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Full Length Research Article

AN AFFORDABLE FABRICATION AND SYNTHESIS OF NOVEL BI/CU_2O/BI HETERO-STRUCTURE PEC SOLAR CELL

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A B S T R A C T
Cuprous oxide (Cu_2O) and cupric oxide (CuO) furnish a unique possibility to tune the band gap into the middle of the maximum efficiency for solar cell applications and photoelectrochemical (PEC). Photoactive material containing Bi/Cu_2O/Bi has been prepared with high constancy and quality by simple, reliable and an economic thermal oxidation method and Powder Vaporization method. These materials have been characterized using FTIR, at which numerous peaks are present in the sample, were evaluated or assess in detail. The current-voltage characteristic curves were plotted, and the maximum power points of P_{max} was also noted. An open circuit voltage V_{OC} 7.24V, a short circuit current I_{sc} of 14.45A And the maximum power point of 0.476W were acquired correspondingly. This work throw off more light in improving the photo response property and the optimization of the band alignment situated at an interface of hetero-structure photoelectrochemical solar cell.

Keywords: Cuprous oxides; thermal oxidation; photocathodes; annealing; photovoltaic; Cu_2O; heteroepitaxial

INTRODUCTION

Cuprous oxides (p-Cu_2O) due to its extraordinary theoretical conversion efficiency (approx. 20%) have long given tending to Researchers as stuff for solar cells (Asima *et al.,* 2012; Briskman, 1992). Additionally, auspicious for cost-effective manufacturing, suited for building sustainable semiconductors, this material has attracted great interest for use in solar cells and it is also atoxic (Minami *et al.,* 2011; Hoye *et al.,* 2015). Accordingly, over the past few years the use of $Cu_2O$for solar cells has been extensively studied over the past few years (Miyata *et al.,* 2020).

Cuprous oxide (Cu_2O) as a light-absorbing layer has attracted increasing attention in photovoltaic devices (Meyer *et al.,* 2012; Xiang *et al.,* 2011), due to its nontoxicity, copiousness (Wadia *et al.,* 2009), and electrical conversion theoretical efficiency of 20% for homojunction solar cell (Rakhshani, 1986). Cu_2O films can be grown by several techniques including thermal oxidation (Minami *et al.,* 2013; Mittiga *et al.,* 2006), electrochemical deposition (Lee *et al.,* 2011; Musselman *et al.,* 2012), chemical vapor deposition (Eisermann *et al.,* 2012), magnetron sputtering (Deuermeier *et al.,* 2011) and pulsed laser deposition (Ruhle *et al.,* 2014), among which the thermal oxidation method usually endue comparatively long minority carrier transport length and high crystalline quality, leading to higher power conversion efficiency (PCE). To date the highest PCE reported is 6.1% of the devices with Cu_2O layer prepared by this method (Minami *et al.,* 2013; Minami *et al.,* 2014; Minami *et al.,* 2015). However, high energy ingestion of this method curtail its application and high growing temperature (1000°C). Compared with thermal oxidation method, substitute method, e.g. electrodeposition method, offers several advantages like easy control of thickness and morphology, low cost, low deposition temperature, etc. (Therese & Kamath, 2000). A cuprous oxide with the band gap energy of about 2.09 eV is a native p-type semiconductor (Malerba *et al.,* 2011). Due to the inability to obtain n-type Cu_2O for homojunction solar cell It is difficult to achieve a high efficiency for Cu_2O-based solar cell, (Robertson & Clark, 2011; McShane & Choi, 2012).

A well-established method to grow high quality copper oxide, thanks to a thermal oxidation process from copper foil sit is worth mentioning that the most efficient Cu_2O photovoltaic devices were obtained. the high energy consumption of the thermal oxidation done under high temperatures (>1000 °C) for several hours, despite the excellent material properties of the resulting Cu_2O, limits its application for a low-cost industrial scale elaboration of solar devices. Several manufacturing processes using large area capable, environmentally friendly and low-cost methods are currently explored such as sputtering (Ke *et al.,* 2017; de Melo *et al.,* 2019) or electrodeposition (Kaur *et al.,* 2017; Tran *et al.,* 2018). In order to reach the photovoltaic market (Ke *et al.,* 2017; de Melo *et al.,* 2019). The spray pyrolysis process is among the high interest, low-cost technologies, and the subject of increasing research for the production of Cu_2O solar cells currently (Kosugi & Kaneko, 1998; David *et al.,* 2018).

