

Structural, Electrical and Sensing properties of Cd-doped ZnTe thin films, prepared by thermal evaporation method.

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ABSTRACT

This study concentrates on the examination of the functional, electrical, and sensing qualities of ZnTe thin films that were prepared by the thermal evaporation method, with a thickness of 300 nm deposited on glass bases prior to annealing at a temperature of (350°C). The influence of doping with cadmium (7%) on the structural, electrical, and sensing properties of dopant films was also investigated. The results of XRD showed that the pure and doped films were polycrystalline and cubic. According to the findings of the electrical properties of this study, the specific resistance decreases with increasing temperature. It was found that the sensitivity of ZnTe films rises upon doping and annealing, so the sensitivity was calculated.

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الخصائص التركيبية والكهربائية والتحسسية لأغشية ZnTe الرقيقة المشوبة بالـ Cd والمحضرة بطريقة التبخير الحراري

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الكلمات المفتاحية:

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الخلاصة

تم في هذا البحث دراسة الخصائص التركيبية والكهربائية والتحصسية لأغشية ZnTe الرقيقة التي تم تحضيرها بطريقة التبخير الحراري بسمك (300 nm) المرسبة على قواعد زجاجية قبل التلدين وبعده عند درجة حرارة (350°C). كما تم دراسة تأثير التشويب بالكاديوم بنسبة (7%) على الخصائص التركيبية والكهربائية والتحصسية للأغشية المشوبة. أظهرت نتائج XRD أن الأغشية النقية والمشوبة كانت متعددة التبلور ومن النوع المكعب. وفقاً لنتائج الخصائص الكهربائية لهذه الدراسة تقل المقاومة النوعية مع زيادة درجة الحرارة. وجد أن حساسية أغشية ZnTe تزداد عند تناول إضافة الشوائب وكذلك عند المعالجة الحرارية، لذلك تم حساب التحسسية.

1. INTRODUCTION

Zinc telluride is an attractive chalcogenide semiconductor used in the production of solar cells, radiation detectors, and blue light emitting diodes (ZnTe). ZnTe is usually a p-type semiconductor due to its direct energy gap of 2.26 eV (or 548 nm) at 300 K and lattice constant of 6.103. Several techniques have been developed for the production of ZnTe films, including liquid phase epitaxy (LPE), molecular beam epitaxy (MBE), thermal vapor deposition, and pulsed laser deposition (PLD). One way to make cadmium-doped ZnTe films is to heat ZnTe and Cd from two different sources and let them evaporate [1]. When a semiconductor comes into contact with a metal, the Schottky barrier typically exists. In order to create ohmic contact during the manufacturing process of CdTe solar cells, one of the most significant challenges that must be overcome is the Schottky barrier. It has been suggested by Mayer's that ZnTe thin films might be used as the back contact for CdTe solar cells. This is due to the fact that the difference in valence band energy between ZnTe and CdTe is just 0.05 eV [2]. The II-VI family of semiconductors, including zinc selenide (ZnSe), cadmium selenide (CdSe), zinc telluride (ZnTe), and cadmium telluride (CdTe), has drawn attention of researchers and developers due to its high absorption coefficient and inexpensive cost. ZnTe stands out from other materials that could be used to make heterostructures with quantum-dimensional properties [3]. Hence, an effort was made to synthesize ZnTe, ZnTe:Cd nanocrystalline thin films using thermal evaporation and to analyze the effect of vacuum annealing on the structural, electrical, and sensitizing properties.

