International Journal of Engineering, Mathematical and Physical Sciences
ISSN: 2517-9934
Vol:5, No:11, 2011

Electrical Properties of n-CdO/p-Si Heterojunction Diode Fabricated by Sol Gel

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Abstract**—**n-CdO/p-Si heterojunction diode was fabricated using sol-gel spin coating technique which is a low cost and easily scalable method for preparing of semiconductor films. The structural and morphological properties of CdO film were investigated. The X-ray diffraction (XRD) spectra indicated that the film was of polycrystalline nature. The scanning electron microscopy (SEM) images indicate that the surface morphology CdO film consists of the clusters formed with the coming together of the nanoparticles. The electrical characterization of Au/n-CdO/p–Si/Al heterojunction diode was investigated by current-voltage. The ideality factor of the diode was found to be 3.02 for room temperature. The reverse current of the diode strongly increased with illumination intensity of 100 $mWcm^{-2}$ and the diode gave a maximum open circuit voltage V_{oc} of 0.04 V and short-circuits current I_{sc} of 9.92×10^{-9} A.

Keywords**—**CdO, heterojunction semiconductor devices, ideality factor, current-voltage characteristics

I. Introduction

CADMIUM oxide (CdO) attracts a great attention due to its electrical and optical properties. CdO is an n-type semiconductor with direct band gap at approximately 2.3 eV. This films have been widely studied for optoelectronic applications in transparent conducting oxides (TCO), solar cells, smart windows, optical communications, flat panel displays, photo-transistors, as well as other types of applications like IR heat mirror, gas sensors, low-emissive windows, thin-film resistors, etc [1-4]. Many physical and chemical preparation techniques such as pulsed laser deposition [5], sputtering [6], chemical vapor deposition [7], reactive evaporation [8], spray pyrolysis [9], sol-gel [10-12], etc. have been used in order to obtain CdO films. The sol-gel spin coating technique has various advantages such as cost effectiveness, thin, transparent multicomponent oxide layers of many compositions on various substrates, simplicity, excellent compositional control, homogeneity and lower crystallization temperature. In this paper, the structural and morphological properties of CdO film obtained by sol-gel spin coating technique have been investigated. Also, the electrical properties of p-Si/n-CdO heterojunction diode have been investigated by means of current-voltage (*I-V*).

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II. Experimental Details

The sol-gel spin coating technique was used to deposit the CdO films. The coating solution was prepared by using 0.5M cadmium acetate dihydrate [$C_4H_6CdO_4.2H_2O$] together with 2-methoxethanol and monoethanolamine (MEA). 2-methoxethanol and MEA were used as a solvent and stabilizer, respectively. The solution was stirred constantly during its preparation. The solution was stirred at room temperature for 2 h to yield a clear and homogeneous coating solution. The CdO films were deposited on both silicon and glass substrates under the same experimental conditions. Thus, both films were fabricated at the same time and conditions. One of the CdO films deposited on the glass substrates was used for the structural properties. The other CdO film, deposited on the p-Si substrate was used for the electrical properties. The Si substrate is a p-type (boron-doped) single crystal silicon <100> with a thickness of 600nm and a resistivity of 1–10Ω-cm. First, Si wafer was degreased through RCA cleaning procedure, i.e., a 10min boiling in $NH_4OH+H_2O_2$ + 6 deionized (DI) (18MΩ DI water), which was followed by a 10min boiling in HCl $+H_2O_2$ + 6 DI. Before forming an CdO layer on p-type Si substrate, the native oxide on the polish surface of the substrate was removed in $HF:H_2O$ (1:10) solution, and finally, the wafer was rinsed in DI water. The CdO films were deposited on substrates by sol–gel spin coating method. The coating solution was dropped onto substrates and then the substrates were rotated at 2000 rpm. After the spin coating, the films were dried at 300˚C for 10 min. This coating/drying procedure was repeated for ten times and then annealed at 500˚C in air for 1 h. The ohmic contact was formed by evaporating Al metal on the back of Si wafer and then, it was annealed at 570 ◦C for 3 min in N2 atmosphere. After thermal annealing process, Au metal contacts were formed on CdO film deposited on p-type-silicon using PVD-HANDY-MT/101T (Vaksis Company) vacuum thermal evaporation in the pressure of 5×10^{-5} Torr and the contacts were formed in the form of circular dots of 1mm in diameter. Fig. 1 shows the schematic diagram of an n-CdO/p-Si heterojunction diode.