Cupric II oxide (CuO) and Cuprous I oxide (Cu_2O) are the most studied transition metal oxides due to their interesting properties as a p-type semiconductor with band gap of about 1.2 and 2.2 eV, respectively (Zhang *et al.,* 2014; Xu *et al.,* 2006). Cuprous oxide (Cu_2O) is used as anode material in thin film lithium batteries (Musa *et al.,* 1998) [33 as well as in solar cells and is an attractive semiconductor material (Akimoto *et al.,* 2006; Musa *et al.,* 1998; Nozik, 1978; Tang *et al.,* 2005).

Its semiconductor properties and the emergence of photovoltaic effect were discovered by Edmond Becquerel 1839th experimenting in the laboratory of his father, Antoine-César Becquerel. Cu_2O is a p-type semiconductor with a direct band gap of 2.0–2.2 eV (Grozdanov, 1994) which is suitable for photovoltaic conversion. Tang et al. (2005) found that the band gap of nanocrystalline Cu_2O thin films is 2.06 eV, while Siripala *et al.*

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(1996) found that the deposited cuprous oxide exhibits a direct band gap of 2.0 eV, and shows an n-type behavior when used in a liquid/solid junction.

Cu_2O its reasonably good electrical properties and attracts the most interest because of its high optical absorption coefficient in the visible range (Musa *et al.,* 1998). The unit cell of cuprous oxide with a lattice constant of 0.427 nm is composed of a body centered cubic lattice of oxygen ions, in which each oxygen ion occupies the center of a tetrahedron formed by copper ions (Xue & Dieckmann, 1990). The oxygen O atoms in a bcc sublattice and the Cu atoms arrange in a fcc sublattice the unit cell contains 2 O atoms and 4 Cu atoms.

The work lineation in this paper is thus focused on synthesis of Bi/Cu_2O/Bi hetero-structure PEC solar cell. In a first part Cu_2O/Cu/Cu_2O hetero-structure was synthesized using Thermal oxidation method. In a second part Bi/Cu_2O/Bi hetero-structure was synthesized using Powder Vaporization, the effect of the hetero-structure layer are investigated using Fourier transform infrared (FTIR) spectroscopy which is used to study model devices of the sample is a dependable, fast, precise method for studying composition and molecular structure. Both quantifiable and qualitative examine can be executed on a wide variety of materials.IR spectroscopy works by inquiring the vibrational oftenest of chemical bonds. The interaction of the Bi/Cu_2O/Bi with the infrared radiation provides information on the structure of the material.

This segment explicates the nature of the photovoltaic energy conversion principle entangled in the Cu–Bi/Cu_2O/Bi photoelectrochemical solar cells. The relevant solar cell current-voltage equation and those used for the computation of the fill-factor and the electrical power conversion efficiency of the fabricated solar cell are given.

Light is absorbed by a semiconductor immersed in an electrolyte solution in photoelectrochemical solar cells. At the semiconductor electrolyte interface charge separation takes place with the hole or electron stimulating an electron – transfer (redox) response at the surface. In Photo-electrochemical cells there are two primal types; photo electrolysis cells in which some of the light energy is used to drive a chemical reaction up hill in energy thus implementation as a type of solar battery and liquid – junction photovoltaic cells to convert light to electricity. The electron donors move the Fermi level ($E_{F,SC}$) in n-type semiconductor toward the conduction band (see figure 1.0 below)

