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Physical properties of ZnTe semiconductor thin films prepared by high vacuum resistive system

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Zinc telluride (ZnTe) polycrystalline films have been grown on well-cleaned glass substrates by thermal vacuum evaporation technique using 99.99 % pure ZnTe powder as an evaporant. The samples were prepared at different substrate temperatures, rates of evaporation and thicknesses. The X-ray diffraction was used to study the structure of the films. The structures of the samples were found to be polycrystalline with preferred (1 1 1) orientation. Transmission spectra of all ZnTe films were recorded in the range of 300 nm to 2500 nm. The films were electrically characterized using Hall effect measurements at room temperature. It has been stated that the electrical resistivity, mobility and carrier concentration are strongly influenced by the substrate temperature. From the SEM results, it is clear that the surface of ZnTe is very smooth with occasional large particles on it.

Keywords: *ZnTe thin films; heat resistive materials; vacuum evaporation; electrical properties; optical and structural characterization*

1. Introduction

Zinc telluride (ZnTe) is a group II-VI p-type semiconductor compound with a wide energy band gap of 2.26 eV at room temperature. Its crystal structure is cubic-like that of diamond. Its lattice constant is 0.61034 nm, allowing it to be grown on aluminum antimonide, gallium antimonide, indium arsenide, and lead selenide [1–3].

It has an appearance of grey or brownish-red powder, or ruby-red crystal, when refined by sublimation. ZnTe can also be prepared as a hexagonal crystal (wurtzite structure). Zinc telluride can be easily doped to enhance its properties and for this reason, it is one of the most common semiconducting materials used in optoelectronics [4].

ZnTe is important for the development of various semiconductor devices, including blue LEDs, laser diodes, solar cells, and components of microwave generators. ZnTe is also one of the most important and leading thin film materials for the fabrication of solar cells [5–16]. It can be used for solar cells as a back absorbing p-layer. The II-VI semiconductor thin films fabricated by physical vapor deposition (PVD) and chemical vapor deposition (CVD) are also of great importance from research point of view as well as in the microelectronics industry [17–20].

2. Experimental

In this research work, the ZnTe thin films were deposited by resistive heating thermal evaporation in the Leybold Heraeus 550 VA type high vacuum coating plant, under a vacuum of 5×10^{-9} Pa. These films were grown on the glass substrates. The glass substrates were cleaned first in a pure isopropyl alcohol (IPA) for 30 min and then in acetone for 30 min. The molybdenum boat was used as an evaporating source. ZnTe material in the form of powder (99.999 % purity) was loaded into the boat. The glass substrates were fixed at a height of about 30 cm from the source material which was heated by the infrared heater present at the top of the glass substrates. A thermocouple near the substrates was

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used to monitor their temperature during the deposition process. After creation of high vacuum of 5×10^{-9} Pa, the current was supplied to the molybdenum boat for the evaporation of the ZnTe material. There was also a second quartz crystal thickness monitor (IC-6000 INFICON) used for monitoring the thickness of the film and the rate of evaporation. There was a shutter above the Mo boat to stop the unwanted flux of the evaporated material before or after the deposition. Vacuum system was equipped with a liquid nitrogen trap to avoid the fast oil particles from diffusion pump to enter the chamber and hence, contaminating it. The material was heated slowly by increasing the current of the boat to get the desirable rate and then the shutter was open to start the evaporation.

There were four parameters of the deposition, namely, chamber vacuum, substrate temperature, rate of evaporation and thickness of the films. Various thin films of ZnTe were grown on the glass substrates, changing its temperature from the ambient one to 400 °C, rate of evaporation from 2 Å/s to 20 Å/s and thickness from 1000 Å to 5000 Å. After the deposition, the samples were brought to room temperature, then the chamber was lifted up and the samples were removed.

Films of the size of 4 mm × 4 mm were also simultaneously deposited on the glass substrates for Hall effect measurement. Four silver Ag contacts were then evaporated at four corners of the ZnTe films prepared for electrical measurements. The deposition process was conducted under the pressure of 6×10^{-4} Pa, keeping the source to substrate distance at 20 cm. Deposition parameters of all the films are given in Table 1.

