Preparation and optical properties study of CuO thin film as applied solar cell on LAPAN-IPB Satellite

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Abstract

In this study, copper oxide (CuO) thin films were deposited by chemical solution deposition (CSD) method with layer variation to observed and determined crystal structure and optical properties of CuO films. The crystal structure of films was characterized by X-ray diffraction (XRD). The optical properties were studied with annealing temperatures 350°C, 450°C, and 550°C by spectrophotometer VIS-NIR. Absorbance spectra showed that CuO film has absorbance in the visible region. Band gap energy of CuO is found to decrease from 2.05 – 1.89 eV as a result of the increasing annealing temperature. The result of this study concludes that CuO thin film has the potential to be developed as solar cell on of LAPAN IPB satellite.

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1. Introduction

Solar cell is a material with high potential as an energy source in the application of technology in the future. In 1839, Edmond Becquerel found that two different brass plates immersed in a liquid produced a continuous current when illuminated with sunlight [1]. The traditional solar cell electricity applications were at remote locations where utility power was unavailable, for example, campers and boats, temporary power needs for disaster situations, and power for remote communication station repeaters. Solar cells began to be routinely used to provide site-specific energy for urban and suburban homes, office buildings, and a multitude of other mainstream grid-connected applications. Also, solar cell electricity systems have become very important sources of energy in the developing world. Today, for an increasing number of power needs, solar cell electricity is the cheapest and best way to generate electricity [2].

Solar cell technology is beset with two major challenges today and these challenges have limited their widespread use for several decades. The cost of manufacturing solar cell components is very high making it very expensive and the operational efficiency (the percentage of converted solar power) is 30% which is extremely low. In solar cell technology, there are some materials that can be used as its base material. Three of them are CulnSe2 (or its alloys such as CulnS2 or CulnGaSe2), CdTe and amorphous silicon materials, CuO or Cu2O have visible region [3-6]. These materials only require one micron thickness to establish efficient solar cells, due to their high light absorption [7].

Copper oxide (CuO) is a semiconductor material which many application for fabrication of photovoltaic solar cells [8]. The features of copper oxide semiconductors are high optical absorption and nontoxic and low cost fabrication [9]. CuO are p-type semiconductors with band gaps 1.5 – 1.8 eV for indirect transition and 1.9 eV for direct transition which are close to the ideal energy gap for solar cells and allows for good solar spectral absorption due to this direct band gap [1-3]. The investigations carried out concern mainly its growth, optical properties, electrical properties.

CuO thin films have been prepared using various thin film deposition techniques such as chemical vapour deposition, vacuum evaporation, electro-deposition, thermal oxidation, sputtering process, electron-beam evaporation, chemical solution deposition (CSD) [10-13]. CSD method is of particular interest because of its good control of stoichiometry, ease of fabrication and low temperature synthesis. Since it is relatively new, hence a greater understanding is required before the film quality can be optimized. It was reported that CSD derived thin films are thermodynamically stable [14-15]. This method is also known as the sol-gel method. Preparation of CuO film using chemical solution deposition (CSD) with annealing temperature variation and optical properties have been studied. The objectives of this study are observe the crystal structure, investigate the absorbance of CuO films with layer variation, and determine band gap energy with annealing variation.

2. Experimental Method

CuO thin film has been synthesized by sol-gel method. Copper acetate (Cu(CH3COO)2, 99%) was dissolved in ethanol (C2H5OH) 96% with 0.3 M concentration and stirring for 30 minutes. Then, 0.25 ml diethanolamine (C4H11NO2, >98%) was added to the solution and stirring again for 30 minutes. Finally, 1 ml ethylene glycol (C2H6O2, >= 99%) was mixed to the solution and continuously stirred for 1 hours. Quartz glass as substrate was cleaned in acetone solution and was vibrated use ultrasonic cleaning bath for 1 hours. Films were prepared by depositing the solution onto quartz glass. Coating thin film use spin coating technique. A thin layer was spin-coated at 3000 rpm on substrate for 40 s and was dried on hotplate for 10 minutes in air. This process was repeated for the next layer. There were three sets of the samples: 1 layer, 2 layers, and 3 layers.

