Synthesis and Characterization of Copper Oxide Nanoparticles for Perovskite Solar Cell Applications

Ghasaq A. Tomaa[1*], Zaid K. Alkaabi[2], Mostafa Salim Mohammed[3]

Abstract

In the present study, various calcination temperatures for auto-combustion technique was used to investigate the capability for tune a structural, visual and dielectric property of a synthesized Copper oxide. The smaller phase variations or lattice distortion seemed because of ever-changing the diffraction angle peaks to large angle in copper oxide are resembled with increase the calcination temperature. The crystalline size seems for reduction in grain size between 5.6nm and 3.98nm with enhancing calcination temperature of CuO nanoparticles. Electronic transportation properties were unrushed through impedance analyzer on the frequency range of 0-8MHz at numerous temperatures. Dielectric permittivity of CuO nanoparticles was found to decreases in energy losses 0.00023 to 0.00015 with increment of calcination temperature. The alternating current conductivity mechanism in the CuO calculated by Maxwell-Wagner Model. The optical properties containing the absorption spectra for synthesized samples were examined by ultra-visible spectra. The value of energy band gap was also establishing reduction from 4.37eV to 2.38eV by increasing the temperature. The consequences exposed that the copper oxide NPs by increasing ultra-wide band gap would be presented better photo-response for solar cell as well as photo-detectors applications.

Key Words: CuO, XRD, SEM, UV, Solar Cell Applications.
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Introduction

With increasing the environmental issues and enhancing energy crisis, the production of sustainable and clean energy has become a major issue that each country needs to solve urgently by employing cheap nanomaterials and exceptional processing methods. The solar energy is one of greatest important sources of renewable energy due to its wide distribution area, clean and pollution free [1]. Total solar energy that cleanses the entire earth surface per year about 10,000 times than the whole energy feeding of world per year. The density of its power 1 kWm^{-2} throughout sunshiny days, and the power of the solar energy globally about 160,000 TW. The accessibility of a great possible for sustainable and renewable energy sources is necessary [2]. Photovoltaic is such procedure in which energy of light is changed into electricity by the separation photoinduced bound excitons [3]. The photovoltaic solar energy is the growing industry around the whole world, for keeping that pace, new progresses has been growing when it comes to material utilize, energy consumption to production of these materials, manufacture technologies, device design and also ideas to improve the global efficiency of the cells [4-6].

Corresponding author: Ghasaq A. Tomaa
Address: [1*]Department of Pharmacy, Al_Maaref University College, Iraq; [2]Department of Radiology and Sonar, College of Health and Medical Techniques, University of Alkafeel, Iraq; [3]Department of Dentistry, Al-Zahrawi University College, Iraq.
E-mail: [1*]dr.ghasaq.ali@uoa.edu.iq; [2]zaid.alkaabi@alkafeel.edu.iq; [3]Mostafasalim@g.alzahu.edu.iq
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The photovoltaic effect occurred due to the transformation of solar radiation into electricity, that first time was detected by Becquerel in 1839 [5,6,7–13]. This influence arises in constituents known as semiconductors, that current two energy bands, in one of them the existence of electrons is allowed (valence bad) and in the other there is no presence of them. The purpose of sunlight on the photovoltaics is to provide the energy to the valence electrons to make it conceivable to move between the valence and the conduction band in any atom, in this way electricity is produced.

Solar cells (SCs) are greatest energy sources due to sources of renewable and sustainable energy, and environmentally friendly. Reducing the cost of solar sell and enhancing the efficiency are much significant responsibilities that are thoroughly connected to photovoltaic change of solar energy [14]. Due to environmental issues and pollution issues, researchers have adopted an initiative to find alternative materials for photovoltaic cells. Semiconductor CuO used in solar cell are mainly regulate through their optical characteristics, band gap and charge carrier diffusion length [15]. Copper oxide is a p-type semiconductor material; its crystal structure is given in figure. Copper oxide (CuO) is a best semiconductor for higher competence solar cells due to its direct low band gap of 1.2 eV that is close to the band gap of solar cells. The utilize of this materials is advantageous because of its simple synthesis process solar cells [16].