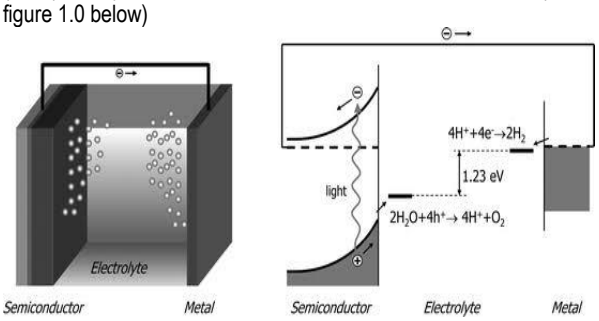

Figure 1.0: Schematic energy diagram in a photoelectrochemical solar cell

MATERIALS AND METHODS

This part reveal the little-by-little procedure used in arriving at copper (I) oxide, Cu_2O starting from the initial element, copper. It also explained how the Cu–Bi/Cu_2O/Bi photoelectrochemical solar cell was constructed and the measurements of fill factor, electrical power conversion efficiency, open circuit voltage V_{oc} and the short circuit current I_{sc}. It also explicate why the current-voltage characteristics measurement of the solar cell was measured.

For fabrication of Cu – Bi/Cu_2O/Bi photoelectrochemical solar cell it is essential for the p-Cu_2O metal oxide semiconductor to be obtained first. The process for obtaining this semiconductor and that for production of the photoelectrochemical solar cell is given below

THERMAL OXIDATION

High purify copper (99.97%) in the form of foils (thickness 0.1mm) were cut into standard size wafers of 2cm × 2cm,The sample of copper foil were wrapped up with tissue paper and smoothened by rubbing with the edge of a beaker to remove the kinks on the samples. The sample were cleaned by etching in dilute nitric acid, HNO_3 and rinsed in distilled water to remove any impurities on the surface of the copper, and finally dried with oven at 40-50°C and stored in clean envelops ready for high temperature oxidation.

The oxidation temperature of 950ºCwasset after the furnace switched on. It took the furnace about one hour to attain the oxidation temperature and copper sample was placed in the ceramic crucible and place inside the furnace and oxidized for eight minutes (8mins) and instantly quenched in cold distilled water. The sample was removed from the distilled water and dried by placing them between tissue papers.

The oxidized samples were annealed at a temperature of 500ºC. The annealed samples were quenched in cold distilled water and air dried.

CHEMICAL ETCHING

Subsequent to cleaning of the sample, oxidation and annealing has been completed in addition to the liver red cuprous oxide (Cu_2O) a black surface of cupric oxide (CuO) is usually formed. The black CuO was removed by chemical etching. Four (4) grammes of $FeCl_2$ and Four (4) grammes of NaCl were dissolved in 100ml of distilled water. 2ml of concentrated HCl was added to the solution, shaken carefully until the black colour is completely etched. The samples were then removed, rinsed with distilled water and dried between tissue papers and finally in air.

A further chemical etching was carried out using 8g of potassium persulphate dissolved in 100ml of the distilled water. The samples were as a final point rinsed in distilled water and dried between tissue papers. The appearing of characteristic liver red colour of Cu_2O considered the complete etching process.

The black CuO layer formed during oxidation was removed when shaken in a solution of $FeCl_3$, HCl and NaCl, leaving behind the red Cu_2O.

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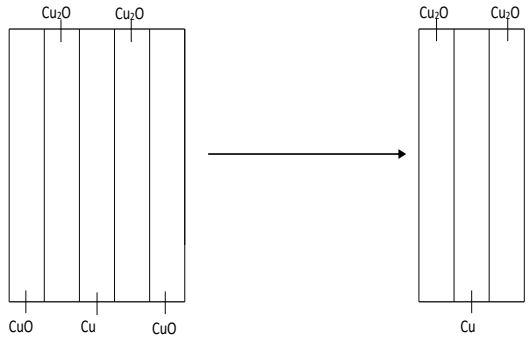

Figure 2.0: Block diagram of the etching process

Chemical Vapour Transport

After the chemical etching process the next method used in the synthesis of the sample is the chemical vapour transport (CVT) (Figure 3.0) consists of mixing stoichiometric amounts of the post transition metal with the chalcogen, in this experiment we used the furnace oxygen as the chalcogen and Bromine (Br) as the transport agent in an unsealed vacuum. The unsealed vacuum was placed in-between the ceramic crucible and is then placed in a high-temperature furnace (700–1000°C), where a temperature gradient across the unsealed tube provides a driving force for the deposition of the Bismuth with the help of the transport agent (Br), forming Bi/Cu_2O/Bi on both side of the sampleCu_2O.

