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ABSTRACT

This study demonstrates an improvement in the photodetection response of a Cupric Oxide (CuO) thin film through the annealing process. The CuO thin film (400 nm thickness) was deposited on a silicon substrate using DC magnetron sputtering system. Annealing of the as-deposited film was carried out in a muffle furnace at 400 and 500 °C for two hours. X-ray diffraction pattern revealed the formation of a single phase CuO film whose crystallinity improved with increase of the annealing temperature. The field emission scanning electron microscopy indicated a compact and fine granular structure of the as-deposited film whereas the segregation and agglomeration of grains was observed after the film's annealing. The photodetection performance of CuO film with Al contacts was investigated under the exposure of visible light ($\lambda=460$ nm). The current-voltage graphs of as-deposited and annealed films displayed Schottky contact formation between the metal and semiconductor, owing to a lower work function of Al than that of the CuO. The photo-to-dark current ratio of the device was significantly enhanced after the film's annealing. The increase in photocurrent became more pronounced upon increasing the light intensity from 58.4 to 511 $\mu\text{W}/\text{cm}^2$. The maximum current gain and sensitivity values were found to be 66 and 7086.8 % respectively at 10V bias for the film annealed at 500 °C. The rise and fall time of the Al/CuO/Al photodetector was decreased after the film's annealing.

Keywords: metal oxide semiconductor, annealing, copper oxide, photo-detection, band gap

1. Introduction

Copper oxide is a II-VI semiconductor that is often obtained in two phases named as cupric oxide (CuO) and cuprous oxide (Cu₂O). The CuO has a lower band gap (1.2 to 2.1 eV) as compared to the cuprous oxide phase (2.1 to 2.7 eV). Both of these phases find applications in various electronic and optoelectronic devices such as in solar cells, lithium batteries, light emitting diodes, photodiodes and optical fiber [1-5]. Copper oxide thin films have been synthesized by using various techniques including thermal evaporation, spray pyrolysis, sol gel, chemical vapor deposition (CVD), molecular beam epitaxy, pulsed laser deposition (PLD) and DC/RF magnetron sputtering [6-12].

Post-deposition annealing of a metal oxide film in air is thought to be an effective way to enhance its crystalline quality. In the case of copper oxide, it has been realized that it is quite difficult to form cupric oxide phase without annealing. The as-prepared copper oxide films often contain cuprous oxide phase that can be changed into the cupric oxide at a certain annealing temperature [13-14]. Johan and co-workers [13] prepared copper oxide film on glass substrate by chemical deposition method. The films were annealed in air between 200 to 400 °C. The results showed that the films annealed at 300 °C contained mixed phase whereas the cuprous oxide phase was transformed into the cupric oxide phase at 400 °C. Figueiredo *et al.* [14] synthesized copper oxide film through the thermal oxidation of metallic copper and annealed it in the temperature range of 100 to 450 °C. The films at 100 °C exhibited mixed Cu and Cu₂O phases, whereas between 200 to 300 °C, Cu₂O phase was obtained. The Cu₂O phase was transformed into CuO phase with further increase of the annealing temperature. Similarly, some other studies were also conducted to investigate the changes in copper oxide film phases through the post-deposition annealing process [15-16].

In recent times, there has been a significant interest in developing various photodetectors based on metal oxide semiconductors [17-20]. For this purpose, a lot of work has been done to fabricate ultraviolet photodetectors based on wide band gap semiconductors [21-24]. However, for the visible photodetectors, often silicon was utilized [25]. It has been found that the silicon based visible photodetectors are undesirable in flexible and transparent electronic applications due to their bulky and brittle properties [26-28]. Moreover, these photodetectors show lower current gain in the visible region as compared to the infrared region. Copper oxide is a p-type semiconductor that exhibits band gap wavelength corresponding to the visible region. Therefore, it can be effectively used for the photodetector application. Previous literature shows a limited work on the copper oxide film-based photodetectors [26,29-31]. Particularly, improvement in the performance of CuO photodetectors through annealing has been rarely investigated as compared to other photodetectors [29]. In this work, thin film of CuO has been deposited and characterized for the fabrication of a metal-semiconductor-metal photodetector and its performance has been improved through the annealing process.