2. Experimental part

The high purity ZnTe compound (i.e. 99.9%) (-Alfa Aesar) was used to prepare the un-doped and doped films by 7% via thermal evaporation in a vacuum using the thermal

evaporation system and by resistance heating to obtain a thickness of 300 nm. The thickness was measured using the gravimetric method as shown in the following equation [4]:

$$t = \frac{m}{\pi \rho r^2} \quad (1)$$

Where, m: the mass of the material that must be placed into the boat (g), t : the thickness of the film (cm), r : the distance between the substrate and the pot (cm), ρ : the material's density (g/cm³). The material was placed in a boat of molybdenum with a melting point of (3896°k) much which was greater than the melting point of ZnTe, as well as not chemically reacting together, and placed between the two electrodes inside the vacuum chamber. The ZnTe is a volatile material, as it does not settle in the boat when the vaporization temperature is reached, so the perforated cover was made from the boat material itself. Then the floors that was cleaned with high purity ethyl alcohol 99.99% were placed at a height (9 cm) from the middle of the boat to avoid the heat generated and to ensure the homogeneity of the film. When the required pressure was reached to (3.5×10^{-5} mbar), an electric current was gradually passed until we reach the glowing state. A short period of time later, the material began to evaporate without melting on the glass substrates. When the deposition process was completed, the electric current was separated while the films remained under low pressure for a certain period of time to eliminate of the heat resulted from the evaporation process and to ensure the homogeneity of the film. The pure and doped films were annealed at a temperature (350°C) for a period of 1 hr.

3. Results and discussion

3.1. Structural properties

The X-ray diagnostic results of ZnTe films before and after annealing were prepared by thermal evaporation in a vacuum with a thickness of 300 nm. The technique showed that these films had a polycrystalline structure and a

type (cubic) with the appearance of some hexagonal phase of the element telluride Te, as seen Figure 1. The X-ray diffraction spectrum of the prepared films shows the presence of three peaks at the angles (25.55°, 42.12°, and 49.79°) that were demonstrated for the levels (111), (220), and (311), respectively, where it is clear that there is a dominant peak. It is (111) before and after annealing, in addition to the appearance of the least intense peaks (220), (311), with a slight growth before annealing and faster growth by increasing the annealing temperature, indicating that there was a deviation in the location of the peaks depends on the annealing temperature, that is, they are few crystallization. When comparing the results

with the international standard card (ASTM-01-080-0022), It was found that there is a great agreement with these results [3,5], as shown in Table (1). The addition of impurities within the crystal structure of the semiconductor was led to a change in most of the physical properties. In the simplest case, a change can occur in the crystal size and the distance between the crystal surfaces depending on the radius of the impurity atoms with the host material in the lattice. The impurity atom is much smaller than the radius of the impurity atom, and the diffusion of intercalation-type impurities into the interspaces will distort the crystal structure [6], as shown in Figure 2. . 5 12

Table (1): The structural parameters (crystal size, lattice constant).

Sample	Annealing temperature	2 (θ) d	θ (d)	Cos θ	a (Å) EXP.	a (Å) Sat.	β (rad)	G.S	hkl
ZnTe	RT	25.40	12.701	0.9755	6.07	6.04	0.01148	11.774	(111)
	350	25.45	12.725	0.9754	6.05	6.04	0.00329	40.988	(111)
ZnTe : Cd 7%	RT	25.33	12.668	0.9756	6.08	6.04	0.00928	14.565	(111)
	350	25.21	12.609	0.9755	6.11	6.04	0.00513	32.840	(111)

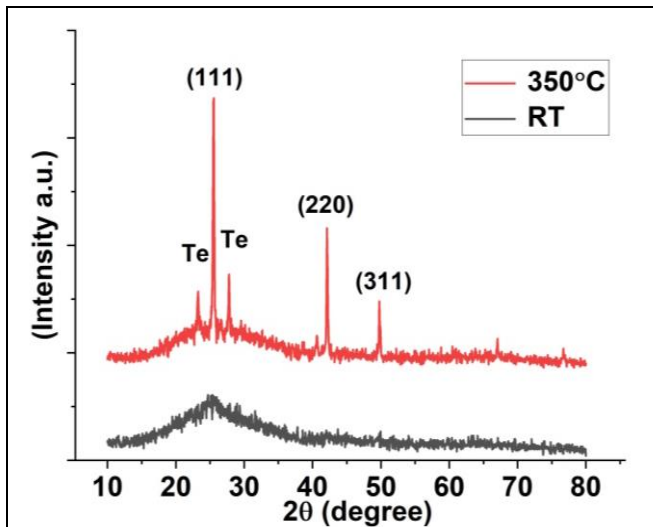


Figure 1: X-ray diffraction pattern of ZnTe before annealing and after.