Copper oxide is semiconducting material and has monoclinic structure. It exhibited gained extensive attention of researchers because of its exceptional physical characteristics, thermal conductivity, electrical conductivity, magnetic characteristics and optical properties and also due to its ductility and stiffness. Copper oxide nanoparticles have higher melting point and boiling point. All the characteristics of CuO NPs can be accustomed through method of fabrication [17]. Copper oxide (CuO) nanoparticles are utilized in many applications like gas sensors, catalysis, semiconductors and biomedical applications. Copper oxide nanoparticles are used in developing solar photovoltaics, super capacitors, lithium ion electrodes, electronic devices, infrared filters, solar cells, magnetic storage devices and optoelectronic devices [18].

Copper oxide (CuO) nanoparticles with well-adjusted shape and size have exhibited their huge interest in the solar cells field for photovoltaics due to their distinguishing chemical and physical characteristics different as compared to bulk materials. During the one decade, significant determinations are constructing to fabricate the CuO NPs proficient of utilizing UV light energy. In present year, this material has gained specific concentration of scientists and numerous industrial fields due to their potential for photovoltaic application because of its smallest optical band gap of (1.20 eV) [19].

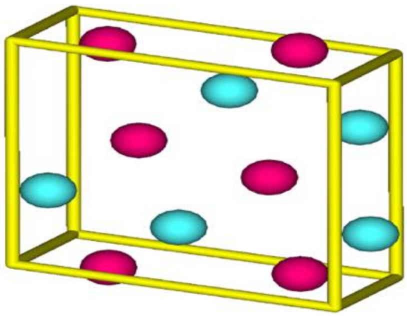

Figure 1. Crystal structure of CuO [1]

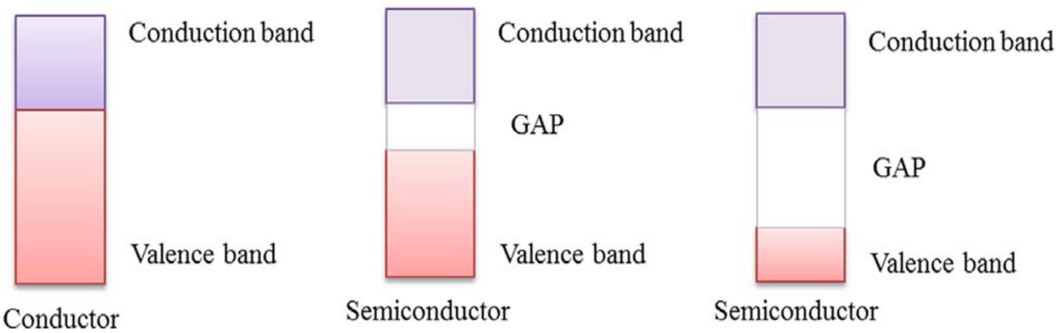

Figure 2. Band of valence, band gap (GAP) and the conduction band: insulator, conductor and semiconductor

Forms of CuO

Different CuO-based nanostructures were synthesized in various forms, such as nanorods, nanowhiskers, nanowires, nanoribbons, nanoplateletes, urchin-like, plates-like and feather-like.

CuO Nanowires

Yang *et al*. produced the copper oxide nanowires on the nickel foam surface through utilizing a hydrothermal technique for the water splitting purpose. Morphological studies revealed that length and dimension of these CuO nanowires were 1-2 um and 100 nm, respectively. In these images, lattice fringes were observed. These nanowires showed the maximum voltage about 1.53 V and current density about 10 $mAcm^{-2}$ [20].

