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| RESEARCH ARTICLE

Cuprous Oxide (Cu_2O) Based Solar Cell Thickness Dependence

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| ABSTRACT

The rapid advancement of devices that transform light into other energy forms has led to the growth of various solar cell structures established on silicon and other compound semiconductors. Photovoltaic devices that are efficient are required to ensure solar power's competitiveness with traditional energy sources. The most intriguing phase of copper oxides is Cu_2O. There have been several findings of Cu_2O-based solar cells; nevertheless, their efficiencies are quite minimal due to charge recombination at the crystal boundary and other factors. The goal of the present study is to review the effect of Cu_2O thin film thickness prepared by oxidation techniques on efficiency, and then previous related work was systematically studied to investigate their structural and morphological properties. Gravimetric measurements were used to determine the thickness of Cu_2O on Cu. The XRD pattern presented shows a single phase of Cu_2O with no obvious impurity peaks. The finding shows that when the thickness is 26.30μm, the conversion efficiency is high; image analysis from a different method of deposition demonstrated that the films were compact throughout the entire sample surface, with no observed pinholes. The morphology of the stratum was strongly dependent on the deposition techniques.

| KEYWORDS

Cu_2O, Solar cell, Thickness, Oxidation

| ARTICLE INFORMATION

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1. Introduction

Investigators suggest that the globe will require thirty terawatts of energy supplies by 2050 to keep the economy growing. Many experts are convinced that the sun is the only frontrunner capable of providing a comprehensive solution to the energy revolution. As a result, solar cells will be viewed a popular renewable energy tool once their production costs are reduced to a level similar to other accessible energy resources (Asim et al., 2012). Over ninety-five percent of all solar cells in the globe are constituted by Silicon. These material-based solar cells are expensive, and the creation of revolutionary photovoltaic devices based on low-cost, non-toxic products generated through effective processes is required (Han & Tao, 2009). The individual choice for silicon solar cells is oxide semiconductors (Motoyoshi et al., 2010). Oxide semiconductors are commonly used in photovoltaics, optoelectronics, and functional coatings due to significant optical absorption and a moderate price for raw materials (Winkler et al., 2018), (Abdu & Musa, 2011).

Copper oxide has dual basic semiconductor phases' cuprous oxide (Cu_2O) and cupric oxide (CuO) of cubic and monoclinic structures, respectively (Ozmentes & Temirci, 2017). Cu_2O unit cell comprises copper and oxygen ions and pertains to the space group Pn3m (Kara et al., 2018). Cu_2O is the most impressive phase of copper oxide because of its exceptionally good optical absorption coefficient in the visible range and reasonable electrical properties (F.K1 et al., 2013). Cu_2O realizes p-type behavior as a whole due to an acceptor level of 0.4 eV over the valence band yielded by openings in copper ions. Because of oxygen vacancies at 0.38 eV on the lower face of the conduction band's bottom, donor levels in Cu_2O were also witnessed, illustrating the existence of Cu_2O with n-type conductivity. (Jayathilaka C.et al., 2020). Cu_2O has been found to be stable over a narrow temperature and oxygen pressure range.

A lot of work on Cu_2O solar cells brand was published; regrettably, unresolved charge recombination at the crystal boundary and indeed the barrier properties of Cu_2O, their efficiencies seem to be very low. In this work, a review of the effect of Cu_2O thin film thickness prepared by oxidation techniques on efficiency was analyzed; afterward, past related work was systematically studied to investigate structural and morphological possessions of Cu_2O cover. Also, the different techniques considered to expand the photovoltaic properties of Cu_2O -built solar cells are also highlighted.

2. Cuprous oxide-based solar cell

The necessity of viable generating power has prompted research into a wide range of photovoltaic materials and structures, with a stronger focus on achieving a balance of both cost and performance (Siddiqui et al., 2012). As Cu_2O is expected to have an extreme hypothetical efficiency of twenty percent, it was ascertained to have the possibility of meeting global electricity demand while lowering PV costs when associated with crystalline silicon. However, experiments are considerably short of this theoretical efficiency (Gershon et al., 2012). The target research on cuprous oxide-based solar cells is to maximize power while minimizing cost. In general, copper oxide-based solar cells have some disadvantages, such as low conduction as well as high series resistance, which leads to reduced efficiency. Struggles are being made to diminish the sheet resistance of the absorber layer and expand its charge transport properties (Masudy-Panah et al., 2015). Nevertheless, to maximize the charge conveyance in a Cu_2O -based solar cell for demand to achieve the highest efficiency when light rays strike the Cu_2O device, consequently planned to increase the favorite absorption (Fig. 1.3) and absorption after reflection (Fig. 1.5).

