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GROWTH OF CADMIUM OXIDE NANORODS BY VAPOR TRANSPORT

M. ZAIEN*, N. M. AHMED, Z. HASSAN
Nano-Optoelectronics Research and Technology Laboratory
School of Physics, Universiti Sains Malaysia, 11800 USM, Penang, Malaysia

Cadmium oxide (CdO) nanorods were successfully synthesized at 1400 K using a vapor transport process (solid-vapor deposition) without catalyst. Field emission scanning electron microscopy revealed the diameter of the nanorods was (128.5nm) with different lengths were more than (1µm). X-ray diffraction and energy dispersive X-ray techniques were used to characterize the structural properties of the nanorods. Photoluminescence spectroscopy was conducted to investigate the optical properties of the nanostructures. The red-shift direct band gap energy of the CdO nanorods is 534 nm (2.32eV). In comparison, the optical direct band gap energy of the CdO thin film on quartz substrate is 496 nm (2.5eV), as measured by UV-Vis spectrophotometer.

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Keywords: Nanorods; CdO; solid-vapor deposition

1. Introduction

Currently, nanostructured materials are not only in the forefront of the hottest studies on fundamental materials, but are also gradually entering the daily lives of people. One-dimensional (1D) metal oxide semiconductor nanostructures, such as nanorods and nanowires have attracted wide attention for their potential applications in device and interconnect integrations in nano and molecular electronics [1,2]. Cadmium oxide (CdO) has a narrow direct band gap of 2.2 eV to 2.5 eV [3,4]. This n-type semiconductor has a cubic [NaCl, face center cubic (fcc) type, and lattice constant a = 0.4695 nm] crystal structure with alternating Cd and oxygen atoms located at the lattice scale [5,6]. CdO is solid brown in color, and has a high density (8150 Kg/m^3) and melting point(1500 ^oC). Cadmium oxide is an important II–VI semiconductor [7,8]. Such semiconductors are now widely used as transparent conductive oxides (TCO) in many physical applications, specifically in optoelectronic devices such as solar cells [9,10], diodes and transparent electrodes [11-13]. CdO has high transparency in the visible region of the solar spectrum [14]. Many methods have been adopted to grow CdO, including chemical bath deposition [15], sol–gel method [16,17], vapor–liquid–solid (VLS) [18,19], thermal evaporation [20], and it has been synthesized directly and grown by evaporating CdO powder at 1000 °C [2]. Cadmium can be directly heated up to 900 °C in air or with a trace amount of oxygen in an argon (Ar) flow [18]. In the present paper, CdO nanorods were synthesized via a vapor transport process (solid-vapor deposition) at high temperature without a catalyst. The morphological, structural, and optical properties of the CdO nanorods were also studied and investigated.

2. Experimental procedures

CdO nanorods were synthesized using a vapor transport process (solid- vapor deposition). This method was selected for its lower cost and simplicity.The substrate used in the present paper was silicon (Si). The products were obtained by controlling several parameters, such as

* Corresponding author: mustafa1973_zzz@yahoo.com

temperature (T), reaction time (t), the gas flow rate (Ar), and the position of the substrate in the furnace.The process of the Radio Corporation of America was used to remove the oxide layer from a P-type Si wafer (1 cm × 1 cm × 283 μm) with a (111) orientation and a resistivity of 0.75 Ω cm. CdO powder (purity: 99.99%, Aldrich) in a quartz boat was placed at the center of a horizontal quartz tube furnace (inner diameter, 20mm).The Si substrate was placed downstream (10cm from the boat, with the polished side facing the source material) of the flowing gas. A flow of Ar gas was initially used to purify the tube. When the temperature reached 1400 K, the CdO powder and Si substrate were placed inside the furnace with an Ar flow of approximately 250 Sccm.The process ran for one hour.The samples were then cooled for two hours at room temperature.The structural morphologic properties of the nanorods were examined using X-ray diffraction (XRD) (X'Pert PRO MRD PW3040, PANalytical), field emission scanning electron microscopy (FESEM), and energy dispersive X-ray (EDX) analysis (Leo Supra 50VP,Carl Zeiss,Germany).The optical properties of the nanorods were investigated by photoluminescence (PL) spectroscopy (HR 800UV, Jobin Yvon, USA) at room temperature using an He–Cd laser (λ = 325 nm), and the optical absorbance of the quartz substrate was measured by UV-Vis spectrophotometer (U-2000, HITACHI).