CuO Nanoleafs

Copper oxide nanoleafs can be solution prepared through a double step procedure on crystallite Si substrates. In [21], copper oxide nanoleafs were grown on profitable surface of textured n+-p Si solar cells deprived of passivation layer. After development, the nanoleafs exhibited the average width of ~83 nm and length of ~280 nm. The layer of nanoleafs improves the absorption of light in the solar cell of silicon by performing as a layer of graded index that rises trapping and light scattering crossways a comprehensive spectral region. When the morphology of the nanoleafs is enhanced, the solar cell can reach 11.07%, that is expressively high as compared to a control device (9.39%) [21]. Newly, copper NPs synthesized through green preparation have also been utilized as counter electrodes solar cells [22].

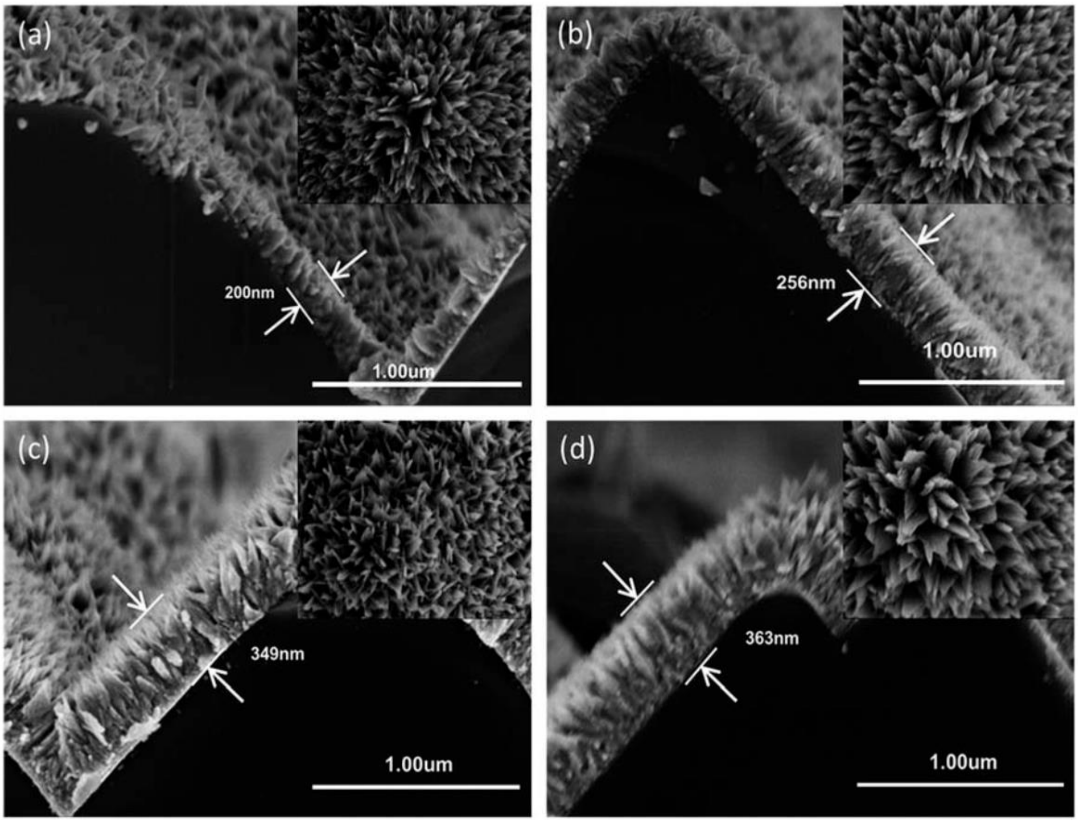

Figure 3. Cross-sectional FESEM image of copper oxide developed on pyramid-textured silicon substrates for (a) 30 min; (b) 45 min; (c) 60 min; and (d) 90 min in a double step procedure. Inset of each image illustrations the conforming top interpretation. Reformed in part form J, Mater. Chem.A, 2014, 2, 6796 with permission from The Royal Society of Chemistry [21].