The X-ray diffraction study of all the ZnTe thin film was performed on an XRD system PANalytical Xpert' Pro (Holland). The structure of the deposited film was studied by using X-ray diffraction technique. The percentage transmittance (T %) of all the films has been measured for wavelength λ ranging from 300 nm to 2500 nm using a PerkinsElmer UV-Vis-NIR spectrometer model LAMBDA 900. The SEM image of thin film sample 6 was examined by SU-1500 scanning electron microscope (Japan). Hall effect apparatus Ecopia model HMS-3000 was used to measure Hall parameters.

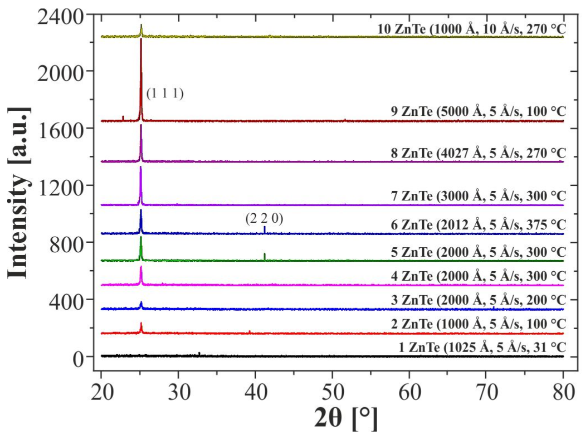

Fig. 1. XRD patterns of ZnTe films deposited at different substrate temperatures.

3. Results and discussion

3.1. Structural characteristics

X-ray diffractograms of the ZnTe thin film samples grown at different temperatures are shown in the Fig. 1. It is observed from the XRD patterns that the films exhibit cubic structure with (1 1 1) preferred orientation.

Sample 1 grown at the ambient temperature displays no peak indicating amorphous film. With the increase of temperature, the intensity of the preferred peak (1 1 1) increases while the intensity of other small peaks becomes prominent. The X-ray diffraction patterns of the samples deposited with different thicknesses ranging from 1000 Å to 5000 Å and deposition rate of 5 Å/s are also shown in Fig. 1. The intensity of all the peaks increases with the increase of the thickness of the film, indicating simultaneous growth. The peak of sample 9 has the highest intensity as compared to the samples having lower thicknesses. This shows that if the thickness is large, the atoms have enough time to get arranged on the substrate and the peak of preferred plane (1 1 1) has the highest intensity. This leads to the improved crystal structure of ZnTe samples.

Table 1. Deposition parameters of all ZnTe thin films.

Sample name ZnTe	Thickness [Å]	Evaporation rate [Å/s]	Substrate temperature [°C]
1	1075	5	31
2	1000	5	100
3	2000	5	200
4	2000	5	300
5	2000	2	300
6	2012	5	375
7	3000	5	300
8	4055	5	270
9	5000	5	270
10	2144	10	274
11	1990	2	254
12	2000	15	300
13	2135	20	245
14	2044	5	ambient
15	2000	5	100
16	1059	5	270

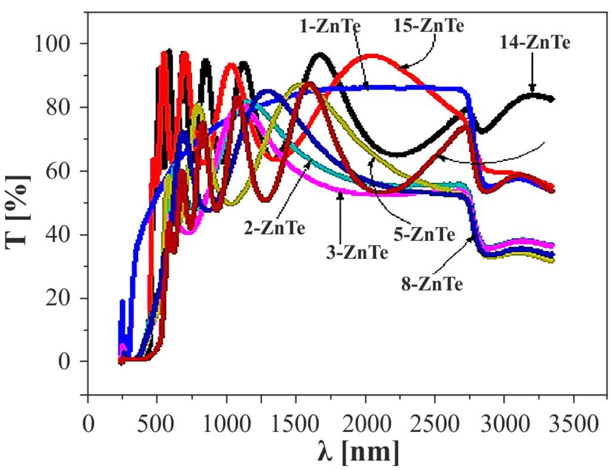

Fig. 2. Transmittance curves of all the thin film samples.