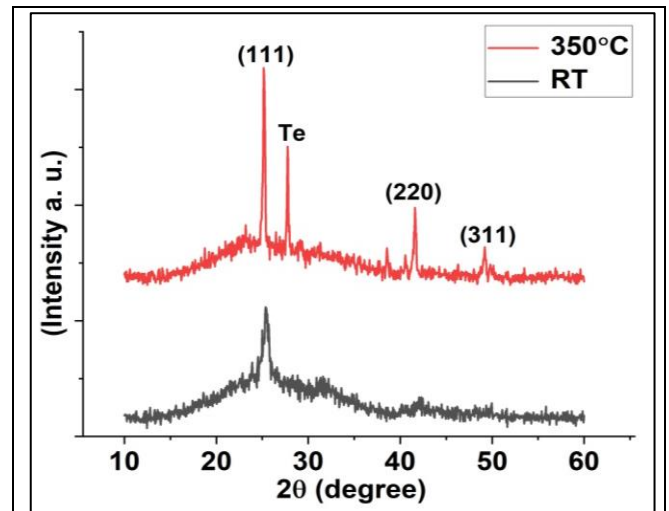


Figure 2: X-ray diffraction pattern for thin films (Cd: ZnTe) at 7%.

3.2 Electrical Properties

Figure 3 shows the change in the resistance of the ZnTe film as a function of temperature. It can be noted that the resistance

decreases with the increase in the film temperature. It can be a general characteristic of semiconductors, which is due to the increase in the concentration of charge carriers, and, consequently, its transition from the valence band to the conduction band increases thus, the electrical conductivity increases and the specific resistance decreases. Regarding the effect of annealing, it was found that the electrical conductivity increases with increasing the annealing temperature. The results obtained showed that the specific resistance of ZnTe films doped with cadmium before and after annealing decreases from (0.0008 Ω.cm) to the least amount (0.0001 Ω.cm) when the temperature was increased from (303°K) to the highest temperature (430°K)[7,8]. The

resistivity (ρ) was calculated using the equation [9]:

$$\rho = \frac{R \cdot \ell \cdot t}{L} \tag{3}$$

Figure 4 depicts the temperature dependence of the electrical conductivity of un-doped and Cd doped ZnTe films. It can be noticed that d.c. electrical conductivity goes up as the temperature goes up and also when cadmium is added, which is a characteristic of semiconductors. Increasing the density of charge carriers [7, 8], the electrical conductivity ($\sigma_{d.c}$) was calculated by the equation [10]:

$$\sigma_{d.c.} = \frac{1}{\rho} \tag{2}$$

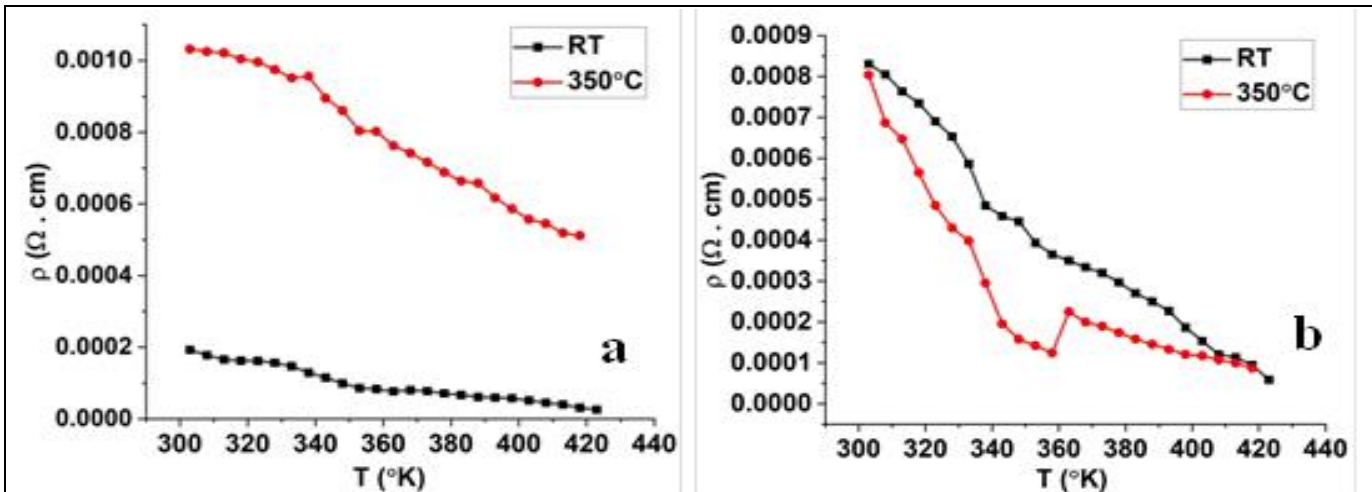


Figure 3: The specific resistance of ZnTe films before and after annealing as a function of temperature, (a) un-doped, (b) dope ratio (7%).

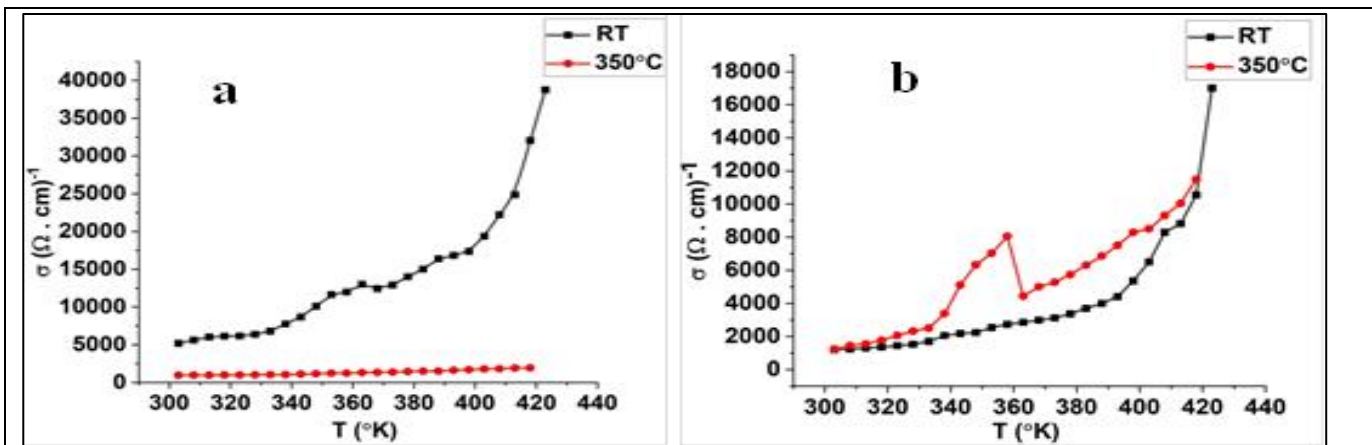


Figure 4: Electrical conductivity of ZnTe films before and after annealing as a function of temperature, (a) un-doped, (b) dope ratio (7%).

4. Sensing Properties

The sensing properties of ZnTe films were studied using NO₂ gas through the below equation [10]:

$$S = \frac{R_{gas} - R_{air}}{R_{air}} \times 100\% \quad (4)$$

The selection of the appropriate operating temperature depends on obtaining the maximum response by which the sensor is sensitive to NO₂ molecules; the reaction energy is activated at these temperatures. Furthermore, the conditions under which the film was prepared, as well as its crystal structure and nanoparticle size, all play a role in the film's sensitivity process. Through the results shown in Table 2, the maximum sensitivity was seen with cadmium-doped zinc telluride with the ratio (7%) and the plasticizer, as it reached (100°C) at the operating temperature (35.807%), which indicates that it has improved the sensitivity properties of ZnTe films as in figure 5. [12].