2. Experimental Work

Copper oxide (CuO) thin films were deposited on Si (100) by using direct current (DC) magnetron sputtering system. As received silicon wafer was cut by a diamond cutter in different pieces ($2 \times 2 \text{ cm}^2$). The samples were cleaned by using acetone to remove any contamination. The DC magnetron sputtering system (DaON 1000S) was used for the film deposition. The samples were mounted on the substrate holder inside the sputtering system. Pure Copper was used as a target material and it was fixed on a holder inside the chamber. The chamber was evacuated using rotatory and turbo molecular pumps. Afterwards, argon and oxygen gases were filled inside the chamber at 90:10 ratio. In the absence of gases, the base pressure was 2.3×10^{-5} mbar. However,

when gases were entered inside the chamber, the working pressure was noted to be 1×10^{-3} mbar. The target was sputtered at 30 W in Ar-O₂ atmosphere to deposit copper oxide film on Si substrate. The thickness of the deposited film (about 400 nm) was estimated from the thickness profilometer fixed on the sputtering system. The average deposition rate during the film's deposition was 0.8 Å/sec. The as-deposited films were annealed (in air) at 400 and 500 °C for 2 hours in a muffle furnace. The annealed films were characterized by various techniques such as x-ray diffraction, field emission scanning electron microscope and UV-vis reflectance spectroscopy for structural, morphological, and optical measurements respectively. For the fabrication of Al/CuO/Al MSM photodetector, the film of optimum crystallinity was used. The Al contacts were deposited on the film by using RF sputtering through metal mask (Figure 1). The length and width of the metal mask were 3 and 0.12 mm respectively. The activation area for the incident light was 0.036 cm². The current-voltage system Keithly (SCS-4200) was used for the determination of photodetection characteristics of the copper oxide film [31].

3. Results and Discussion

3.1 X-ray Diffraction Results

Grazing incident x-ray diffraction (GIXRD) patterns of as-deposited and annealed CuO films in the 2θ range of 30-80° are shown in Fig. 2. These patterns show a well-defined cupric oxide (CuO) peak oriented along (-111) plane. When the film is annealed at 400 °C, crystallinity of the film improves as the width of the diffraction peak decreases which is followed by an increase in its intensity. By increasing the annealing temperature to 500 °C, the width of CuO peak is further reduced. In addition, the diffraction peaks of CuO also appear along (200) and (202) planes. This indicates further improvement in the crystalline quality of the film. The peaks of CuO along (200)

and (202) planes below 500 °C could not be detected due to their low structural quality. For the observation of crystallite size (D) before and after annealing, the Scherer formula was used;

$$D = \frac{K\lambda}{\beta \cos \theta} \quad (1)$$

Here, 'λ' is the wavelength of x-rays, the shape constant 'k' has a value of about 0.9, 'β' is the FWHM (in radian), 'θ' is the Bragg's angle (in radian) [32]. The values of crystallite size for as-deposited CuO film is found to be 16 nm whereas after annealing at 400 and 500 °C, the crystallite size was obtained as 18 and 26 nm respectively. The increase of crystallite size after the annealing is due to removal of strain/stress in the film by the heat treatment process [33]. When the CuO film is annealed at 400 °C in air then the thermal energy relaxes the internal strains within the atoms of the film thus promoting crystallites of larger size with reduced grain boundaries. The small crystal size shows nanocrystalline nature of the film. The microstrain in the film was evaluated from the following equation [34];

$$\varepsilon = \frac{\beta \cos \theta}{4} \quad (2)$$

The microstrain before annealing was calculated to be 0.0021 whereas after annealing at 400 and 500 °C, the strain was reduced to 0.0018 and 0.0013 respectively. The dislocation density inside the pre- and post annealed films was found by the following formula;

$$\delta = \frac{1}{D^2} \quad (3)$$

The values of dislocation density came out to be 38×10^{14} , 29×10^{14} and $14 \times 10^{14} / \text{m}^2$ for the as-deposited and annealed films at 400 °C and 500 °C respectively. This analysis suggests that the CuO shows enhanced crystallinity when it is annealed at 500 °C. Annealing of CuO film facilitates the re-arrangement of atoms in the crystal thus improves its structural quality.