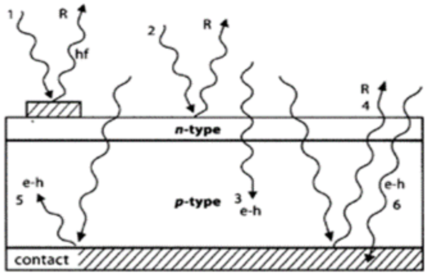

Figure 1. Manners of light shining on a solar cell: (1.1) Reflection and absorption at upper contact. (1.2) Reflection at the cell surface. (1.3) Favorite absorption. (1.4) Reflection from rear out of the cell. (1.5) Absorption after reflection. (1.6) Absorption in back contact

Cuprous oxide solar cells can be configured in three ways: A Schottky barrier, a homojunction, and a heterojunction. The heterojunction structure has been used with a variety of n-type window layers, such as ZnO and TiO_2. This section will provide a brief overview and explanation of related work of the various architectures of cuprous oxide-based solar cells. Musselman et al. (2012) assess the efficiency of bilayer and nanowire (NW) Cu_2O -ZnO solar as a function of Cu_2O absorbing layer thickness, ZnO NW length, and NW seed layer thickness. Their findings show that a thick layer depletion region emerges in the Cu_2O layer of bilayer devices due to the low carrier density of electrodeposited Cu_2O and efficiency of 0.38%; however, replacing nanoparticles with ZnO Nanowires improved efficiency to 0.85%. Miyata et al. (2019) used AZO/p-Cu_2O heterojunction solar cells to investigate the photovoltaic properties of Cu_2O -based heterojunction solar cells. The highest efficiency was obtained, which was 3.21%. The success was attributed to a reduction in deficiency levels at the boundary between the AZO thin film and the Cu_2O piece.

The performance of (AZO)/n-type oxide semiconductor/p-Cu_2O heterojunction solar cells fabricated with p-type Cu_2O piece deposited by means of thermally oxidizing Cu sheets are being explored. When $ZnGa_2O_4$ is used, the cell has the highest efficiency of 5.36%. Zn_2SiO_4 has the lowest efficiency of 0.01%. As a matter of fact, the highest efficiency of 6.25% was obtained for MgF_2/AZO/n-($Ga_{0.975}Al_{0.025}$/2O_3/p-Cu_2O:Na heterojunction solar cell constructed using a Cu_2O: Na heterojunction solar cell. (Minami et al., 2016). In comparison to cells with normal sputtered ZnO thin film, Perng et al. (2017) report a high Jsc of 9.53 mA/cm^2 for low-cost electrodeposited (ED) semi-transparent Cu_2O /ZnO nanorod (NR) solar cells. This is because charge losses have been significantly reduced. Using atmospheric atomic layer deposition of $Zn_{(1-x)}Mg_xO$ on cuprous oxide. Ievskaya et al. (2015) created $Zn_{(1-x)}Mg_xO$ / Cu_2O heterojunction solar cells. The efficiency stated was 2.2%, and the open-circuit voltage was 0.65 V. Chatterjee et al. (2016) created heterojunction devices with a staircase-like energy level of $NiO/Cu_2O/ZnO/SnO_2$. The energy conversion effectiveness of 1% was achieved when Cu_2O thin-films were formed via SILAR route.

3. Techniques for growing cuprous oxide-based solar cell

The cuprous oxide potential for use in solar cells was discovered around 1920. The preparation method influences the parameters, namely; the optical band gap, morphology, crystallite size, and cell efficiency. Many techniques exist for producing cuprous oxide films. Among the methods are: thermal oxidation (Abdu & Musa, 2011); chemical vapour; spin-coating method (Motoyoshi et al., 2010); spraying (Kardarian et al., 2016); thermal evaporation (Tuama et al., 2020); electrodeposition (Niu et al., 2016); DC magnetron reactive sputtering; and molecular beam epitaxy have been used to prepare Copper Oxide thin films.

