

Structural Electrical and Detection Properties of Copper Oxide Based on Optoelectronic Device

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Abstract. In this work, the effect of different substrate temperatures on the electrical and detection properties of CuO₂ copper oxide thin film has been carried out using Reactive Pulsed Laser Deposition technique (RPLD). $\lambda = 1046$ nm Q-switch Nd-YAG laser with (900 mj) laser energy's has been used to ablated pure copper target and deposited on the Silicon substrates. The X-ray diffraction in sour the formation of polycrystalline Cu₂O nanostructure thin film.

Keywords: copper Oxide; PLD; heterostructure; detector parameters

1. Introduction

There are many well-known transparent conductive oxide (TCO) materials and their doped derivatives. TCOs such as e In₂O₃, SnO₂ are n-type materials and are used, for example, as transparent electrodes in flat panel displays, solar cells, and touch panels. These materials need to have good optical transparency and electrical conductivity for their applications [1-3].

There are, however, new TCOs with p-type conductivity. Indeed, the development of p-type transparent conducting oxides is one of the key technologies for p-n junction-based oxide devices, such as diodes, transistors and light-emitting diodes [4, 5].

Cuprous oxide (Cu₂O) or (CuO), a p-type semiconductor, has brown colour and possesses direct band gap around 2 eV [6, 7]. A crystal of Cu₂O has a cubic structure. It has high specific electrical resistivity and optical transmittance in the visible region of the solar spectrum which makes it useful for various applications such as solar cells, photodetectors, and phototransistors [8, 9].

In addition, the Cu₂O or CuO, films have been attractive in the field of gas sensors made by employing the hetero-structure with SnO₂ [10, 11]

There have already been several reports on the methods of preparation of Cu₂O or (CuO) crystals, e.g. reactive magnetron sputtering [12], reactive evaporation [13], RF sputtering [14], ion beam sputtering [15], plasma evaporation [16], and molecular beam epitaxy [17].

In this study we report the fabrication and characterization of nano-structured copper oxide thin films deposited on silicon substrates with the aid of PLD technique

2. Experimental work

Undoped Cu₂O hetrostructure were prepared and deposited on a cleaned wafer of N-Si as a substrate using a tattoo removal Nd: YAG laser at different substrate temperatures. The pulse duration of the Q-



switched Nd: YAG laser is 7 ns (FWHM) with wavelength= 1.064 nm, the laser beam was focused through a lens with a focal length=10 cm spotted on a silver target (99.999% provided from Fluka com.). The targets spin at a rate of one cycle per minute. The energy of the pulsed laser at the target surface was maintained within the 900 mj. All the deposited thin films were created by 50 laser shots at the temperature of the substrate arranged 200-600 °C. A (P-type) Cooper oxide (CuO) nanostructure thin film was deposited using the RPLD technique, with the aid of halogen lamp at oxidation temperature of (623 K) and (90 sec) as an oxidation time. The calcinations process was done at 250 °C for 30 min in static air within oxygen atmosphere to remove any organics. (Lenton VTF/12/60/700) tube furnace. The crystalline properties of the Cu₂O films were analyzed by an X-ray diffractometer (N 1999 JCPDS prevalent) using Cu K α radiations (λ =0.15406 nm) and operating at an accelerating voltage of 40 kV and an emission current of 40 mA.

The white light response of the photodiode was tested by placing it under illumination of a (100W) tungsten filament lamp, placed 15 cm away. The I-V characteristics were measured using a DC power supply and Keithley electrometer. The spectral responsivity of the photodiode was measured for the spectral range (450-900nm) using a calibrated monochromator. All measurements were carried out at room temperature. The Photoconductive property of semiconductors can be used to determine the excess minority carriers lifetime.

3. Results and discussion

3.1 Structural properties

XRD patterns of the copper oxide films oxidation annealed at 500 °C temperature and (900 mj) laser energy along with that of an as-prepared sample were shown in Fig.1. Well defined for Cu₂O peaks at 36.23, 42.20, 61.24° and 74.07 corresponding to reflections from (111), (200), (220) and (311) planes are observed in Fig.1. This indicates that all samples are polycrystalline and matched the characteristic peaks due to the mineral cuprite, Cu₂O (JCPDS 5-667). Annealing the samples in air at temperature up to 500 °C. start affect the composition of the film we see CuO detect at 2θ =35.53°, 38.70° which match reflection from (-111) and (200) planes of CuO , on general we note Defeat appearance of pure Cu at 2θ = 43.09 , 50.32, and 75.07 at planes (111) , (220) and (200) and appearance for Cu₂O at 2θ =36.23 , 42.29 , 61.24 , 74.07 at planes(111) , (200) , (220) and (311) . The increase in crystallite size can be attributed to the change in crystallographic phase from Cu to Cu₂O. This relatively small crystallite size in nanometer was due to the low growth rate of copper oxide film. In the end at a temperature of 600 °C it's clear to see Cu₂O can noticed overcome the appearance to Cu and CuO due to the oxidation process