3.2 FESEM analysis

The surface analysis is an important property of a thin film which may directly affect its electrical and optical properties. Therefore, investigation of the surface morphology of CuO film is of critical importance. In this work, the surface morphology of the CuO film was investigated by FESEM and the images obtained are presented in Fig. 3 (a-c). All these images were captured at 500 nm along with a magnification of 100,000 X. The micrograph of the as-deposited film is shown in Fig. 3 (a). The figure reveals a compact and smooth surface of the film containing fine granular structure with homogeneous distribution of grains over the surface. The average grain size of CuO was estimated to be 25 nm. The surface features of CuO film annealed at 400 °C and at 500 °C are shown in Fig. 3 (b) and (c) respectively. The film annealed at 400 °C indicates that the grains are not as inter-connected to each other as observed in the case of as-deposited film. However, the average grain size becomes larger than that of the as-deposited film (30 nm). A few cracks on the film's surface are also seen that may be due to thermal stresses generated during the annealing process. When the film is annealed then the thermal energy supplied to the material not only facilitates in the rearrangement of the atoms, but it also produces thermal stresses that cause the generation of cracks inside the film. When the annealing temperature increases to 500 °C, then small grains merge together to form larger grains due to increased thermal energy. The average grain size at this temperature is found to be 42 nm. The grains are slightly elongated and the film structure becomes denser as seen from the Fig. 3 (c). Moreover, the surface shows small cracks due to thermal stresses as explained above. These cracks normally occur in the copper oxide film when it is given a heat treatment and it is in accordance with the literature [35]. These results are consistent with the XRD results in which crystallite size was increased with increase of the annealing temperature to 500 °C.

3.3 Optical characterization

The optical characterization of copper oxide film of optimum crystalline quality (annealed at 500 °C) was performed by using ultraviolet-visible reflectance spectroscopy to obtain the film's band gap. The spectroscopy was performed in a reflectance mode and the reflectance spectrum of the film is shown in Fig. 4. The spectrum shows constructive and destructive interference fringes due to light reflection from the CuO film and the silicon substrate. The reflected light waves interfere with each and produce fringes. At a certain wavelength, the copper film absorbs energy and these fringes are vanished. This point where the fringes disappear is referred to as cut-off wavelength point. The optical band gap of the CuO film was calculated by finding the cut-off wavelength and using the following relation [36];

$$E = \frac{hc}{\lambda} \quad (4)$$

Here,

h = Planck's constant,

c = speed of light

λ = wavelength of light

The cut-off wavelength of the CuO film was found to be about 470 nm whereas the corresponding band gap energy was calculated to be 2.63 eV. The value of the band gap energy of CuO film in this work is higher than its normal value range. This may be due to quantum size effect that occurs in the film due to its small crystallite size which results into a splitting of energy levels of the film [37]. In this way the distance between the energy levels/bands of the film increases and hence the higher band gap was obtained.

3.4 Photo-detection characteristics

3.4.1 Current-Voltage characteristics

Current-voltage (I-V) curves of Al/CuO/Al device at 10V bias voltage before and after annealing are shown in Fig. 5 (a-c). The curve without light illumination represents dark I-V characteristics whereas the curve under visible light ($\lambda=460$ nm, $I=58.4 \mu\text{W}/\text{cm}^2$) represents photo I-V characteristics. As we see that the I-V characteristics of the as-deposited film do not display any appreciable difference between the dark and photocurrents (Fig. 5 (a)). These curves show inconsistent behavior in the variation of current with voltage in both dark and illuminated conditions. The insignificant increase in photocurrent from the as-deposited film occurs due to structural defects in the un-annealed film [38]. These defects may act as trapping centers which reduce the flow of charge carriers and thus no considerable increase in the photocurrent occurs. Moreover, the inhomogeneous metal semiconductor interface in this film may be responsible for producing uneven I-V curves.