3.1 Thermal Oxidation

Thermal oxidation is one technique used to create first-class, equally distributed Cu_2O films. The oxidation process could occur either in clean oxygen or laboratory air. At high temperatures, Cu_2O thin films of various widths can be deposited (1000-1500°C). The first compound formed during film formation is Cu_2O, and as the oxidation time is extended, another phase of the copper compound, CuO, is evolved. However, a mixture of the oxide phases forms at atmospheric pressure and temperatures below 100°C.

$$4Cu + O_2 \rightarrow 2Cu_2O \tag{1}$$

$$2Cu_2O + O_2 \rightarrow 4CuO \tag{2}$$

An etching solution prepared by adding $FeCl_3$, HCl, and NaCl can be used to remove the unloved CuO.

4. Methodology

The clean substrate was placed inside a furnace at a high temperature (e.g., 1000°C). Subsequently, the sample was removed and quickly transferred to deionize water to stop further oxidation. The procedure could be repeated with the rest of the substrate at various temperatures and times to produce Cu_2O of different thicknesses. CuO then removes because the oxide film is of different phases by immersing the sample in an appropriate amount of Iron (II) chloride ($FeCl_2$), aqueous sodium chloride, Hydrochloric acid, aqueous sodium persulphate, and then cleaning in deionized water.

5. Discussion of related results

It appears that by optimizing the synthesis and deposition techniques, the effectiveness of the cuprous oxide (Cu_2O) device can be increased. Figure 2 shows the XRD result of Cu_2O thin film deposited by electrodeposition on n-TiO_2 thin film prepared by radio-frequency sputtered. As can be seen, from the pattern Cu_2O cubic phase is responsible for the sharp peaks at 2Θ values of 29.68, 36.524, 42.60, and 61.76, which are indexed to (1 1 0), (1 1 1), (2 0 0), and (2 2 0), respectively (JCPDS No. 05-0667) (Rahman & Islam, 2016) There were no obvious impurity peaks in the XRD pattern, implying the realization of an unadulterated crystalline part of Cu_2O with no secondary phases. The intense peak (200) indicates the preferential growth direction of Cu_2O film.

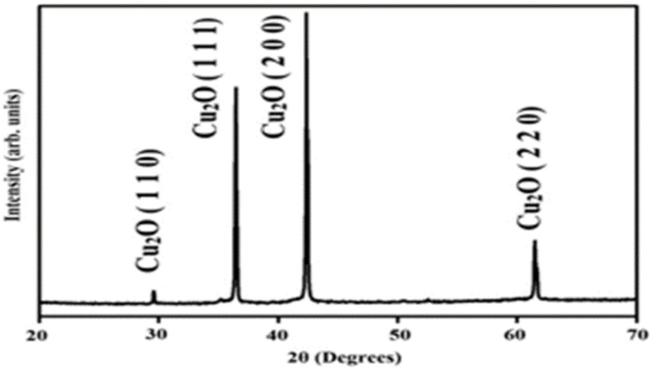

Figure 2. X-ray diffraction pattern for the Cu_2O/TiO_2 thin film heterojunction solar cell. Reproduced from [23] with permission, copyright@2012, Elsevier.

The field emission scanning electron microscopes (FESEM) and Scanning electron microscopes remain techniques used to investigate the surface morphology of films. Figure 3 shows the FESEM image of the Cu_2O thin-film image created using the thermal evaporation technique. The picture has uniform topography with no pinholes, indicating that Cu_2O film is distributed evenly. The calculated average grain size was around $18 - 24nm$

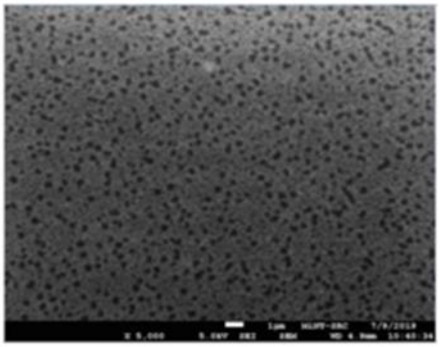

Figure 3. FESEM images of pure cuprous oxide (Cu_2O) films prepared by thermal evaporation technique Reproduced from [20] with permission, copyright@2020, UMP

Figure 4 presents images from SEM to probed surface characteristics of Cu_2O set by spray pyrolysis. The shape and morphology reveal that the individual grains were composed of particles of various sizes. The grains were distributed equally with textures surface.

