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Electrical Properties of Copper Iodine Prepared by Exploding Wire

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Electrical Properties of Copper Iodine Prepared by Exploding Wire

Abstract

Copper iodide (CuI) is one of the promising materials for use in many applications such as organic electronic devices. In this work, CuI nanoparticles were prepared using the exploding wire technique in an iodine solution and were deposited as thin films by a spin coating method to study its electrical properties. This study showed that all prepared thin films were a poly-crystalline structure with γ phase. The electrical study showed that al film was p-type. The dielectric parameters depended on frequency and voltage. It can be noticed a small increase in ac conductivity by increasing the applied voltages in the lower range, but there is a noticeable increase in conductivity at 1 volt.

Keywords

exploding wire, Copper iodide, electric properties

1. Introduction

Copper iodide (CuI) belongs to the I-VII semiconductors [1]. It has three crystalline phases, α, β and γ. CuI exists as a γ-phase (Zincblende structure) at low temperature (less than 370 °C), α-phase (Cubic structure) exists above 390 °C while β-phase is an intermediate case [2]. The low-temperature γ-phase behaves as a p-type semiconductor. The fundamental band gap of CuI corresponds to the energy difference in the direct transition was reported as 3.1 eV [3]. CuI is a promising material for use in many applications such as solar cells and superionic conductor [4]. Also, CuI thin films properties make it very useful as hole collector in the dye-sensitized solar cell [5,6] Also, CuI has a great potential for application in blue organic light−emitting [7].

A large number of researchers were interested in studying the structural, optical and electrical properties of copper iodide novelty [8,9].

Copper iodide has been prepared by several techniques such as electrochemical deposition [10], reactive sputtering [11], and wet chemical synthesis [12]. It is one of interesting material which can be easily synthesized by electro exploding wire technique [13]. The exploding wire method is one of the easiest method used in the production of a metal nanoparticle and their compounds [14]. This method is capable to produce bulk amounts of metal and semiconductor nanoparticles at low-cost.

Recently, many studies about electrical properties of a wide-gap semiconductor such as copper iodide semiconductor under different parameters were studied [15].

The CuI conductivity approaches 0.1 Ω^{-1} cm^{-1} in γ-phase, and it is slightly higher in α and β-phases. The copper iodide conductivity depends on its stoichiometric and the amount of iodide in it [16].

In this work, copper iodide nanoparticles were fabricated by exploding copper wires using different currents in an iodine solution. The electrical properties of the produced samples were examined by direct current conductivity test (DC), Hall Effect measurements and ac conductivity to characterize its electrical behavior.

2. Experimental part

Iodine solution was fully dissolved in distilled water as 5 g/100 ml by a magnetic stirrer for 35 h parted in five days. The stirred was done at a fixed temperature (333 K) to help the dissolving process. Copper wires with a diameter of 0.24 mm and 2 cm long were exploded using high currents, 100 and 160 A, with energy higher than the evaporation energy of Cu, in 100 ml Iodine solution to produce CuI nanoparticles. Thin films were produced by a spin coating technique. Thin films thicknesses were measured by using optical spectroscopic reflectometer (TFProbe TM from Angstrom Sun Technology Inc.), which is about 250 nm. The prepared samples were examined using X-ray diffraction (XRD Shimadzu), atomic force microscope (AA3000 Scanning Probe from Angstrom Advance Inc). Aluminum electrodes for dc, ac conductivity, and Hall effect were prepared by thermal evaporation deposition under vacuum. The dc conductivity was studied at temperature range (20−150) C. The Hall effect measurements were done at room temperature. The ac conductivity was studied at a frequency range from 75 Hz to 1.2×10^6 Hz.

3. Result and discussion

Fig. 1 shows the XRD patterns for CuI thin film, produced by exploding Cu wire in iodine solution using 100 and 160 A current and deposited on glass substrates. The two films have poly-crystalline structure identical with standard card No. 96-900-8845 for γ -CuI phase.

Fig. 2 illustrates atomic force microscope images (AFM) for CuI nanoparticles prepared at different currents (100 and 160 A) and deposited on glass substrates. The average of aggregations' diameters increases from 130 to 153 nm and the root mean square roughness (RMS) varies from 116 to 123 nm with increasing the current from 100 to 160 A.

Fig. 3 shows the logarithm of electrical conductivity as a function of inverse temperature for CuI films prepared from nanoparticles fabricated by exploding wire technique using 100 A and 160 A. The conductivity increases with temperature and the preparation current. The two samples have two regions, i.e. two activation energies.

The activation energies and their ranges were calculated from the slope of the linear part as shown in Table 1.