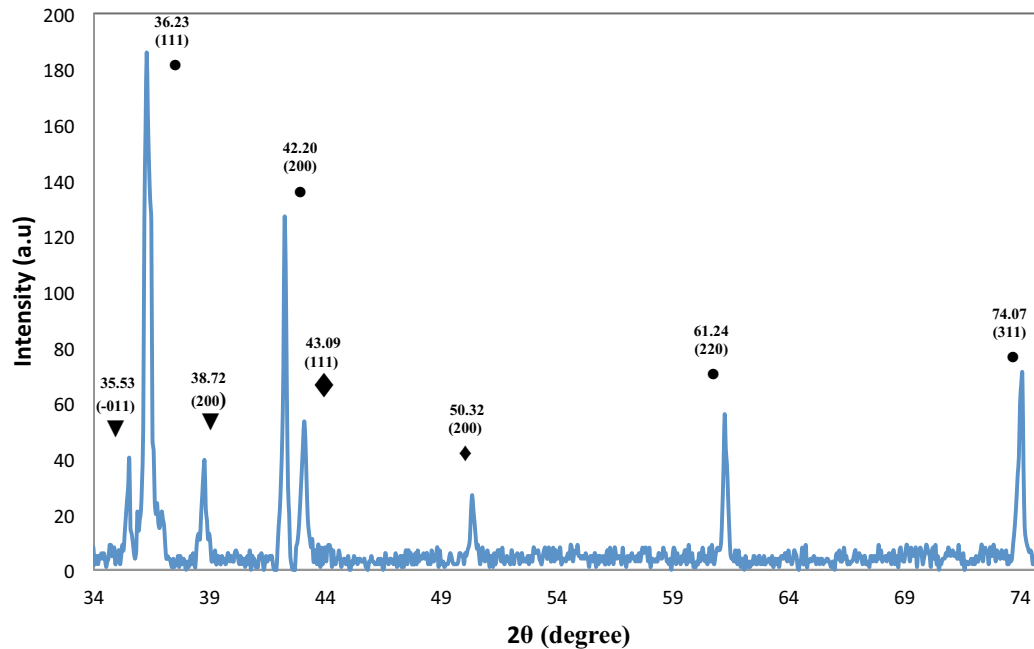


Figure1. XRD patterns of annealed and reference samples of Cu_2O thin films.

3.2 Electrical measurements of device

Current-Voltage characteristics: The results in figure 2a give the I-V characteristic behavior of the $\text{Cu}_2\text{O}/\text{N-Si}$ heterojunctions in the forward bias. Two regions are recognized; the first one represents recombination current while the second represents the tunneling current. Figure (2) gives a comparison between the results obtained at substrate temperature and different forward voltage for two junctions.

Most of the samples prepared at various deposition temperatures exhibit good rectification behavior and their leakage currents tend to increase with the substrate temperature.

Using n-type silicon substrate $\text{Cu}_2\text{O}/\text{Si}$ heterojunction device was deposited, the results of the current-voltage (I-V) measurements in the dark for the prepared heterojunctions was present on the figure (2). These characteristics are very important to describe the heterojunction performance and all heterojunction parameters depending on these characteristics.

Fig. 2b presented curves, for the I-V characteristics under reverse bias, it is clear that the curve contains two regions; the first is the generation region where the reverse current is slightly increased with the applied voltage and this leads to generation of electron-hole pairs at low bias.