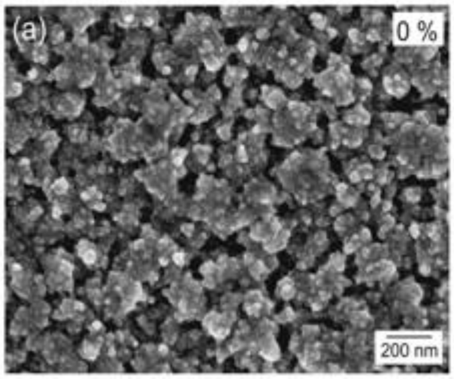

Figure 4. SEM images of the Cu_2O using Spray pyrolysis Reproduced from [19] with permission, copyright@2015, Elsevier

Nordseth et al. (2017) created Cu_2O on a quartz substrate using reactive sputtering of a Cupper objective in O_2/Ar (6/49 sccm). The power density has been set at 2.2 W/cm^2. Figure 1 shows a SEM image of his measurement. The image depicts how the particles are distributed. The particle size of the Cu_2O coating layer is approximately $70nm$. This means that surface properties are suitable for photovoltaic applications.

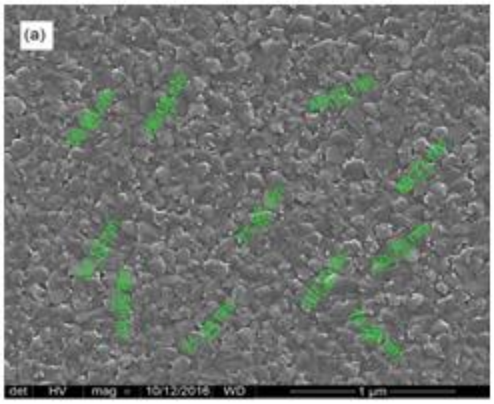

Figure 5. SEM image of Cu_2O thin film on quartz direct current/radio frequency (DC/RF) magnetron sputtering system Reproduced from [24] with permission, copyright@2017, Authors and SRPI

Figure 6 shows the surface morphology image of the sample with a magnification of 500nm; electrodeposition was employed to make the Cu_2O film on gold coated silica which served as the working conductor. The deposition was accomplished at -0.4 V in reference to an Ag/AgCl electrode. The SEM image discloses different grain sizes, and the surface of Cu_2O is highly textured.

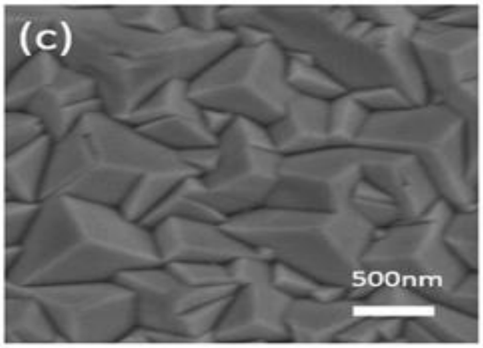

Figure 6. The surface morphology of the as-grown Cu_2O layer by electrodeposition method Reproduced from [21] with permission, copyright@2016, Elsevier

The topography of pure Cu_2O films on FTO glass is depicted in Figure 7; the AFM images of the films revealed an identical morphology with a granular form, root mean square values, and a roughness average of grains is $0.427nm$ and $0.332nm$ respectively