Films with variation layer were annealed for 1 hours in an air atmosphere using furnace Vulcan model 3-130. CuO films were annealed at 350°C, 450°C and 550°C. The structural properties of the films were investigated by means of X-ray diffraction (XRD) (Shimadzu XRD-7000) using Cu Kα radiation (λ = 1.5406 Å). In this study, film with 3 layers was investigated. The Optical properties of CuO were characterized using Spectrophotometer Vis-NIR USB 1000 Oceanoptic in the range 339 – 1022 nm.
3. Results

The Thickness of CuO was obtained using gravimetric methods. The film thickness \(d\) can be calculated from actual \(m\) mass deposited onto substrate, \(\rho\) density of copper oxide \((6.31 \text{ g/cm}^3)\), and the area of the film \(A\) \([15, 16]\). The formula of gravimetric methods is:

\[
d = \frac{m}{\rho A}
\]  

Fig. 2 shows the thickness of CuO films with annealing variation and layer variation. The increase in thickness of CuO film as a result of increasing the number of layers can be seen from Fig. 2. It was observed that increasing the annealing temperature resulted in a decrease in film thickness from 0.36 \(\mu\)m (350°C annealing) to 0.14 \(\mu\)m (550°C annealing) at 1 layer, 0.62 \(\mu\)m (350°C annealing) to 0.42 \(\mu\)m (550°C annealing) at 2 layers, and 1.16 \(\mu\)m (350°C annealing) to 0.65 \(\mu\)m (550°C annealing) at 3 layers. The increasing annealing temperature result the arrangement of crystal structure and space between atoms shorter.

Fig. 1 Flow diagram for CuO films from sol-gel process
Fig. 2 Thickness of CuO Film

Fig. 3 X-ray diffraction pattern of CuO thin film

![Graph showing the thickness of CuO film at different temperatures.](image)

![Graph showing the X-ray diffraction pattern of CuO thin film.](image)
Fig. 4 Absorbance of CuO with annealing temperature (a) 350°C; (b) 450°C; (c) 550°C

Fig. 5 Band gap energy of CuO with annealing temperature (a) 350°C; (b) 450°C; (c) 550°C
Fig. 3 shows diffraction pattern of CuO films deposited on quartz substrates by spin coating technique annealed at temperatures 350°C. Analysis of diffraction spectra indicates 4 peaks positions for CuO crystal planes, 35.3°, 46.2°, and 53.4°, and 59.3° that were associated with the reflection of CuO (JCPDS no. 44-0706). According the pattern, the annealing temperature at 350°C, small peaks were observed and the film shows a good crystallinity.

The variation of optical absorbance (A) of the CuO film is shown in Fig. 4. This spectrum reveals that as deposited CuO film has high absorbance in the visible region, which is the characteristic of CuO. Wavelength 500 nm to 700 nm has low absorbance, which may be due removal after annealing. The highest absorbance occurs at annealing temperature 550°C. Increasing the number of layer result increasing absorbance for all annealing temperature. This case occurs because the more the number of layers leads more CuO crystal absorb the energy of photon. From this spectrum, the optical absorption coefficients (α) of this film was determined from the spectral absorbance the equation;

$$\alpha = \frac{(2.303)A}{d}$$

(2)

Where d is the film thickness and A is Absorbance of CuO film. The theory of optical absorption gives the relationship between the absorption coefficient (α) and the photon energy (hv) for indirect allowed transition as;

$$\alpha = \frac{(hv - Eg)^2}{hv}$$

(3)

where hv is the photon energy and Eg is the energy gap. These energy gaps are calculated from the intercept straight line on the photon energy (hv) of (αhv)2 versus (hv) plot. According Fig. 5, the band gap energy value is found to decrease from 2.05 - 1.98 eV as a result of the increasing annealing temperature from 350°C - 550°C. The decrease in band gap energy indicates an improvement of the quality of the film due to the annealing out of the structural defects [16]. A shift of the energy gap was mainly due to both the quantum size effect and the existence of an amorphous phase in films. Amorphous phase in films can be reduced with increasing annealing temperature. The increasing temperature provide a more energy in the atoms to growth [16].

4. Conclusions

The CuO films were successfully prepared by sol-gel method with number of layers variation. CuO film were annealed at temperatures 350°C, 450°C, and 550°C. Variation in the number of layers indicated thickness increasing. The absorbance spectra showed CuO films has absorbance in the visible region and the highest spectra of absorbance occurred at temperatures 550°C. The increasing of annealing temperatures lead to decrease band gap energy from 2.05 eV to 1.98 eV. The XRD result that CuO films were formed crystal structure. These results indicate that the CuO film prepared by sol-gel method has the potential to be developed as solar cell on satellites of LAPAN IPB.

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