The I-V curves of Al/CuO/Al photodetector annealed at 400 °C are shown in Fig. 5 (b). The figure shows an increase in the photocurrent when the device is exposed to visible light (460 nm). This means that the annealing of CuO film reduced structural defects inside it that caused the current flow in the device. The incident light on CuO film creates electron-hole pairs that increases the photocurrent. The Fig. 5 (b) shows the formation of Schottky contact between the metal (Al) and semiconductor (CuO film). The Schottky contact is formed due to lower work of Al (4.1 eV) as compared to the p-type CuO film (4.7eV). Consequently holes from p-CuO move towards Al and thus a Schottky barrier is formed between the metal and semiconductor. The I-V curves of CuO film annealed at 500 °C are shown in Fig. 5 (c). The figure shows that with increase of annealing temperature to 500 °C, the photocurrent further increases. This occurs due to further

improvement in the crystallinity of the film due to its annealing at higher temperature. [39]. The process of annealing causes atoms to migrate in the crystal lattice and thus number of dislocations are reduced that reduce the trapping centers of the charge carriers. The ad-atoms become more mobile and migrates towards favorable sites in the crystal lattice, thus, resulting in an improvement in the crystallinity of the film. This decreases the number of trap centers created by the defects and accelerate the recombination process of the free charge carriers. Hence, increasing annealing temperature effectively enhances the photo detection response of the CuO film.

3.4.2 Current-Voltage characteristic at variable light intensities

At variable intensities, I-V characteristic of Al/CuO/Al photodetectors annealed at 400 °C and at 500 °C are shown in Fig. 6 (a-b) respectively. The Fig. 6 (a) shows that with increase in the intensity of incident light, the photocurrent increases. This increase in photocurrent is due to increase in the number of photons that impinge on sample's surface [40]. When we increase the intensity, then the number of incident photons on the film are also increased, that generate more electron-hole pairs, thus photocurrent increases. The Schottky contact formation between the metal and semiconductor is also noticed from the figure. Since the energy of the incident light is slightly greater than the band gap energy of the film therefore, the light is absorbed by the semiconductor and free charge carriers produced cause photocurrent. Greater the number of incident photons, more will be the generated charge carriers and vice versa. Therefore, the photocurrent increases consistently with increasing the light intensity. Similarly, I-V curves of CuO film annealed at 500 °C show increase in the photocurrent both in forward and reverse directions with increase of the light intensity (Fig.6 (b)). However, as compared to the film annealed at lower temperature (400 °C), the values of photocurrent is higher at 500 °C. This means that the annealing of CuO film improves its photodetection properties and a higher photocurrent is produced [41].

3.4.3 Current-time (I-t) calculations at 10 V

The I-t measurements of Al/CuO/Al photodetector were performed to observe the repeatability performance of the fabricated device. The I-t measurements were recorded by switching ON and OFF the visible light (460 nm) after regular intervals. Figure 7 shows I-t graphs of as-deposited and annealed film (400 °C). We see that the current increases when the light is incident on the film and once the light is turned OFF, the current falls again to its initial level. This means that the photodetector works consistently under the exposure of light. Both the dark and photocurrents of the as-deposited film are quite low therefore the pulses are not clearly visible on this larger graph scale. However, the photocurrent increases as the annealing temperature is increased. The difference between dark and photocurrents is larger in the case of CuO film annealed at 500 °C as compared to that annealed at 400 °C (Fig. 8). Similarly, when the intensity of light is changed, then the I-t graphs show a consistent increase in the heights of I-t pulses indicating an increase of the photocurrent. The results show that by increasing the annealing temperature as well as the light intensities, the device shows better performance. In order to evaluate the current gain and sensitivity, the following equations were used [42-43];