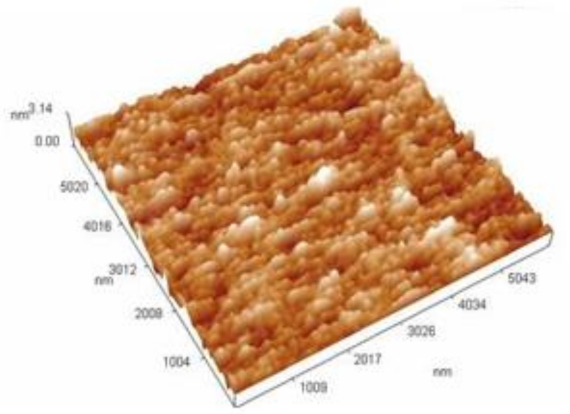

Figure 7. The Atomic Force Microscopy images of (a) Cuprous oxide Reproduced from [20] with permission, copyright@2020, UMP

In the unit cell of Cu_2O, there are six atoms, and as a result, eighteen phonon branches are possible. The Raman spectra for Cu_2O deposited by electrodeposition techniques under the following condition; $pH = 10.5$ and supplied potentials (-0.2V; -0.4V) is depicted in Figure 8; the pulse at 108, 148, 214, 297, 413, 495, and 647 cm^{-1} demonstrates the occurrence of Cu_2O in the formed film. E_u ,T_{1u} ,$2E_u$, $2E_u$, $2E_u$, $2E_u$, and T_{1u} define these peaks.

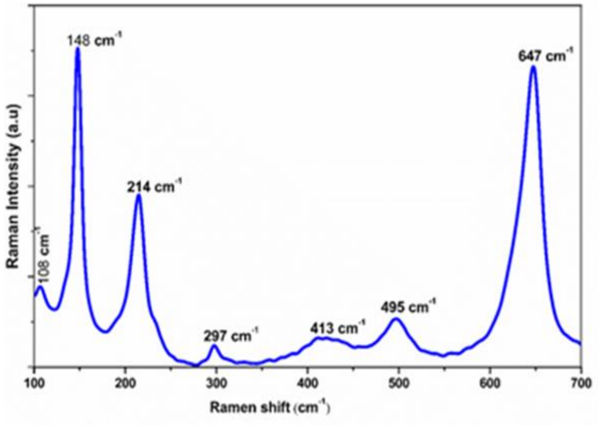

Figure 8. Raman spectra of Cu_2O Reproduced from [25] with permission, copyright@2020, Authors

In the oxidation process toward Cu_2O formation, varying the oxidation time and temperature resulted in a change in sample thickness. Figure 7 depicts a histogram of solar cell performance versus thickness. From the histogram, we discovered that when the thickness is 26.30μm, the conversion efficiency is high, indicating that electron mobility is high and there is less recombination within the bulk material. In this case, we can predict that at this thickness, carriers diffuse quickly, and charges reach the external.

As a consequence, the Voc of high-mobility Cu_2O solar cells is lower than that of low-mobility Cu_2O solar cells (Takiguchi & Miyajima, 2015).

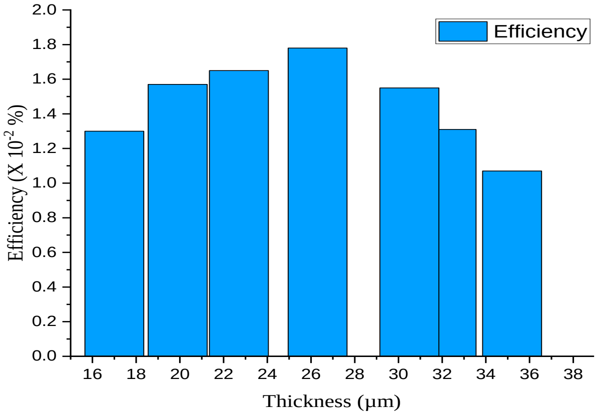

Figure 9. The efficiency of Cu_2O /Cu solar cells at various thicknesses Reproduced from [27] with permission, copyright@2013, Authors, and IJES

6. Conclusion

The assessment of the thickness dependence of cuprous oxide (Cu_2O) prepared by oxidation was explained. We discovered that when the thickness is 26.30 μm, the conversion efficiency is encouraging. Morphology analysis from various methods of depositions demonstrates that the films were compact throughout the entire sample, with no observed pinholes. The deposition techniques influence the exterior morphological features of the layer. In conclusion, the variation of thickness in Cu_2O film deposited using the above method shows an impact on energy output. The deposited Cu_2O thin films accessible in this paper have virtuous prospects as absorber material in solar cell applications.

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