Table (2): The sensitivity values for un-doped and doped ZnTe films before and after annealing.

Sample	Annealing temperature	T Gas (°C)	S %
ZnTe	RT	25	2.692
		100	1.065
		200	10.649
		300	4.665
	350 °C	25	0.631
		100	4.761
		200	10.182
		300	5.526
ZnTe : Cd	RT	100	7.540
		200	2.166
		300	10.819
		25	2.591
	350 °C	100	35.807
		200	7.778
		300	5.141
		25	5.141

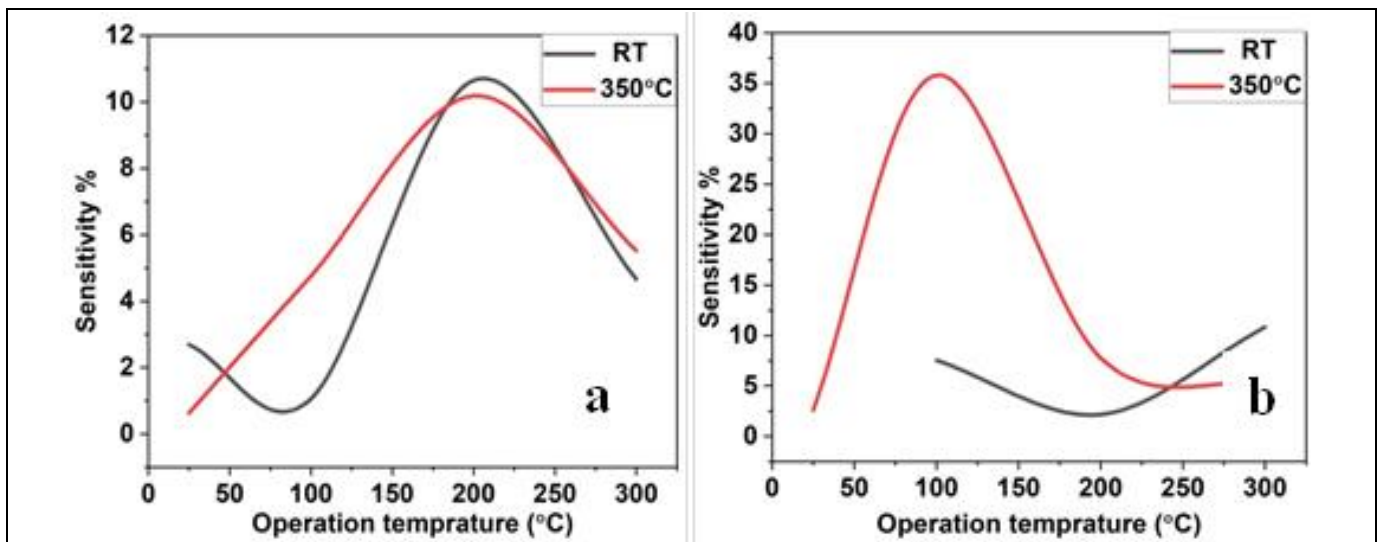


Figure 4: The sensitivity values of ZnTe films before and after annealing as a Function of temperature, (a) un-doped, (b) dope ratio (7%).

4. Conclusion

The structural investigation of ZnTe films which were prepared by the thermal evaporation method in a vacuum proved that they are of polycrystalline structure and cubic type with some hexagonal phase of Te telluride in the

preferred direction of growth (111). Both the specific resistance and electrical conductivity were calculated, where it was found that the specific resistance drops at higher temperatures, whilst the electrical conductivity rises at higher temperatures. The sensitivity of ZnTe films of

pure and cadmium-doped films to NO₂ gas was calculated, where the highest sensitivity rate was recorded when doping, which was (35.807%). The ZnTe films can be considered are good gas sensors and can be used in the field of gas sensor applications.

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