X-ray diffraction (XRD) experiments were performed by X-ray powder diffractometer (D8 Advance, BRUKER AXS) in air. The diffractometer reflection of all the films was taken at room temperature. Surface morphology was studied using a ZEISS Ultraplus model field emission scanning electron microscopy (SEM). The current–voltage characteristics of the diode were performed using a KEITHLEY 4200 SCS-CV Semiconductor Characterization System. The photocurrent measurements were performed using Sciencetech Arc Lamb System (Air Mass 1.5 G) under $100mW/cm^2$ intensity by a KEITHLEY 6517A Electrometer.

International Journal of Engineering, Mathematical and Physical Sciences
ISSN: 2517-9934
Vol:5, No:11, 2011

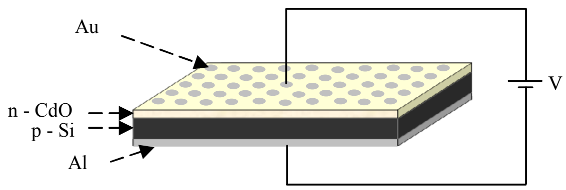

Fig. 1 The schematic structure of n-CdO/p-Si heterojunction diode

III. Results and Discussions

A. Structural and Morphological Properties of CdO Film

Fig. 2 shows an XRD spectrum of a CdO film grown on the glass substrate. All the peaks belong to cubic monteponite phase of the CdO (JCPDS card no: 005-0640). No metallic cadmium phases existed in the XRD pattern.

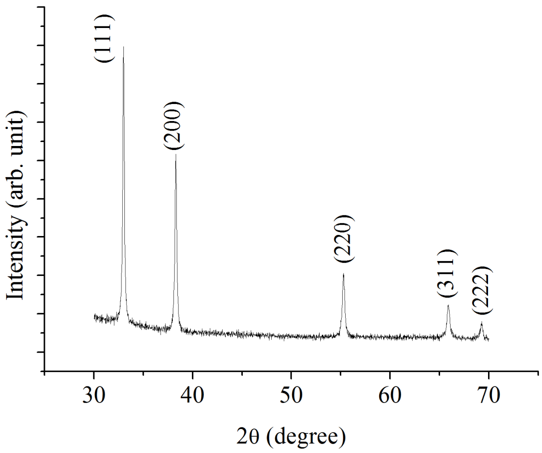

Fig. 2 XRD pattern of the CdO film.

The texture coefficient *(TC)* represents the texture of particular plane, deviation of which from unity implies the preferred growth. Quantitative information concerning the preferential crystallite orientation was obtained from the different texture coefficient *TC(hkl)* [13]. The texture coefficients were calculated for all the peaks. $I(hkl)/I_o(hkl)$ and TC*(hkl)* values were found to be 2.30, 1.53, 0.58, 0.35 and 0.24 for planes (111), (200), (220), (311) and (222), respectively. So, the film is polycrystalline in nature with preferential orientation along the (111) crystal plane. The average crystallite size of the CdO film was calculated using the Scherrer's equation [14]. The average crystallite size of the CdO film was found to be 47 nm for the (111) direction.

Fig. 3 shows the SEM image of the CdO film which was used on the nanocluster n-CdO/p-Si heterostructure. In Fig. 3, the clusters which homogenously spread on the whole of the film surface are seen. Also, as seen in Fig. 3, the clusters are formed from the nanoparticles. The sizes of the clusters are approximately 1 μm and the diameters of nanoparticles are about 200 nm.

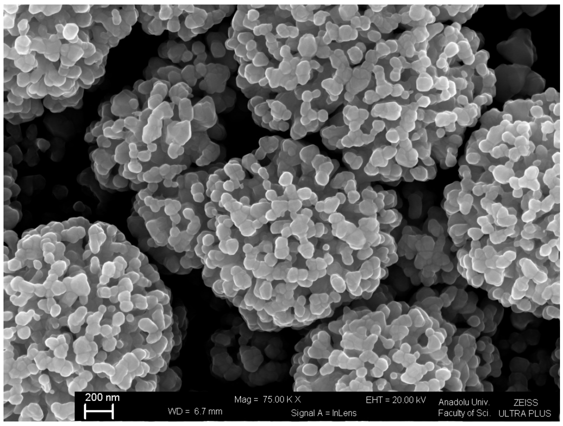

Fig. 3 SEM images of CdO film

B. Current-Voltage Characteristics of n-CdO/p-Si heterojunction diode

The current–voltage *(I–V)* characteristics of the n-CdO/p-Si heterojunction diode are shown in Fig. 4. The *I–V* characteristics of the diode can be analyzed by the following relation [15],