CuO Nanoparticles

Salim *et al*. prepared copper oxide NPs on the substrates through sol-gel technique for the determination of heterojunction devices. CuO nanoparticles exhibited that current density enlarged from 10.0 mA/cm^2 to 11.4 mA/cm^2, voltage enlarged from 0.56 V to 0.59 V and FF from 54 to 62 %, consequence in an enlarged PCE from 3.0 % to 4.1 %, the enhancement in these parameters was due to the combination of copper oxide nanoparticles in the active layer in materials [23].

CuO Nanofibers

Sahay *et al*. fabricated copper oxide nanofibers for examining its suitability as blocking layer in zinc oxide nanoparticles based solar cells and deliberate the influences of abode time of the cycle on the size crystalline. The crystalline size was decreased with

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the in dwelling time, crystallinity of CuO nanofibers improved. It was observed that current density was ~25% increased due to the application of CuO fibers [24].

Crystal Structure of CuO

It is well known that copper oxide crystalline possessing the monoclinic space group $C2/c$ with four copper oxide units in the elementary cell sa=4.67 Å, b=3.41 Å, c=5.12 Å, a =g =90°, b =99.5°d. In this structure, Cu is collinearly enclosed by 4 oxygen atoms that settle on the closely rectangular parallelogram corners (CuO-plaquettes with side length 2.62 Å and 2.9 Å, and angle at the corners 89.7° and 90.3°). It can seems in the viewpoint view at the crystal structure of copper oxide in figure, the coplanar assemblage of the oxygen neighbors of each copper atom contributes increase to 2 diverse types of chains, the other in f1¯10g direction, one propagating [110], where both are linked by O_2 atoms at the corners and have intersect under the angle 77.84°. The presence of two alignments of the copper oxide stops an alignment of the occurrence polarization perpendicular to both plaquettes consecutively.

The single crystal of copper oxide utilized in the process was a plate, 1.5 mm wide, 0.5 mm thick and 11 mm long, where rendering to Laue-diffraction. The experimental arrangement on the HARWI beam line allowed a alternation of the specimen about an axis perpendicular to a planes panned of the crystal, therefore the angle g the b-axis describes and between the incident beam, the course of the occurrence polarization comparative to the organizes of crystal [25].

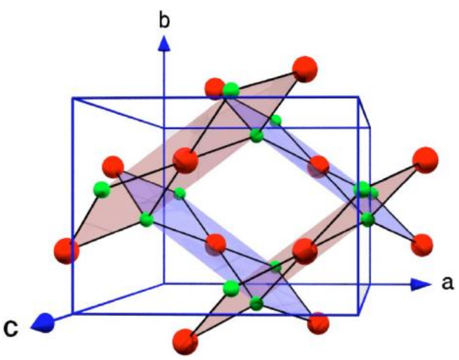

Figure 4. Copper oxide crystal structure [25].

Preparation Techniques

Still, several altered methods are working including the coprecipitation [26], the sol-gel process [27], ceramic method [28], microwave assisted hydrothermal process [29] etc. In co-precipitation technique, a chief task is that wanted adjust of particle size is unimportant during preparation mechanism [30]. The ceramic technique is simple to use in the industrial area, but it possess higher consumption of energy. The hydrometallurgical procedures are fairly incompetent in the industrial area. Among different techniques, the sol-gel technique is originate to be a suitable technique with their better control ratio, ease, extra standardized alignment and a advanced purity [31].

Oku *et al*. described the voltage and current density and power change efficiency and microstructures of copper oxide thin film based solar cells by spin-coating and electrodeposition approaches In-doped or F-doped SnO_2. Copper oxide thin film based solar cells synthesized by electro-deposition showed the current density of 0.0018, voltage of 0.24 and power change efficiency was 9.0x10^{-5}, although the copper oxide thin film based solar cells synthesized by spin-coating showed the current density of 0.025, 0.036 and 2.3x10^{-4}. These cells produced through electrodeposition showed high absorption between 300 and 700 nm in comparison with spin coating, that would be because the thickness of the thin films. The crystalline sizes of CuO and Cu_2O formed though electrodeposition method is 40 nm that are greater in comparison with the fabricated through spin coating method. Crystallinity increases because of the large \thickness of thin film, managed to the growth in voltage [32].