$$G = \frac{I_p}{I_d} \quad (5)$$

$$S = \frac{I_p - I_d}{I_d} \times 100 \quad (6)$$

Here, I_p is photocurrent and I_d is dark current. The values of current gain and sensitivity of the device at a fixed light intensity is shown in Table 1. The table shows that the maximum value of current gain and sensitivity with respect to fixed light intensity are 18.8 and 876.9 % respectively at 500 °C. The current gain and sensitivity of the photodetector increase with increase of the annealing temperature to 500 °C. Similarly, the current gain and sensitivity values of CuO device at different light intensities are given in Tables 2-4. The photocurrent increases with increase of

the light intensity from 58.4 to 511 $\mu\text{W}/\text{cm}^2$ at 10V bias. The maximum current gain and sensitivity values are found to be 66 and 7086.8 % respectively at 500 °C. By increasing the light intensity, more free charge carriers (electrons and holes) are generated that results in an increase of the photocurrent. Hence, the current increases by varying light intensities, resulting in an increase in the sensitivity and current gain of the device. These results show that the photodetection characteristics of the film under visible light exposure are improved after annealing particularly at 500 °C.

3.4.4 Rise Time and Fall Time

In order to further evaluate the performance of the device, the rise time and fall time of current was calculated by magnifying the pulses from I-t graphs. The values of rise and fall time at fixed light intensity (58.4 $\mu\text{W}/\text{cm}^2$) are given in Table 5. The rise and fall time decrease after the annealing of the film. The shortest values of rise time (0.16 sec) and fall time (0.26 sec) were obtained for the CuO film annealed at 500 °C. This shows that the reduction in structural defects allows the free charge carriers to move faster inside the material and thus these take shorter time to reach their respective electrodes. A comparison of photodetection parameters of different types of detectors is given in Table 6.

4. Conclusions

- 1) DC sputtering of copper target at room temperature in Ar-O₂ plasma produces single phase CuO film whose crystallinity improves with increase of the annealing temperature.
- 2) The higher band gap of CuO film (2.63 eV) is due to quantum size effect.
- 3) Aluminum (Al) deposition on CuO film promotes Schottky contact between the film and metal.

- 4) The photodetection characteristics of the CuO film under the visible light exposure are considerably improved after its annealing at 500 °C. The photocurrent increases with increase in the annealing temperature as well as with increase of the incident light intensity.
- 5) The increase in photocurrent after annealing is due to reduction in the structural defects inside the CuO film that act as trapping centers for the free charge carriers.

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5. REFERENCES

- [1] Y. Gulen, F. Bayansal, B. Sahin, H. A. Centinkara, H. S. Guder, *Ceramics International* **39** (2013) 6475-6480
- [2] F. Bayansal, T. Taskopru, B. Sahin, H. A. Centinkara, *Metallurgical and Materials Transactions A*, **45** (2014) 3670-3674
- [3] T. Oku, R. Motoyoshi, K. Fujimoto, T. Akiyama, *Journal of Physics and Chemistry of solids*, **72** (2011) 12061211
- [4] A. Goetzberger, V. H. Hoffman, "Photovoltaic Solar energy Generation, New York: Springer 2007
- [5] I. Sullivan, B. Zoellner, P. A. Maggard, *Chemistry of Materials*, **28** (2016) 5999-6016
- [6] M. F. Al- Kuhaili, *Vacuum*, **83** (2008) 623-629
- [7] A. Moumen, B. Hartiti, E. Comini, *Superlattices and Microstructures* **127** (2019) 2-10
- [8] S.S. Shariffudin, *Materials Science and Engineering* **99** (2015) 012007
- [9] J.M. Valtierra, J. R. Ortiz, F. Ruiz, *Applied Catalysis A: General* **238** (2015) 1-9
- [10] K. P. Muthe a, J. C. Vyas a, S. N. Narang a, *Thin Solid films* **324** (1998) 37-43
- [11] P. Chand, A. Guar, A. Kumar, *Applied Surface Science* **307** (2014) 280-286
- [12] A.A Al-Ghamdi, M. H. Khedr, M. S. Ansari, *Physica E* **81** (2016) 83-90
- [13] M. R. Johan, M.S.M. Suan, N.L. Hawari, H.A. Ching, *Int. J. Electrochem. Sci.*, **6** (2011) 6094-6104
- [14] V. Figueiredo, E. Elangovan, G. Goncalves, P. Barquinha, L. Pereira, N. Franco, E. Alves, R. Martins, E. Fortunato, *Applied Surface Science* **254** (2008) 3949–3954
- [15] A. Hojabri, F. Hajakbari, N. Soltanpoor, M.S. Hedayati, *Journal of Theoretical and Applied Physics* **8** (2014) 132-1- 7
- [16] N.A. Raship, M.Z. Sahdan¹, F. Adriyanto, M.F. Nurfazliana¹ A.S. Bakri, *AIP Conference Proceedings*, **1788** (2017) 030121