$$I = I_0\left[\exp\left(\frac{qV}{nkT}\right)-1\right] \tag{1}$$

where V is the applied voltage, n is the ideality factor, k is the Boltzmann constant, T is the temperature and I_0 is the reverse saturation current. The n of the diode was determined from the slope of the linear region of forward bias of Fig. 4 and it was found to be 3.02. The diode showed a good rectification characteristic, as can be seen in Fig. 4. The obtained n value higher than unity may be attributed to the interface states, series resistance and native oxide layer.

The ϕ_b is the zero-bias barrier height, which can be obtained from the following equation:

$$\phi_b = \left(\frac{kT}{q}\right) ln\left(\frac{AA^{*}T^{2}}{I_0}\right) \tag{2}$$

The ϕ_b of the n-CdO/p-Si heterojunction diode was found to be 0.64 eV at room temperature.

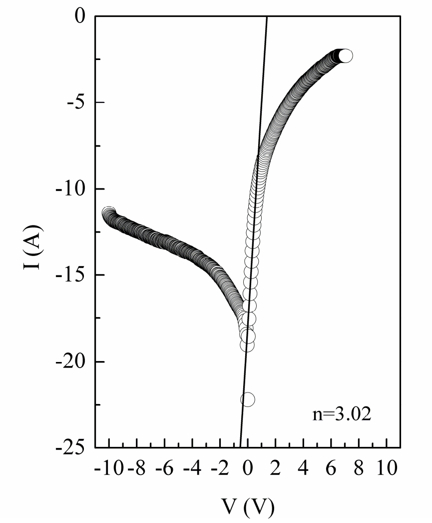

Fig. 4 Current–voltage characteristics of the n-CdO/p-Si heterojunction diode

Norde method is an alternative method to determine value of the series resistance and the barrier height of the diode and we used Norde method given by the following relation [16],

$$F(V) = \frac{V_0}{\gamma} - \frac{kT}{q} ln\left(\frac{I(V)}{A^* AT^2}\right) \tag{3}$$

where γ is the integer (dimensionless) greater than n. *I(V)* is the current obtained from the *I–V* characteristic. Fig. 5 shows the plot of *F(V)* vs. voltage for different temperature. Once the minimum of the *F* vs. *V* plot is determined, the value of barrier height can be obtained from Eq. (4), where $F(V_0)$ is the minimum point of *F(V)*, and V_0 is the corresponding voltage

$$\phi_b = F(V_0) + \frac{V_0}{\gamma} - \frac{kT}{q} \tag{4}$$

The barrier height was found to be 0.71 eV. The series resistance is given by the following relation

$$R_s = \frac{kT(\gamma - n)}{qI_1} \tag{5}$$

where γ is the integer (dimensionless) greater than *n*, *q* is the charge of an electron and I_1 is the current obtained from the minimum point of *F(V)*. The R_s value for n-CdO/p-Si heterojunction diode was determined using Eq. (5) and was found to be 7.13kΩ.