Ahmmed et al. described that voltage and current density and power conversion efficiency and microstructures of copper oxide based solar cells through sol-gel spin coating technique. The Jcs and Voc characteristic analysis shown that improved solar cells showed a power conversion efficiency of 12.09 % by Jsc and voltage of 24 mA/cm2 and 0.748 V, respectively [33].

Structural Analysis

CuO NPs exhibits the crystalline nature was identified by their conforming powder XRD patterns. All peaks were corresponding with monoclinic phase of copper oxide (standard JCPDS File No: 048-1548). Scherer equation was applied to gain average crystallite size. From the consequences, it is incidental that the crystalline size growths with the increase in calcination temperature [34].

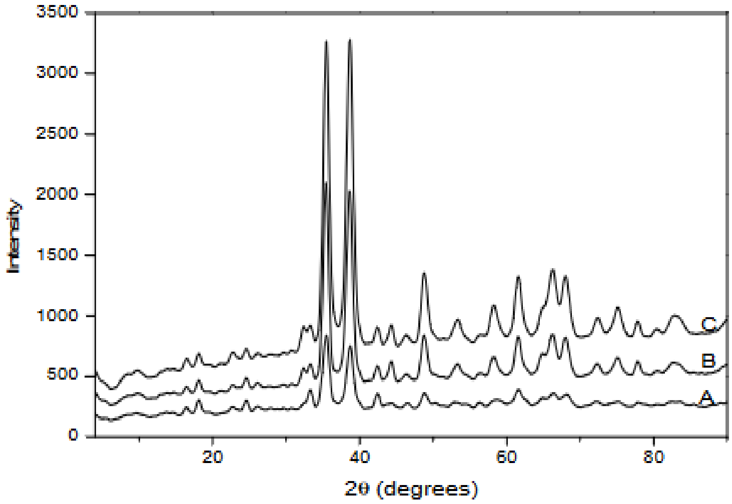

Figure 5. Powder XRD pattern of Copper Oxide nanoparticles [34]

Morphology of CuO NPs

The images of three samples are illustrated in figure. Images shows that are samples are porous balls have good connection with combined with calcination temperature. Hence the detected size enhances in increase in crystallite size and DLS [34].

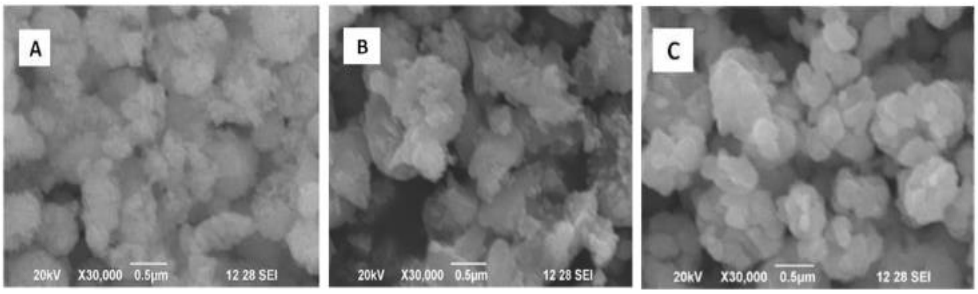

Figure 6. SEM images of CuO NPs [34].