Fig. 4 shows the variation of the logarithm of alternating electrical conductivity with the logarithm of angular frequency at different applied voltages, for the

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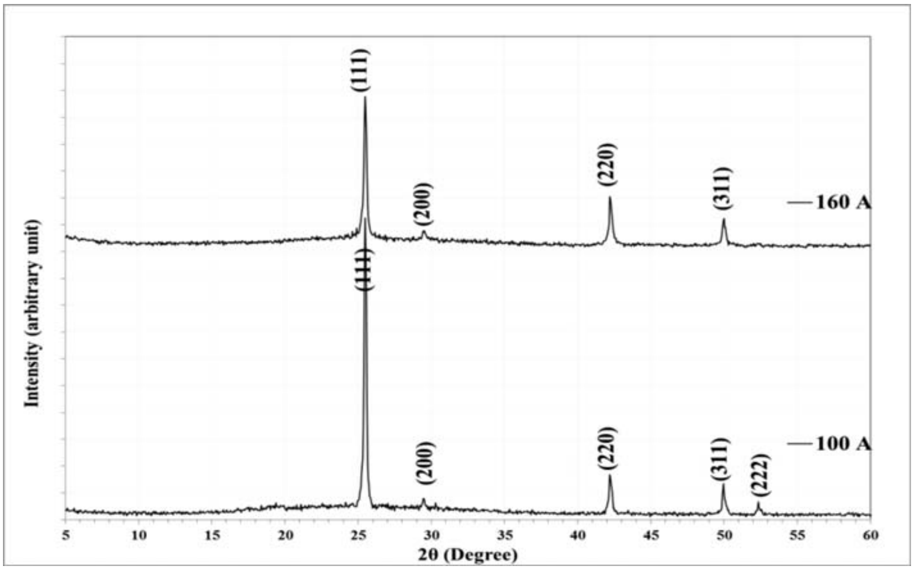

Fig. 1. X-ray diffraction patterns for produced CuI nanoparticles using different current.

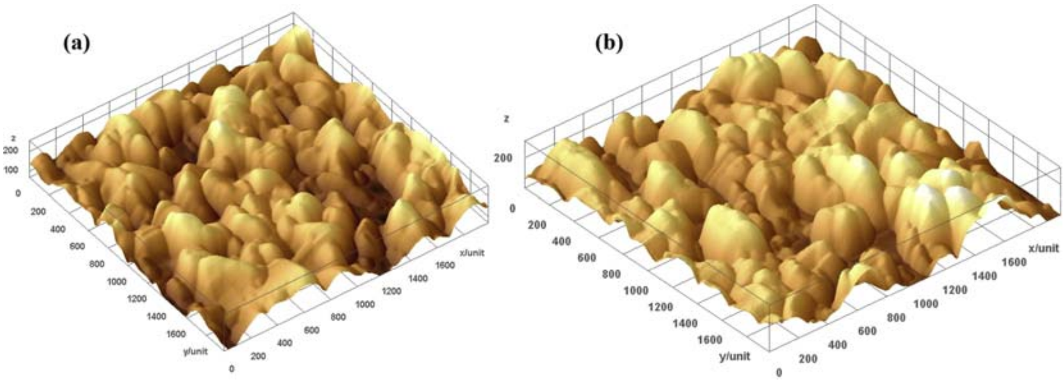

Fig. 2. AFM images for thin films deposited on glass substrate by spin coating from CuI nanoparticles prepared by (a) 100 A (b) 160 A.

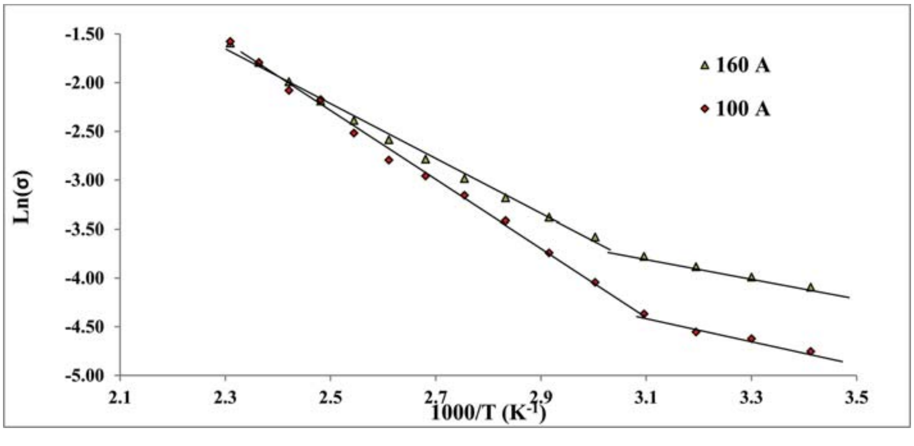

Fig. 3. Variation of Ln (σ) with inverse temperature for CuI thin films prepare by exploding wire at two currents (100 and 160 A).