- [17] S. Abbas, M. kumar, J. Kim, Materials Science in Semiconductor processing **88** (2018) 86-92
- [18] H. Zhu, C. X. Shan, L. K. Wang, The Journal of Physical Chemistry C, **114** (2010) 7169-7172
- [19] T. Zhai, X. Fang, M. Liao, Sensors **9** (2009) 6504-6529
- [20] G. Dushaq, A. Nayfeh, M. Rasras, Journal of Applied Physics **126** (2019) 193106
- [21] M. Patel, H. S. Kim, J. Kim, Advanced Electronic Materials **1** (2015) 1500232
- [22] Y. L. Chu, S. J. Young, L. W. Ji, Sensors **20** (2020) 3861
- [23] C. Zhou, Q. Ai, X. Chen, Chinese Physics B **28** (2019) 048503
- [24] W. Tian, H. Lu, L. Li, Nano Research **8** (2015) 382-405
- [25] B. Esteves, S. Pimenta, E. M. F. Vieira, Materials Letters **286** (2021) 129251
- [26] H. J. Song, M. H. Seo, K. W. Choi, Scientific Reports **9** (2019) 7334
- [27] Q. Lin, A. Armin, D. M. Lyons, Advanced Materials **27** (2015) 2060-2064
- [28] C. Xie, C. Mak, X. Tao, Advanced Functional Materials **27** (2017) 1603886
- [29] P.V. Raghavendra, J. S. Bhat, Superlattices and Micrstructures **113** (2018) 754-760
- [30] Q. Zhang, K. Zhang, D. Xu, Progress in Materials science **60** (2014) 208-337
- [31] S. B. Wang, C. H. Hsiao, S. J. Chang, K.T. Lam, Sensors and Actuators A: Physical **171** (2011) 207-211
- [32] A. hojbari, F. Hajakbari, A. E. Meibodi, J. Thero, Applied Physics **9** (2015) 67-73
- [33] N. Illyaskutty, S.Sreedar, G.S. Kumar, H.Kohlar , M.Schwotzer, C. Natzeel, V.P.M. Pillai, Nanoscale **6** (2014) 13822-13894
- [34] M. Imran, R. Ahmad, N. Afzal, M. Rafique, Vacuum **165** (2019) 72-80
- [35] F. Aksoy, G. Akgul, N. Yildirim, H.Emrah, R. Turan, Materials Chemistry and Physics, **147** (2014) 987-995
- [36] L. Wei, Y. Yang, X. Xia, R. Fan, T. Su, Y. Shi, J. Yu, L. Li, Y. Jiang, RSC Advances **5** (2015) 70512-70521
- [37] S.Rehman, A. Mumtaz, S.K. Hasanain, J Nanopart **13** (2011) 2497-2507
- [38] A.Ghicov, H. Tsuchyia, J. M. Macak, Applications and material science **203** (2006) 28-30