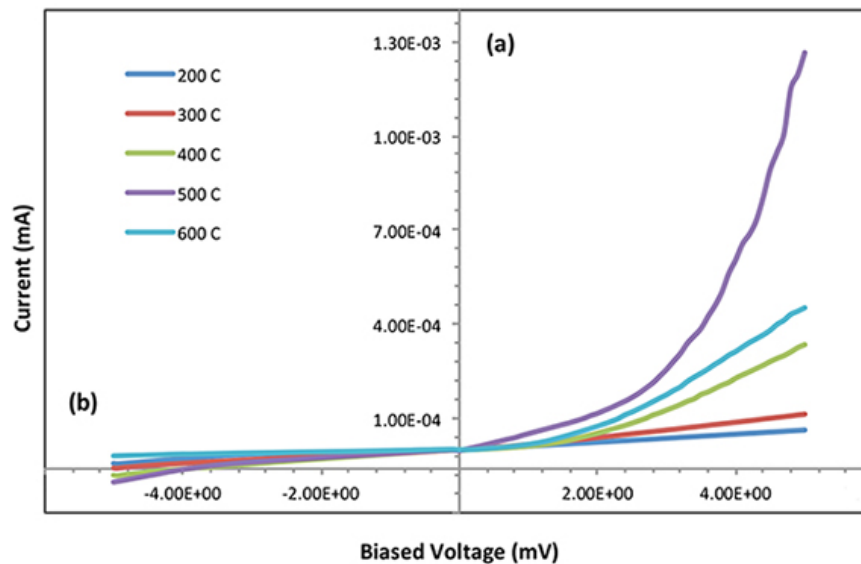


Figure 2. I-V characteristic under forward and reverse biased

It is one of the most important measurements since it determines different parameters such as built-in potential, junction capacitance and junction type.

Give the C-V and C^{-2} -V measurements for both junctions at optimum substrate temperatures and O_2 pressures. Results show that the junction capacitance is inversely proportional to the bias voltage for all prepared samples. The reduction in the junction capacitance with increasing bias voltage is resulted from the expansion of depletion layer with the built-in potential. The depletion layer capacitance refers to the increment in charge per unit area to the incremental change of the applied voltage. This property gives an indication about the behavior of the charge transition from the donor to the acceptor region, which was found to be “abrupt” and this is confirmed when the relation between $1/C^2$ and reverse bias is a straight line.

Figure 3 present the C-V plot and C^{-2} -V of the nano and micro grown silver oxide hetrostructure deposited on the Si substrate at 40 kHz, this fig present an (abrupt junction) as a linear relationship between the $1/C^2$ and the V at the optimum preparing condition to the x-axis (0.77 V) essentially equal to the diffusion potential within Cu_2O side.

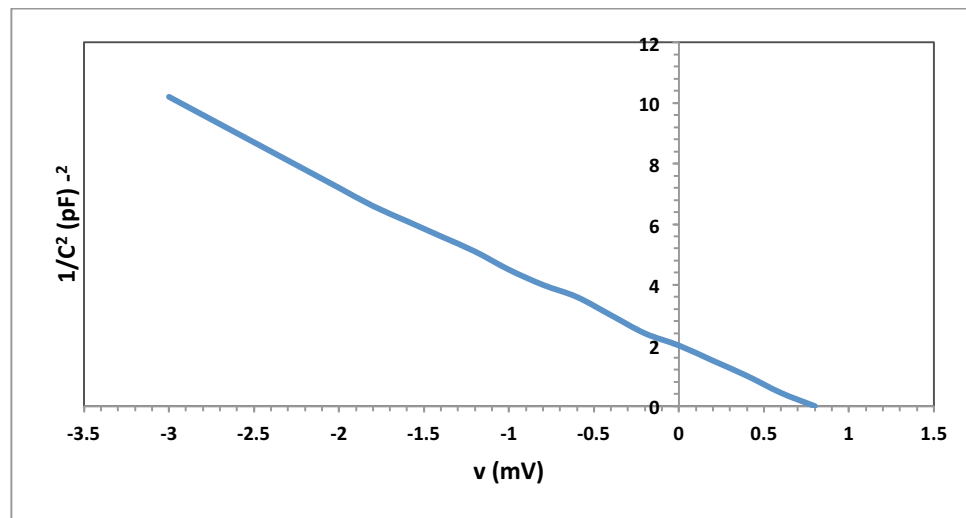


Figure 3. C-V and C-2-V characteristics for Cu₂O/Si heterojunction, error bar (± 0.05 nF).

3.3 Measurements of device Parameters

Spectral Responsivity (R_i): The spectral responsivity represents the ratio between the output generated current to the incident power and it is very important because it specifies the performance range of detector.

The presented results of the spectral responsivity were performed using the double-beam UIR-210A spectrophotometer operating within the range (0.15-1.1) μm of the wavelengths while the current measurements were performed using the Fluke digital millimeter (8010 DMM). The values of the spectral responsivity were calculating using the following equation: [18-21]

$$R_{\lambda} = \frac{I_{ph}}{P_i} \quad \text{A/W} \quad (2)$$

where I_{ph} is the measured photocurrent and P_i is the incident optical power.