Table 1
DC activation energies, their ranges, and conductivity at room temperature for CuI thin films prepared by exploding wire at two current (100 and160 A).

Current(A)	E_{a1} (eV)	Range (K)	E_{a2} (eV)	Range (K)	σ_{RT} ($\Omega^{-1}.cm^{-1}$)
100	0.099	293–323	0.300	323–433	0.0431
160	0.086	293–323	0.240	323–433	0.0833

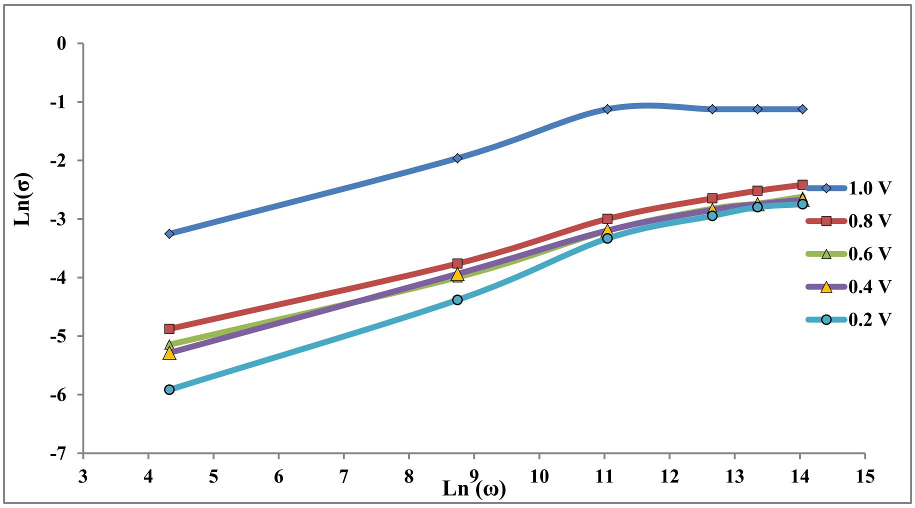

Fig. 4. Variation of ac conductivity with the angular frequency of power supply at a different applied voltage.

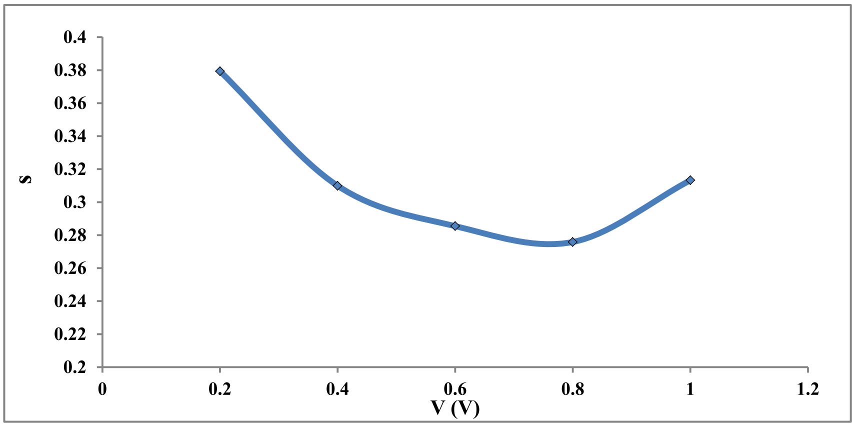

Fig. 5. Variation of the exponent factor (s) with applied voltage.

sample prepared by 100 A current. The conductivity increases with frequency and forms a linear region start from 75 to 6.28 × 10^4 Hz, i.e. the curve is subject to Eq. (1). The slope of this linear region represents the exponent factor that gives a picture of the relationship between ac conductivity and frequency. We also notice a small increase in ac conductivity by increasing the voltages, but there is a noticeable increase in conductivity at 1 V due to the breakdown of the voltage barrier at these voltages. According to the CBH model, the ac conductivity occurs through the jump of the charge carriers over the potential barrier between two defect states and the height of the barrier is associated with the junction between sites through a Colombian reaction.

Fig. 5 illustrates that the (s) values less than unity and reduce from 0.38 to 0.275 with increasing the applied voltage from 0.2 to 0.8 and increase at 1 V.

Fig. 6 illustrates the frequency dependence of dielectric constant (ϵ_1) for CuI samples at the different applied voltage. It has been observed that ϵ_1 decreases with frequency and be near constant at higher frequencies. The decrease in the value of the dielectric constant with the frequency can be attributed to the polarization process which arises from the total of four types of polarization to give full polarization of the insulating material. The first type in the low frequency is the polarization of the charge of the areas shown by the charge carriers at the electrodes. The second type is bipolar polarization that appears in materials containing particles with permanent bi-electric moments that can change their orientations to the direction of the applied electric field. The third type is the ionic polarization that arises due to the displacement of positive and negative ions in relation to each other. The last one is the electronic polarization caused by the displacement of valence electrons from the position of their stability around the positive nucleus, and this type appears at high frequencies. The directed polarization decreases with an increase in frequency because it takes more time and then polarization electronically and ionically. This reduces the value of the total dielectric constant (ϵ_1) with an increase in frequency which finally reaches nearly a fixed value at a higher frequency range.