Optical Study

Ultra-visible spectra of fabricated nanoparticles formed through pulsed laser ablation of Cu into 2mM solution of amount of CTAB were verified into complete visible to infra-red region is showed in Figure 4. The graph has two peaks at 260nm and 650nm. High symmetry of copper ion reasons extra stability of copper oxide NPs in comparison with copper oxide in small size range of (2-7 nm), although copper oxide is additional stable in large sized range of (8-100 nm) because of lower symmetry of copper ion complexes. Consequently, copper oxide NPs are typically create on the external part of copper oxide NPs. CuO voluntarily produces on the surface of nanoparticles and propose that there should be the barrier of energy to its production of small sizes. It is conceivable that for small NPs, the barrier develops extreme and preparation condition of pure copper oxide NPs is auspicious. Consequently copper oxide may really metastable and change to copper oxide.

The band gap energy of the formed nanoparticles is determined by the Tauc's equation:

$$(\alpha hv) = \left(hv - E_g\right)^n$$

The band gap energy is calculated from the straight line intercept at α = 0, that is create was 2.26eV [35].

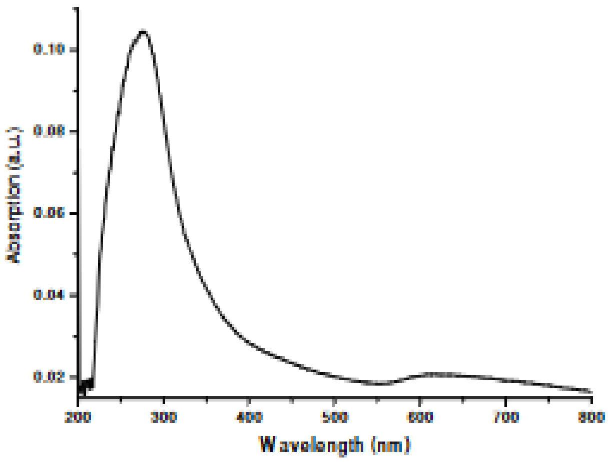

Figure 7. Ultra-visible spectra of fabricated CuO nanoparticles [35].

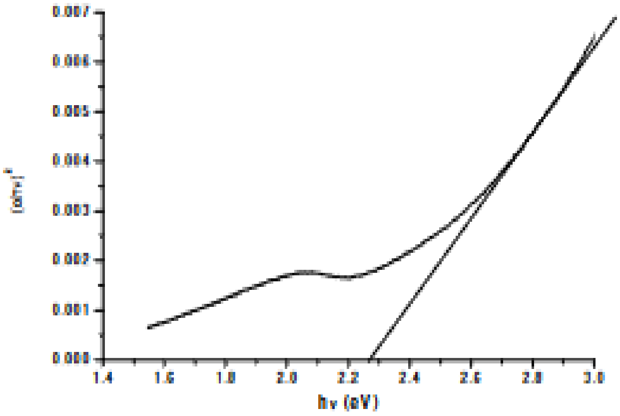

Figure 8. Tauc's plot for as synthesized CuO NPs [35].

Conclusion

In the present study, various calcination temperatures for auto-combustion technique was used to investigate the capability for tune a structural, visual and dielectric property of a synthesized Copper oxide. The smaller phase variations or lattice distortion seemed because of ever-changing the diffraction angle peaks to large angle in copper oxide are resembled with increase the calcination temperature. The crystalline size seems for reduction in grain size between 5.6nm and 3.98nm with enhancing calcination temperature of CuO nanoparticles. Electronic transportation properties were unrushed through impedance analyzer on the frequency range of 0-8MHz at numerous temperatures. Dielectric permittivity of CuO nanoparticles was found to decreases in energy losses 0.00023 to 0.00015 with increment of calcination temperature. The alternating current conductivity mechanism in the CuO calculated by Maxwell-Wagner Model. The optical properties containing the absorption spectra for synthesized samples were examined by ultra-visible spectra. The value of energy band gap was also establishing reduction from 4.37eV to 2.38eV by increasing the temperature. The consequences exposed that the copper oxide NPs by increasing ultra-wide band gap would be presented better photo-response for solar cell as well as photo-detectors applications.

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