3.2. Optical characterizations

Transmission spectra of all ZnTe films were recorded in the range of 300 nm to 2500 nm. There are maxima and minima in transmittance spectra of all the films except sample 1, which is non crystalline. These maxima and minima in each film are due to interference between light scattered from the front and back surface of the films. The thickness of the film can be calculated from the maxima and minima in its transmittance curve [7].

This study revealed that thin film samples of ZnTe are highly transparent in visible and NIR regions as seen from Fig. 2. More than 80 % light is transmitted in these regions. Optical energy band gap E_g of this material lies between 2.15 eV and 2.25 eV as is evident in Fig. 3. High transmission in the visible region shows that the material is suitable for solar cells.

3.3. Electrical characterization (Hall effect)

Hall effect apparatus model Ecopia HMS-3000 was used to measure the Hall parameters by four silver post-evaporated contacts on the glass with 4 mm × 4 mm film on it as shown in Fig. 4.

Four parameters: resistivity, conductivity, mobility, and carrier concentration were studied using Hall effect measurements. The electrical properties of ZnTe thin films depend on the fabrication

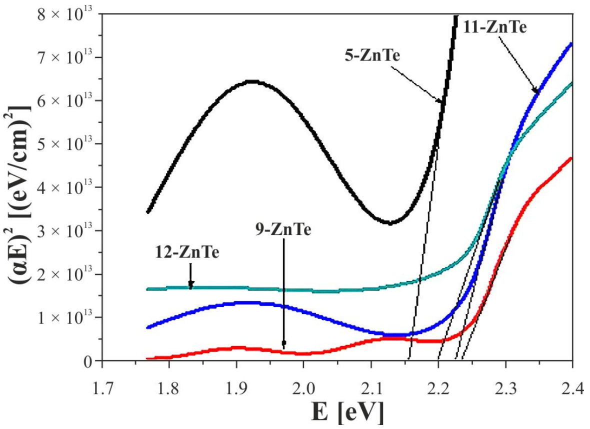

Fig. 3. Energy band gap of the ZnTe thin film samples.

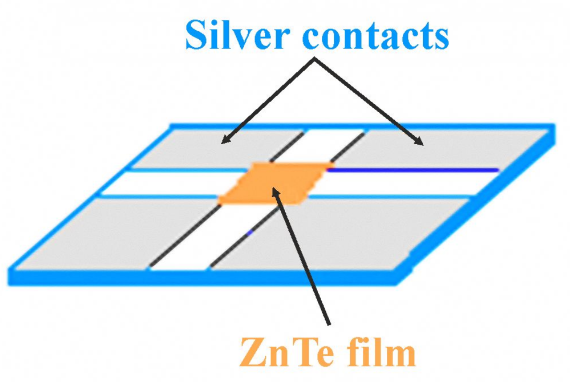

Fig. 4. Ag contacts to the film on a glass substrate for Hall effect measurement.

conditions such as rate of evaporation, substrate temperature and film thickness during the deposition process. All the grown films showed p-type behavior. The sample 4 ZnTe which was deposited at substrate temperature of 300 °C is considered to be the best among all the depositions because it has a high bulk carrier concentration (1.44×10^{13} p/cm^3), high hole mobility (2.74×10^4 cm^2/Vs) and a very low resistivity (1.58×10^1 Ω·cm). The film deposited at ambient temperature has the lowest bulk concentration and mobility while its resistivity has the highest value. This indicates that substrate temperature has a great influence on the electrical properties of the films.

Fig. 5 shows the variation of resistivity with the rate of evaporation. Resistivity of sample 11, which was evaporated at 2 Å/sec, has the lowest value of 1.58×10^1 Ω·cm and resistivity of sample 13, which was evaporated at 20 Å/sec, has the highest value of 7.66×10^3 Ω·cm. Hence, the resistivity strongly depends on the rate of evaporation. The lower the rate of evaporation, the smaller the resistivity.