We can also observe little decrement in the value of the dielectric constant with the increase of voltages, and is obvious decrease when reaching the applied voltage of 1 V.

The variation of dielectric loss (ε_2) with frequency is shown in Fig. 7 which decreases with increase the frequency due to that at low frequencies the value of ε_2

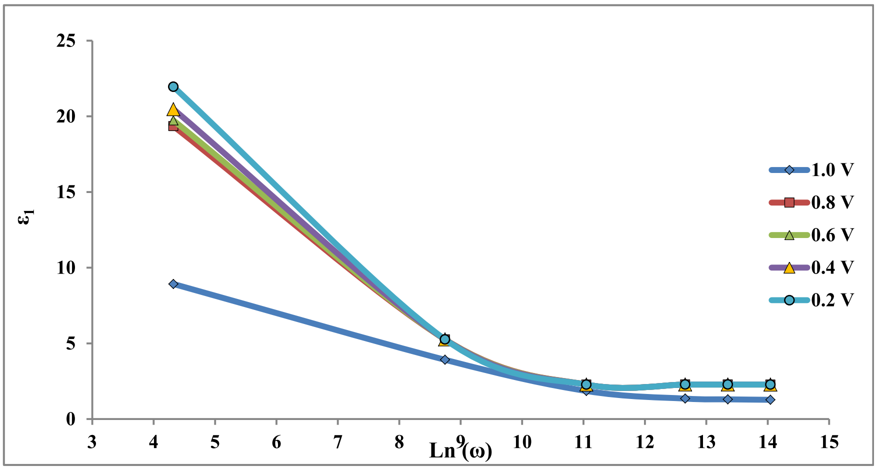

Fig. 6. Variation of dielectric constant with frequency at the different applied voltage.

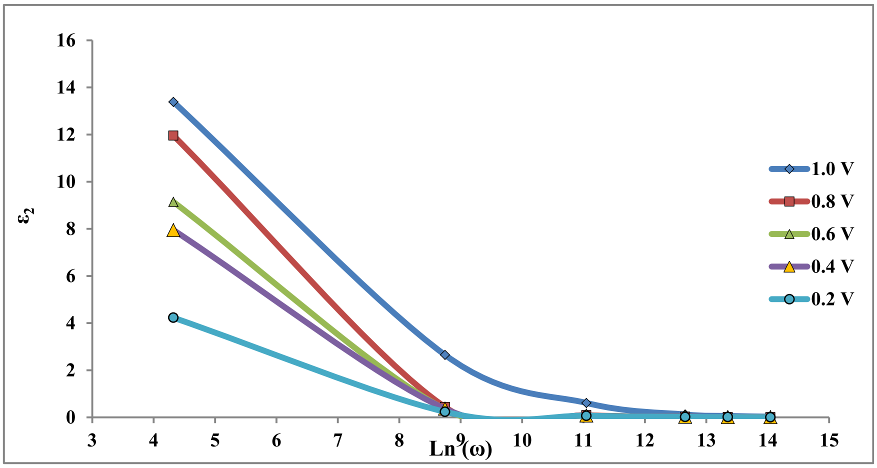

Fig. 7. Variation of dielectric loss with frequency at the different applied voltage.

comes from the migration of ions from the electrodes. At high frequencies, the ionic vibration can be the only source of loss of electrical insulation, so its value is minimized. Also, it can be seen that ε_2 nearly constant with potential up to 0.8 put significantly increase at 1 V.

The results indicate that the electrical and dielectric parameters of CuI were found to be strong functions of frequency and applied bias voltage due mainly to the interfacial polarization and interface traps at metal semiconductor interface [17]. The value of ϵ_1 decreases with increasing applied voltage from 0.2 to 1.0 V, while the values of ϵ_2, exhibits the opposite behavior. Such behavior is known as inductive behavior, due to the effect of series resistance and surface states [18]. The value of C decreases and the conductivity increases due to decrease of $\epsilon 1$ with increasing applied voltage [19].

4. Conclusions

The method of exploding wire is a simple way to produce materials of good specifications for use in many applications such as copper oxide material, which used in solar cells applications. The properties of produced nanomaterial such as their electrical properties can also be controlled by changing the manufacturing parameters. Experimental results indicate that the main electrical and dielectric parameters of CuI thin film were found to be a function of frequency and applied bias voltage.

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