3.Results and discussion

In Fig. 1, the XRD patterns of the CdO nanorods show diffraction peaks absorbed at 2θ values.The peaks can be observed at the (111), (200), (220), (311), (222), and (400) planes. These peaks correspond to those for CdO (JCPDF File No.01-075-0591). The sharp XRD peaks verify the polycrystalline structure of CdO [19,21], except for two peaks at 44.5◦ and 64.4◦.These two different peaks are related to the Si carbide of the XRD sample holder.The strain of the CdO nanorods grown on the Si substrate along the c-axis can be calculated using the following equation [23] :

$$\varepsilon_{ZZ}(\%) = \frac{C - C_O}{C_O} \tag{1}$$

where c represents the lattice constant of the CdO nanorods estimated from XRD data and c_o is the standard lattice constant for the unstrained CdO [6].The negative value of the strain (− 0.021%) reveals the compressive strain of the CdO nanorods. This very low value of compressive strain suggests that the synthesized CdO nanorods have high-quality crystal geometry.

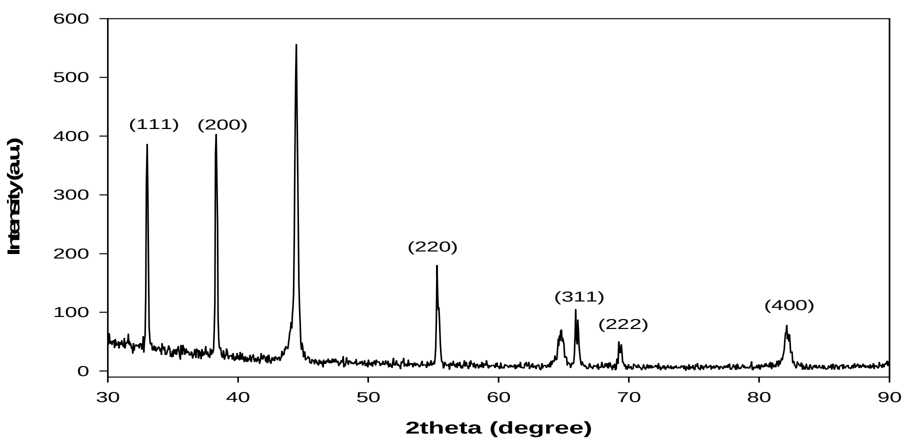

Fig.1-XRD spectrum of CdO nanorods grown on silicon substrate.

Fig. 2 shows the FESEM images of the CdO nanorods deposited on the Si substrate without a catalyst. The diameter of the nanorods was (128.5nm) with different lengths were more than (1μm) due to the high temperature (1400 K),the prolonged reaction time (1 h),the Ar gas flow through the tube, and the position of the substrate in the furnace (10 cm from the CdO powder). The CdO nanorods generated on the Si substrate by this mechanism were formed with a p-n junction. In this junction, the conduction and valence band edges of the wide-gap CdO semiconductor lie within the energy gap of the narrow-gap Si semiconductor to obtain a straddling-gap semiconductor [23,21].

