Research Article

Fabrication and Optoelectrical Properties of IZO/Cu₂O Heterostructure Solar Cells by Thermal Oxidation

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Indium zinc oxide (IZO)/copper oxide (Cu₂O) is a nontoxic nature and an attractive all-oxide candidate for low-cost photovoltaic (PV) applications. The present paper reports on the fabrication of IZO/Cu₂O heterostructure solar cells which the Cu₂O layers were prepared by oxidation of Cu thin films deposited on glass substrate. The measured parameters of cells were the short-circuit current (I_{sc}), the open-circuit voltage (V_{oc}), the maximum output power (P_m), the fill factor (FF), and the efficiency (η), which had values of 0.11 mA, 0.136 V, 5.05 μ W, 0.338, and 0.56%, respectively, under AM 1.5 illumination.

1. Introduction

Cu₂O has long been considered an attractive to silicon, and there are other semiconductors being favored for the fabrication of cheaper solar cells for terrestrial applications [1–4]. The Cu₂O is intrinsically P-type, has a band gap (E_g) of 2.17 eV [5], and is expected to have a maximum theoretical efficiency of 20% [6, 7]. Its advantages include: (1) its nontoxic nature, (2) abundance of the starting material (copper), and (3) cheap production processing. Cuprous oxide is of particular interest in the field of solar energy, because of their low cost, abundance of the starting material (copper), and its nontoxic nature and the light-to-electricity conversion efficiency [8]. IZO/Cu₂O is an attractive all-oxide candidate for low-cost photovoltaic (PV) applications. The indium zinc oxide (IZO) films have been attracting a lot of attention because of good conductivity [9], high optical transparency [10], low deposition temperature, and very smooth surface roughness [11] in comparison with ITO films.

Therefore, Cu₂O thin films can be prepared by various techniques, such as reactive sputtering [12], MOCVD [13], electrochemical deposition [14–17], solution chemical [18–20], and direct oxidation of Cu sheets [21], of which the magnetron sputtering presents many advantages as low-cost approach, large scale, and easy control. Some groups

reported ZnO/Cu₂O solar cells prepared [21, 22]. The efficiency was to be 1–2%. In this work, the effect of the conditions of deposition of the P-type Cu₂O thin films by the radiofrequency magnetron sputtering method is studied; in particular, the effect of changing the temperature and time of annealing to obtain the different performances of P-type Cu₂O thin layers on crystal quality was investigated. Finally, the fabrication and optoelectronic performance of an IZO/Cu₂O solar cell is considered.

2. Experimental

In the study, devices that had copper (Cu) layers of one micron thick were deposited with a purity of 99.995% on a glass substrate by magnetron reactive sputtering from high-purity Cu targets in argon (Ar) gas at a flow rate of 15 sccm and a stable pressure of 3×10^{-3} Torr. The sputtering system consisted of a vacuum chamber with a target and a substrate copper holder, a turbo molecular pump parallel to a rotary pump that provides a high vacuum, a radio frequency (RF) power supply at 13.56 MHz, and mass flow controllers that maintain a steady gas flow rate. The target was cleaned by presputtering with Ar plasma for 5 min prior to each deposition process. In all our Cu deposition

FIGURE 1: Schematic crosssection of the completed structure.

experiments the RF power and the gas pressure were kept constant at 50 W and 3.1×10^{-3} Torr, respectively. The Cu_2O layers were obtained by oxidation of Cu layers annealing at various temperatures for 10 min in air. For easy and convenient characterization of the same material, Cu_2O films were prepared on glass to measure the electronic characteristics by Hall measurements and their absorbance from transmittance spectra. The films' crystallinity was studied by X-ray diffraction (XRD) and exhibits a polycrystalline structure. Indium-oxide-doped zinc oxide (IZO, In:Zn = 1:9) was deposited onto the Cu_2O layer by sputtering, and indium electrodes were formed by the evaporation onto both the surface of the IZO layer and the Cu_2O layer, respectively, to complete IZO/ Cu_2O heterostructure solar cells. Figure 1 shows the crosssection of the completed structure. Additionally, the current density-voltage (J - V) characteristics were determined using a Keithley 2420 programmable source meter under irradiation by a 100 W xenon lamp. Finally, the irradiation power density on the surface of the sample was calibrated as 100 W/m^2 .

3. Results and Discussion

In order to obtain a better understanding of the thermal oxidation mechanism, phase identification was performed. Figure 2 shows the XRD spectrum of the measured Cu_2O films at various temperatures of 300, 400, and 500°C . The XRD diffraction shows that single phase of Cu_2O films is obtained for growth at different thermal oxidation temperature with diffraction peaks at 29.58° and 43.35° corresponding to the (110) and (111) planes of the cubic-structured Cu_2O , respectively. As oxidation temperature increases, the CuO peak decreases and eventually vanished at 500°C . The strong Cu peaks at temperatures below 300°C [23], the sudden stop of mass gain in the using thermogravimetric analysis results, together with the SEM images, imply that a self passivation mechanism may involve in the formation of a compact Cu_2O layer. We employed the X-ray diffraction technique to get main crystalline phases and the possible orientation of crystalline in the films prepared at optimum conditions.

