ni_3Pb_2S_2$ thin films



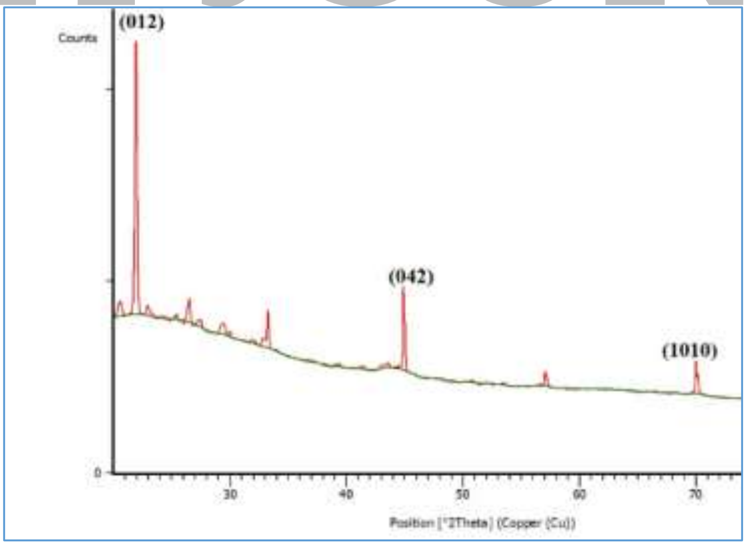


Figure 2: X-ray diffraction pattern of chemical bath deposited $Ni_3Pb_2S_2$ thin films

The optical properties of films were investigated using UV-Visible spectrophotometer in the range of 300-800 nm. The spectrum significantly exhibits higher absorption in ultraviolet region. However, low absorption value in infrared region as shown in figure 3. The band gap was calculated using the absorption spectrum.

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

In this equation, *v, h and k* is defined as frequency, Planck's constant and constant value, respectively. Observation showing that direct transition and indirect transition could be seen when the *n*=1, and *n*=4, respectively. The band gap energy was determined and about 1.4 eV after plotting an extra linear line (Figure 4), when *n*=4 was selected.

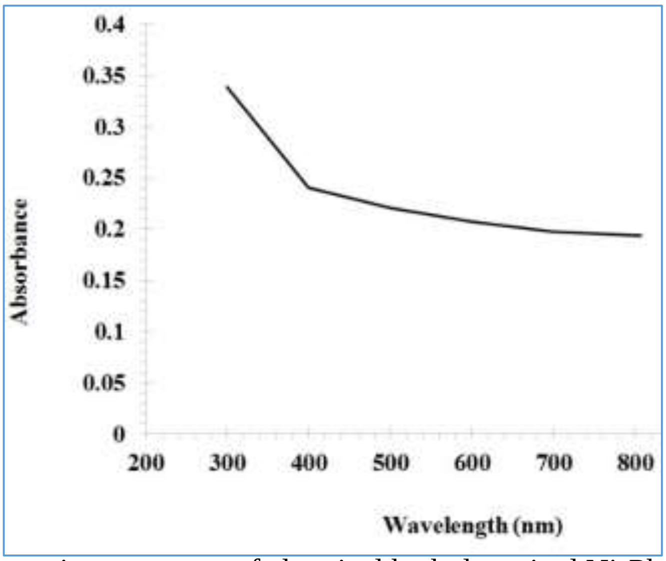


Figure 3. Absorption spectrum of chemical bath deposited $Ni_3Pb_2S_2$ thin films