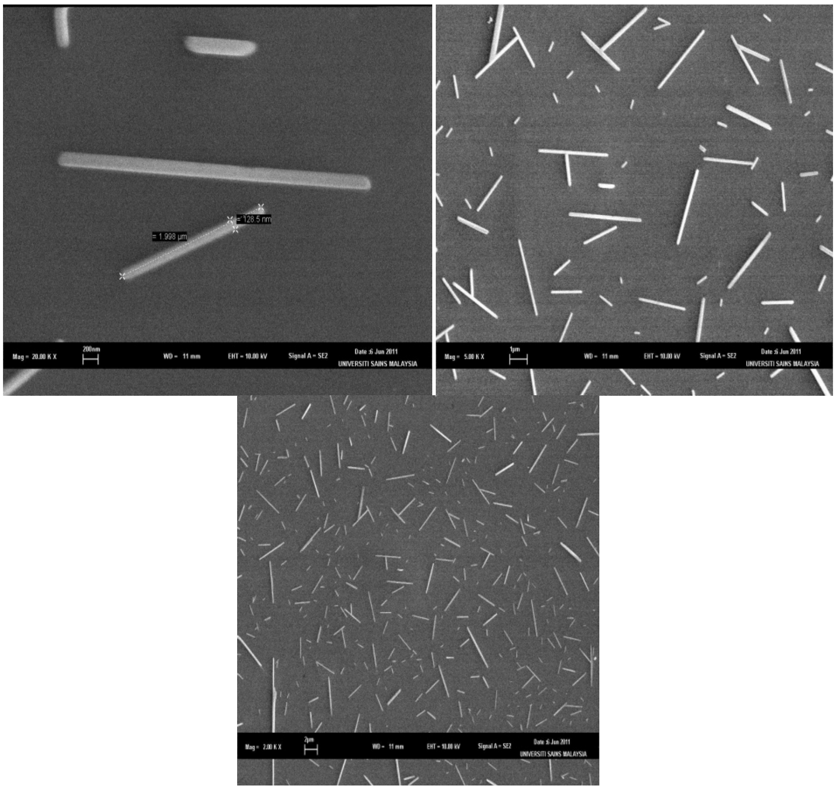

Fig. 2-FESEM images of CdO nanorods grown on Si substrate.

Fig. 3 shows the EDX spectrum of the CdO nanorods. The atomic percentages of Cd, O,and Si were recorded as 32.95%, 42.03%, and 25.02%, respectively. The results were indicated the presence of Cadmium oxide nanorods deposited on the Si substrate.

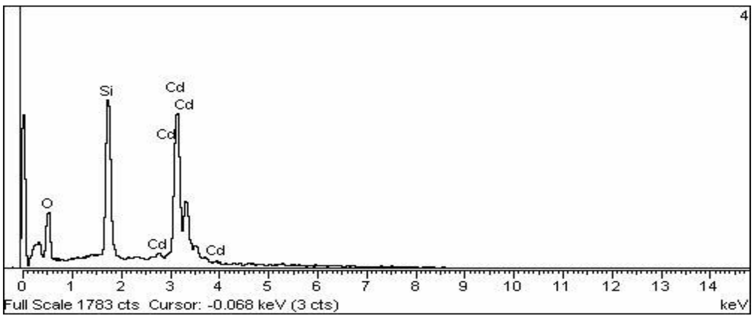

Fig.3- EDX spectrum of CdO nanorods.

To study the optical properties of CdO and compare the differences between CdO nanorods and CdO thin film, growth experiments of CdO and nanorods were carried out using same method. Fig. 4 shows the photoluminescence spectroscopy of the CdO nanorods at 325 nm excitation. Based on the detailed PL measurements, the PL spectroscopy shows a strong emission peak at 534 nm (2.32eV), which is ascribable to the near band-edge emission of CdO [24]. Fig. 5 confirms that the energy gap for the thin film, compared with the nanorods, exhibits a red peak energy shift; the optical direct band gap energy of the CdO thin film is 496 nm (2.5eV). These values agree well with the reported value for CdO nanostructures [19,21], which indicates the quantum confinement effect of the as-synthesized CdO nanorods. This red-shift from 2.32 eV to 2.5 eV was caused by the formation of donor levels (Fermi levels) near the conduction band of the CdO nanorods [21].