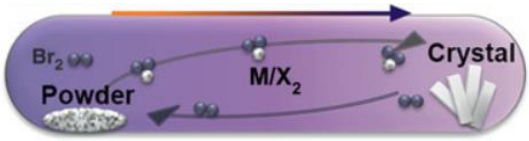

Figure 3.0: Chemical vapour transport

CELL FABRICATION

1 mole of NaCl (i.e. the molecular mass dissolved in 1 liter of distilled water) was poured into the transparent plastic container. Copper wire electrodes were made to the copper (I) oxide and the copper counter electrode using silver paste and both placed inside the plastic container. A complete circuit was then made by connecting the two electrodes to a micro – ammeter as illustrated in fig 4.0.

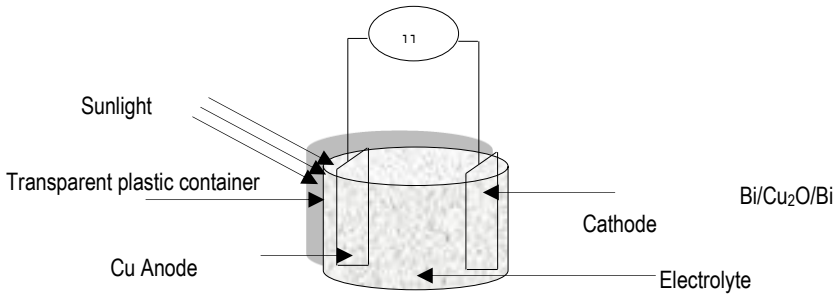

Figure 4.0: Illustration of the fabricated Bi/Cu_2O/Bi Photoelectrochemical solar cell**.**

RESULT AND DISCUSSION

Figure 5.0shows the analysis of Bi/Cu_2O/Bi FTIR. The results can be concluded as follows: There are more than five peaks, regarding the number of peaks, designating that the analyzed chemical is not a simple chemical but rather a complex molecule. The peaks compromised single bond area (2500-4000 cm^{-1}). A hydrogen bond is noticeable at broad absorption band in the range of between 3650 and 3250 cm^{-1} (Nandiyanto *et al*., 2019). While for hydroxyl compound it also has been confirmed due the presence of spectra at frequencies of 1600–1300, 1200–1000 and 800–600 cm^{-1}. The existence of oxygen-related bonding was present due to the presence of sharp bond at about 3500cm^{-1}. There is aromatic structure found due to appearance of a peaks between 3000 and3200 cm^{-1} (Nandiyanto *et al*., 2019). On account of narrow bond at less than 3000 cm^{-1}responded to the C-C bond. In between 2700 and2800 cm^{-1}no specific peak for aldehyde has been found. There is triple bond region (2000-2500 cm^{-1}) was perceived, informing there is C≡C bond in the material (Nandiyanto *et al*., 2018; Nandiyanto *et al*., 2019). Regarding the double bond region (1500-2000cm^{-1}), there is a huge and sharp peak was detected at about 1700cm^{-1}. This informs some carbonyl double bond, which can be from ketones, aldehydes, esters, or carboxyl. Since there is no specific peak for aldehyde at between 2700 and 2800 cm^{-1}theprospective peak for carbonyl should be from ketone. A peak at about 1600 cm^{-1}, demonstrating that there is C=C bonding in the sample. Based on above interpretation, several conclusions can be obtained, including the analyzed material has hydrate component (Nandiyanto *et al*., 2018; Nandiyanto *et al*., 2019) This sample has ketones-related component, there is double or triple bond in the material. Since the peaks were only about 10peaks, the material should be a small organic compound. The absorbance seen below1500 $cm^{-1}$is the fingerprint frequencies, these are highly characteristic of the molecule as a whole; they tell what is going on surrounded by the molecule, as well in this infrared spectrum region however some functional groups will absorb