Figure 3 shows the FESEM micrographs of the Cu_2O layers with thermal treatment at various temperatures. The micrographs indicate that the surface of the film

FIGURE 2: X-ray diffraction patterns of the samples with thermal oxidation at various temperatures.

consisted of small particles. The average particle sizes were approximately (a) 70, (b) 100, and (c) 200 nm for 300, 400, and 500°C annealing, respectively. The particle sizes of layer are increases with oxidation temperature increase. That shows thin oxides formed, particularly developed in the grain boundary areas, implying a product of fast-diffusion processes, which might be responsible for the small value of activation energy at oxidation of 500°C [24].

Figure 4 plots both the carrier concentration and the mobility as a function of thermal oxidation annealing temperatures. As the thermal oxidation annealing temperatures are elevated to 500°C , the carrier concentration is likely to decrease, and at the same time, the mobility increases to $5 \text{ cm}^2/\text{Vs}$. That is, a film with relatively high mobility is obtained by thermal oxidation annealing of 400°C samples, although the temperature required to obtain the same mobility by thermal oxidation annealing appears to be slightly higher than in the case that the film is directly formed by oxidation at elevated temperatures such as 400 to 500°C . The increase of mobility shown in Figure 4 may be attributed to this increase of grain size.

Figure 5(a) shows the results of the absorption measurements for the Cu_2O layers with treatment at various annealing temperatures for 10 min. The layers have a very high absorption in visible region resulting in good materials for the solar energy devices. According to this figure, the absorption increased continuously as the annealing temperature increased from 300 to 500°C owing to that the Cu content decreased. Figure 5(b) shows the results of the absorption measurements for the IZO layers. The IZO layer yields an absorption edge at $\sim 3.25 \text{ eV}$. Therefore, the transparent semiconductor IZO layer is suitable as the upper layer for the IZO/ Cu_2O solar cells.

Figure 6 shows the I - V characteristics of the IZO/ Cu_2O heterostructure with and without any illumination, respectively. The cell performance was measured under AM 1.5 illumination with a solar intensity of 10 mW/cm^2 at 25°C . The cell has an active area of $0.3 \times 0.3 \text{ cm}^2$ and no antireflective coating. The Cu_2O layers were prepared by

FIGURE 3: SEM images of the samples with thermal oxidation at various temperatures.

FIGURE 4: The carrier concentration and the mobility as a function of thermal oxidation annealing temperatures.

oxidation of Cu thin films at 500°C for 10 min. IZO/Cu₂O solar cells exhibited the following static parameters: I_{sc} of 0.11 mA (J_{sc} of 1.22 mA/cm²) and V_{oc} of 0.136 V. As is well known, the fill factor (FF) can be described by [25]

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}}, \quad (1)$$

where I_m is the maximum output current, and V_m is the maximum output voltage. Therefore, using the values of I_m and V_m deduced from Figure 6, the value of FF results is equal to 0.338. Similarly, the conversion efficiency (η) defined by [25]

$$\eta = \frac{I_m V_m}{P_{inc}} \quad (2)$$

with P_{inc} is the incident power, results are to be 0.56%. Low FF value and poor conversion efficiency are owing to the high series resistance ($\sim 760 \Omega$, in this study). The series resistance is mainly caused by the bulk resistance of materials, contacts, and interconnections. However, in this work, the high value of the series resistance may be caused by the Cu₂O layers and the contact resistance between the electrodes and the IZO layer and the Cu₂O layer.

4. Conclusions

The present paper reports on the fabrication of IZO/Cu₂O heterostructure solar cells in which the Cu₂O layers were prepared by oxidation of Cu thin films deposited on glass substrate. The Cu₂O layers have a very high absorption in visible region resulting in good materials for the solar

FIGURE 5: Absorbance spectra for (a) Cu₂O films with thermal oxidation at various temperatures and (b) the relationship between absorption squared versus photon energy.

FIGURE 6: I - V curves evaluated for IZO/Cu₂O heterostructure solar cells in the dark and under an illumination.

energy devices. The measured parameters of cells were the short-circuit current (I_{sc}), the open-circuit voltage (V_{oc}), the maximum output power (P_m), the fill factor (FF), and the efficiency (η), which had values of 0.11 mA, 0.136 V, 5.05 μ W, 0.338, and 0.56%, respectively, under AM 1.5 illumination. Therefore, IZO/Cu₂O is a nontoxic nature and an attractive all-oxide candidate for low-cost photovoltaic (PV) applications in the future.

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