Figure (4) showed the responsivity plot at optimum deposition conditions. It could recognize that the curve consists of two response regions, first region at the short wavelengths region a considerable Increase in the responsivity values appears, these relate to a high value of the absorption coefficient in this wavelength region (600 nm) and it is for the copper oxide that responsive for red region wavelength, at 780 nm wavelength range, the responsivity dependent on the absorption in the depletion region and at the length of diffusion from the minority carriers on both side around the multi-structure this for the silicon and that is responsive for IR region wavelength

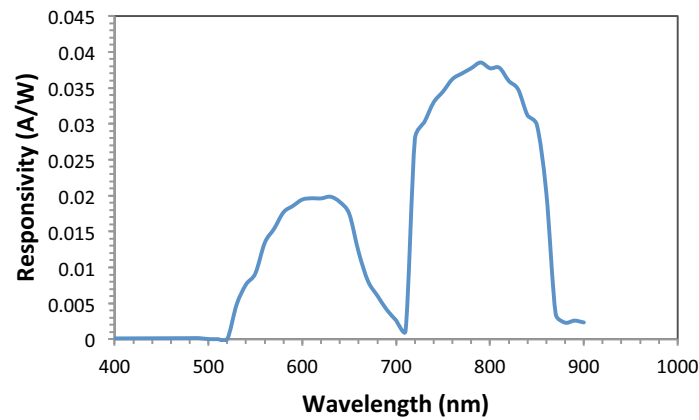


Figure 4. The responsivity characteristics at optimum substrates temperature

Figure (5) present the open voltage decay pulse of the $\text{Cu}_2\text{O}/\text{Si}$ heterostructure and we could recognize the value of the carrier life time of about (113 μs) which give rise in the enhancement of other device photocurrent and quantum efficiency.

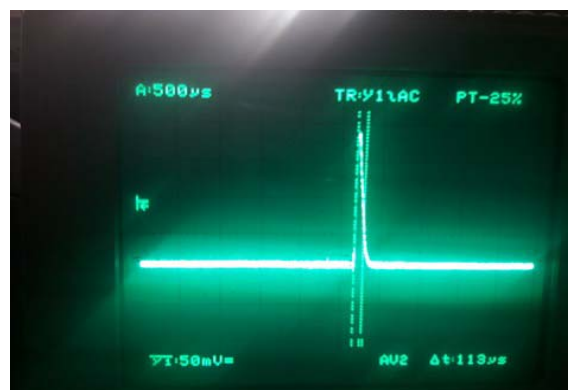


Figure 5. the carrier life time pulse of Cu_2O film

Figure (6) presents the obtain the response time pulse from fabricated detector device, which find to be (5.48 μs),

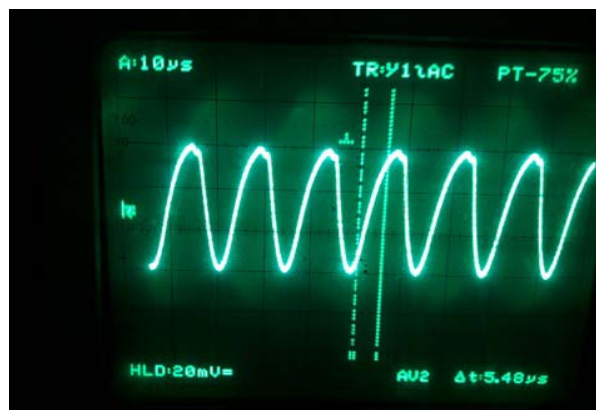


Figure 6. Response time of Cu_2O device

4. Conclusion

The encouraged optoelectronic properties of this heterojunction suggest that it candidate to be visible-enhanced photo detectors. The method of fabricating Cu₂O layer by RPLD method are, cheap, and it is hoped it can be improved either by doping or annealing. According to the obtained electrical properties a good enhancement in the device performance could be achieve and it could recognize clearly that device has two main peak of the Responsivity, at (600nm). The encouraged optoelectronic properties of this heterojunction suggest that it candidate to be visible- enhanced photo detectors. The photodiode exhibited good rectifying characteristics and the turn-on voltage was around I-V. The C-V measurements showed an abrupt type junction and a diffusion potential of I-V.

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