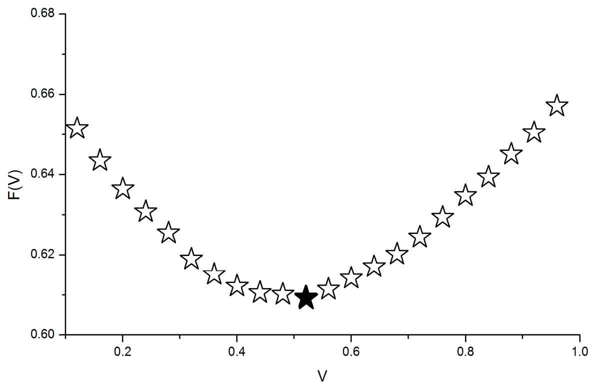

Fig. 5 Plot of *F(V)* vs. *V* for the n-CdO/p-Si heterojunction diode

In order to characterize the photovoltaic behavior of the heterojunction diode, the *I–V* characteristics of the diode under dark and illumination conditions were performed, as shown in Fig. 6. As seen in Fig. 6, the reverse current increases with illumination intensity of 100 $mWcm^{-2}$ and the diode gives a maximum open circuit voltage V_{oc} of 0.04 V and short-circuits current I_{sc} of 9.92×10^{-9} A. These values indicate that the n-CdO/p-Si heterojunction diode exhibits a photovoltaic behavior, because the photovoltaic effect involves the creation of a voltage and current in a p–n heterojunction upon exposure to light intensity. The open circuit voltage V_{oc} of the n-CdO/p-Si heterojunction diode is low. Under illumination, the forward current of the diode is higher than the dark current.

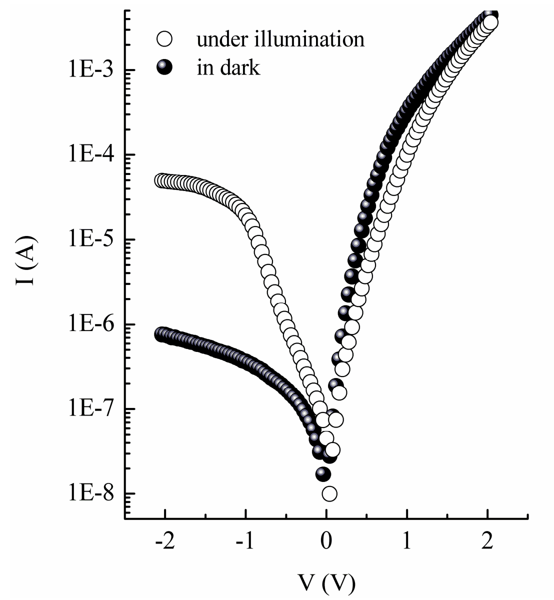

Fig. 6 Current–voltage characteristics of the n-CdO/p-Si heterojunction diode under dark and UV illumination conditions

The phototransient current plot of the diode is shown in Fig. 7. As seen in Fig. 7, the photocurrent changes with time after turning on and off situations. The diode exhibits good photoconductivity. After the switching light on the diode, the photocurrent indicates an abrupt increase and in short time, the photocurrent shows a stable plateau value. This increase in the photocurrent of the diode depends on the difference between the electron affinities of the p-Si and n-CdO semiconductors. After the light off switching, the current reaches the first situation.

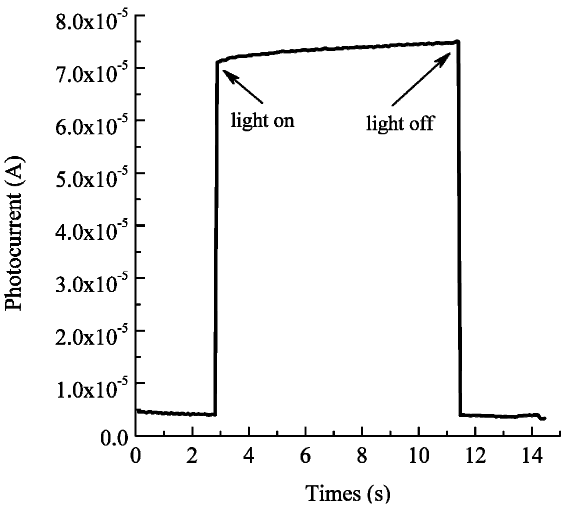

Fig. 7 Time dependent photocurrent response of the n-CdO/p-Si heterojunction diode under 100 mW/cm^2 illumination.

IV. Conclusion

The n-CdO/p-Si heterojunction diode was fabricated by sol–gel spin coating method. The structural and morphological properties of the CdO film were investigated. The average crystallite size of CdO film was determined by both the XRD result and FESEM image. The current–voltage characteristics of the n-CdO/p-Si heterojunction diode showed non-ideal contact behavior with the ideality factor higher than unity. The ideality factor and the barrier height of this diode were determined 3.02 and 0.64 eV by current–voltage methods at room temperature.

Acknowledgment

This work was supported by Anadolu University Commission of Scientific Research Projects under Grant No. 081029 and 1001F05.

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