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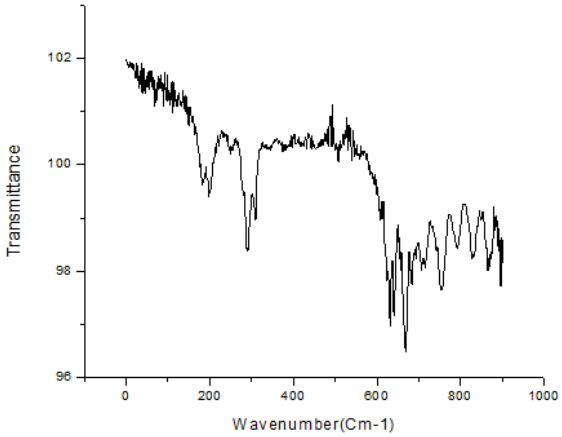

Figure 5 (a): Is the graph of Fourier transform infrared (FTIR) spectroscopy of synthesized Bi/Cu_2O/Bi

The photo voltage and photocurrent was obtained under illumination (Figure 5.0), and the Cu-Bi/Cu_2O/Bi PEC solar cell showed characteristic curves with short-circuit current and open-circuit voltage followed by conversion power efficiency. When tested in the Hadejia Jigawa State Nigeria, The calculated external parameters of the manufactured sample (Bi/Cu_2O/Bi) provided power conversion efficiency (η) of 1.14%, open circuit voltage (V_{OC}) of 7.24V, and short circuit current (I_{SC}) of 14.45A.

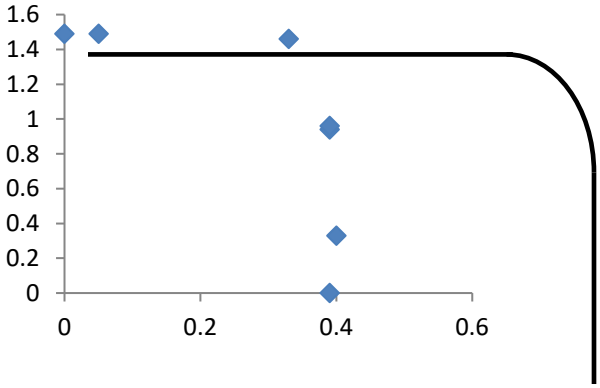

Figure 5.0 (b): The graph of current – voltage characteristic of Bi/Cu_2O/Bi

CONCLUSIONS

Cuprous oxide that was prepared with the thermal oxidation method was subjected to an assortment of annealing temperatures, and the formed structures and phase change occurrences were examined. Copper II oxide and Copper I oxide phase were observed in the structure of the material, which was subjected to annealing treatment after its preparation using the partial thermal oxidation method. Fabrication of Cu_2O thin films at 950°C and deposition of Bismuth post transition metal at 700°C in a high temperature furnace with help of driving force as a result of the temperature gradient within the surrounding of the unsealed tube. Conclusively, by using the thermal oxidation method, multiple-phase of CuO, Cu_2O and bismuth phase mixtures were successfully prepared using an affordable technique. Photocurrent measurements and FTIR characterization demonstrated the successful deposition of cuprous oxide from the initial material copper foil and I-V characteristic showed typical rectification behavior of a *p-n* junction for the fabricated structure, indicating that Bi/Cu_2O/Bi was formed as a semiconducting material and post transition metal has positive impingement on the sample which yields to the stability of the sample. The fabricated cell produced a power conversion efficiency of 1.14%.

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Appendix

Appendix 1. The graph of Fourier transforms infrared (FTIR) spectroscopy of synthesized Bi/Cu_2O/Bi