- [39] M. hajimazdarani, E.Ghasali, N. Naderi, Y.Orooji, *Ceramics International* **46** (2020) 28382-28389
- [40] S.Gunassekran, D. Thangaraju, R. Marnadu, *Surfaces and Interfaces* **20** (2020) 100622
- [41] R. San, C. Wang, C. H. Chan, H. Pin, *Nanoscale Research Letters* **8** (2013) 443
- [42] M.Z. Mohd Yusoff, Z. Hassan, Abu Hassan, Abdullah, M.Rusop, *Materials Science in Semiconductor Processing* **34** (2015) 214-223
- [43] H. Ahmad, N.Afzal, M. Rafique, Anas A. Ahmed, R. Ahmad, Z. Khaliq, *Ceramics Int.* **46** (2020) 20477-20487
- [44] H.T.D.S. Madusanka, H.M.A.M.C. Herath, C.A.N. Farnando, *Sensors and Actuators A: Physical* **296** (2019) 61-69
- [45] D.S. Tsai, K.K. Lu, D.H. Lien, M.L. Tsai, C.F. Kang, C.A.Lin, L.J. Li, J.H. He, *ACS Nano* **7** (2013) 3905-3911
- [46] M. Husham, Z. Hassan, Abass M. Selman, *European Physical Journal: Applied Physics* **74** (2016) 10101-1-8
- [47] N.M. Abd-Alghafour, Naser. M. Ahmed, Z. Hassan, *Sensors and Actuators A: Physical* **250** (2016) 250-257
- [48] N. Afzal, M. Devarajan, *European Physical Journal: Applied Physics* **76** (2016) 10101-1-4

Figure 1 (a) Schematic diagram of metal mask
(b) Schematic diagram of CuO based MSM photodetector

Figure 2 GIXRD patterns of as-deposited and annealed CuO film

RT

400 °C

500 °C

Figure 3 Surface Morphology of as-deposited and annealed CuO film

Figure 4 UV-vis reflectance spectrum of annealed CuO film

Figure 5 I-V curves of CuO film before and after annealing

(a)

(b)

Figure 6 I-V characteristics curve of annealed CuO films at different intensities

Figure 8 Current-time graph of CuO film at variable intensities

Table 1 Current gain and sensitivity of CuO film at fixed light intensity (58 $\mu\text{W}/\text{cm}^2$)

Annealing Temperature (°C)	Current Gain	Sensitivity (%)
RT	1.38	387.6
400	16.8	679.8
500	18.8	876.9

Table 2 Current gain and sensitivity of as-deposited CuO film at different light intensities

Light intensities ($\mu\text{W}/\text{cm}^2$)	Current Gain	Sensitivity (%)
58	1.45	45.02
87	1.76	76.02
146	1.95	96
438	2.07	107
470	2.30	130.4
511	2.44	144

Table 3 Current gain/sensitivity of CuO film annealed at 400 °C at various light intensities

Light intensities ($\mu\text{W}/\text{cm}^2$)	Current Gain	Sensitivity (%)
58	14.19	402.84
87	14.40	426.5
146	15.85	585.3
438	17.60	760
470	18.95	895
511	22	1111.37

Table 4 Current gain/sensitivity of CuO film annealed at 500 °C at various light intensities

Light intensities ($\mu\text{W}/\text{cm}^2$)	Current Gain	Sensitivity (%)
58	48	5175.2
87	50	5240
146	54	5800
438	58	6163
470	61	6500
511	66	7086

Table 5 Rise and fall time CuO film at 511 $\mu\text{W}/\text{cm}^2$

Annealing Temperature (°C)	Rise time (sec)	Fall time (sec)
RT	0.39	0.99
400	0.36	0.42
500	0.16	0.26

Table 6 Comparison of photodetection parameters of different types of photodetectors

Type of Materials	Type of Detector	Fabrication Technique	Wavelength λ (nm)	Bias Voltage (V)	Sensitivity (%)	Rise Time (sec)	Ref.
CuO	MSM	DC Sputtering	470	10	7×10^3	0.16	Present Work
CuO	MSM	Electron beam evaporation	450	5	40	53.8	[29]
Cu ₂ O	Heterojunction	Hydrothermal method	425	0	--	0.0058	[44]
MoS ₂	MSM	Chemical	500	10	--	0.00011	[45]
CdS	MSM	CVD	500	1	9.7×10^3	0.009	[46]
V ₂ O ₅	MSM	Spray pyolysis	540	5	2.6×10^3	0.78	[47]
InAlN	MSM	Co-sputtering	520	5	4.8×10^3	0.62	[48]

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Code Availability: N/A