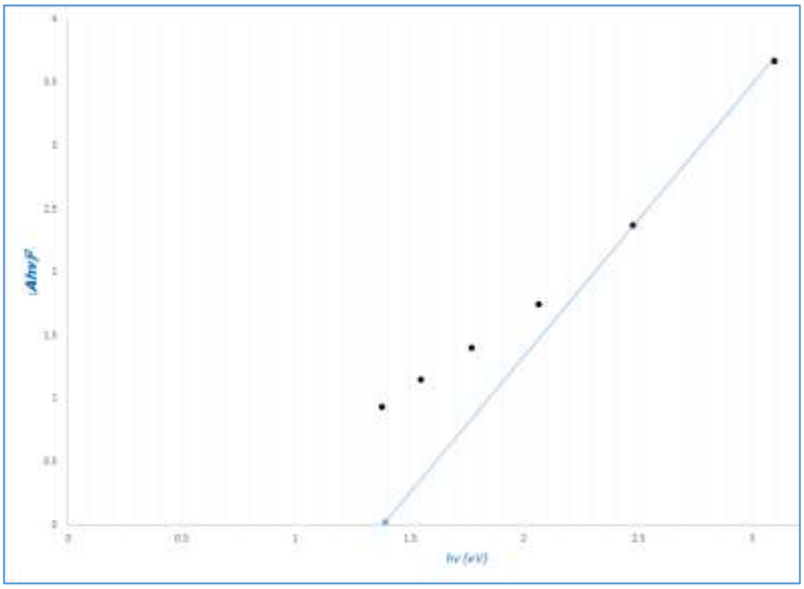

Figure 4. $(Ahv)^2$ versus *hv* plot of chemical bath deposited $Ni_3Pb_2S_2$ thin films



There are many researchers have reported the preparation of metal chalcogenide thin films. The photovoltaic characteristics were investigated and the power conversion efficiencies were described. The solar cell was fabricated and the obtained films were investigated under one sun, AM 1.5 illuminations. For example, solar conversion efficiencies of SnS, InSe, CdSe, PbS, MnCdSe, $Cu_2SnS_3$ and $Cu_2ZnSnS_4$ films are 4.4 % [Jaramillo et al., 2015], 0.5 % [Teena et al., 2017], 0.7 % [Shinde et al., 2014], 0.04 % [Barote et al., 2011], 0.37 % [Shinde et al., 2014], 1.4 -4.3 % [Ayaka et al., 2015; In et al., 2016; He et al., 2017] and 0.1 – 6.8 % [Schubert et al., 2011; Wang et al., 2010; Kazuo et al., 2007; Hironori et al., 2001], respectively.

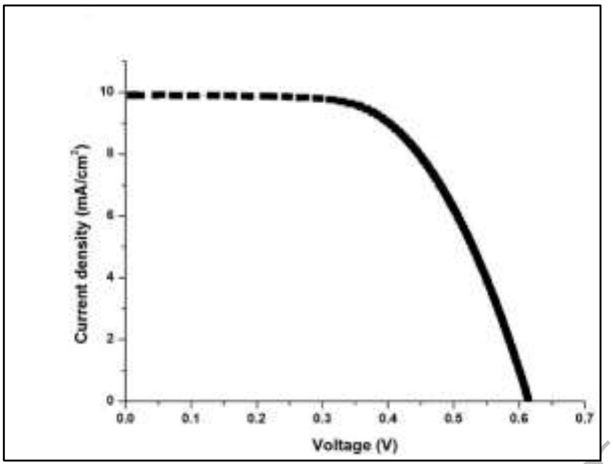


Figure 5. *I-V* characteristics of solar cell device

In this work, heterojunction photovoltaic cell was fabricated. The obtained $Ni_3Pb_2S_2$ films acted as absorbing material. The photovoltaic parameters were investigated. The I-V characteristics (Figure 5) indicated an open circuit voltage of 0.61 eV and short circuit current of 9.9 $mAcm^-{}_2$. The experimental results showed power conversion efficiency and fill factor are 2.7 % and 0.47, respectively.

## Conclusions

Chemical bath deposition of $Ni_3Pb_2S_2$ thin films onto soda lime glass substrate was reported. These ternary compounds have band gap of 1.4 eV. The obtained films could be used as absorbent materials and indicated power conversion efficiency of 2.7 %.

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