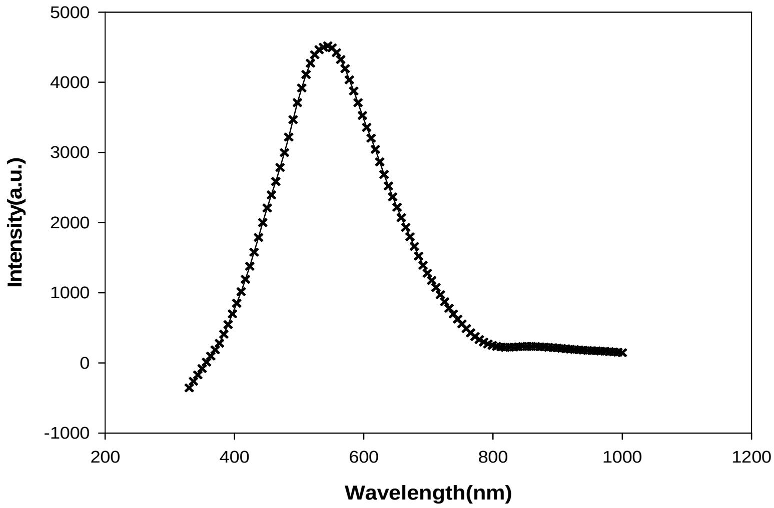

Fig.4- Photoluminescence spectroscopy of CdO nanorods.

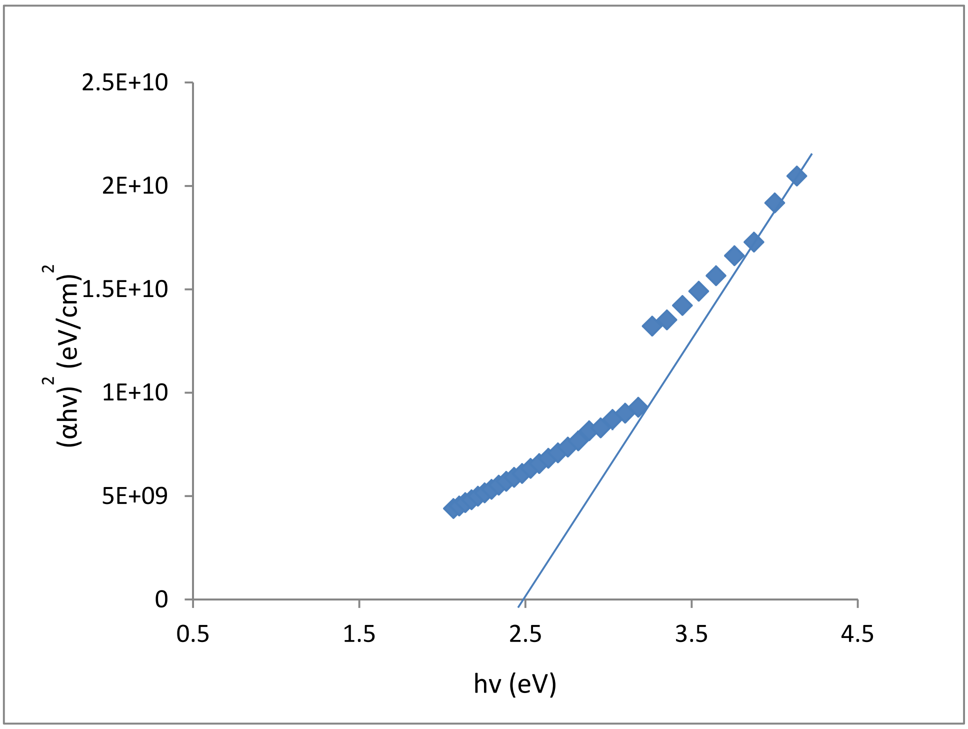

Fig.5-A plot of $(\alpha h\upsilon)^2$ vs. $(h\upsilon)$ for the determination of the direct band gap of CdO thin film.

4. Conclusion

In summary, CdO nanorods were synthesized by a vapor transport method (solid-vapor deposition). This method allows for changes in growth conditions, enabling the size and size distribution of the nanorods to be regulated. The parameters used in the experiment were high temperature, high gas flow (Ar), prolonged reaction time, the position of the substrate in the furnace, and the absence of a catalyst. The sharp XRD peaks indicate that the CdO has a cubic and polycrystalline structure. The CdO nanorods generated on the Si substrate were formed with a p-n junction. These nanorods can be used in high-quality monochromatic laser and optoelectronic devices, especially in solar cells.

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