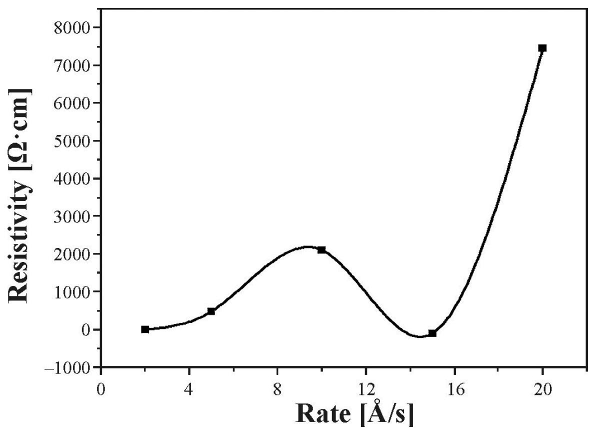

Fig. 5. Resistivity vs. rate of deposition.

Fig. 6 shows the resistivity vs. sample thickness for all the samples. Resistivity of ZnTe films is increasing with the increase of thickness then it decreases but at higher film thickness the resistivity increases again. This may be due to doping changing the concentration of charge carriers.

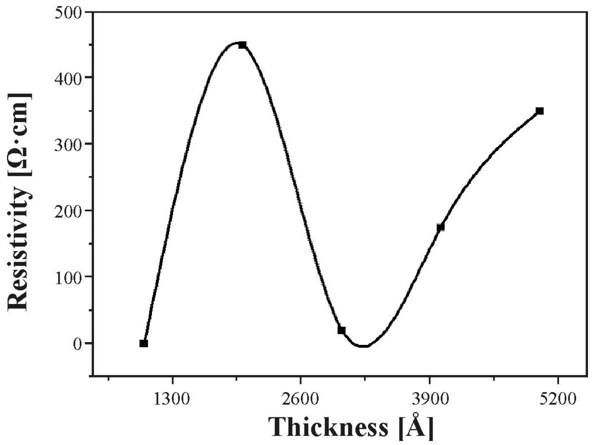

Fig. 6. Resistivity vs. layer thickness.

The behavior of resistivity with increasing temperature is shown in Fig. 7. Resistivity of ZnTe films decreases with the increase in temperature up to 300 °C. Above this temperature, the resistivity increases with the increase of temperature. This occurrence may be due to doping effects changing charge carriers concentration.

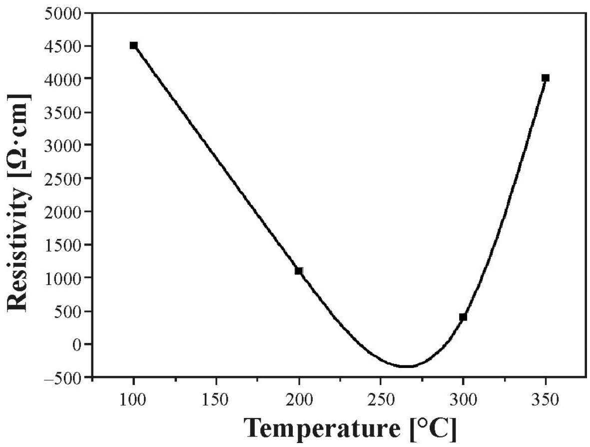

Fig. 7. Resistivity vs. temperature.

3.4. Surface morphology

The SEM images of sample 6 were examined by SU-1500 scanning electron microscope (Japan). The results are shown in Fig. 8. From the SEM images, it is clear that the surface of ZnTe film is very smooth with occasional large particles. The substrate temperature was 375 °C, rate of evaporation was 5 Å/sec, and the final thickness of the film was 2012 Å. Due to very high temperature of the substrate, the ZnTe particles arranged themselves during the deposition, resulting in a very smooth surface.

Some of the particles with slightly bigger size are also observed in the micrographs. It is concluded that high temperature of the substrate (200 °C to 375 °C) during the deposition is beneficial to produce high quality smooth surface films.

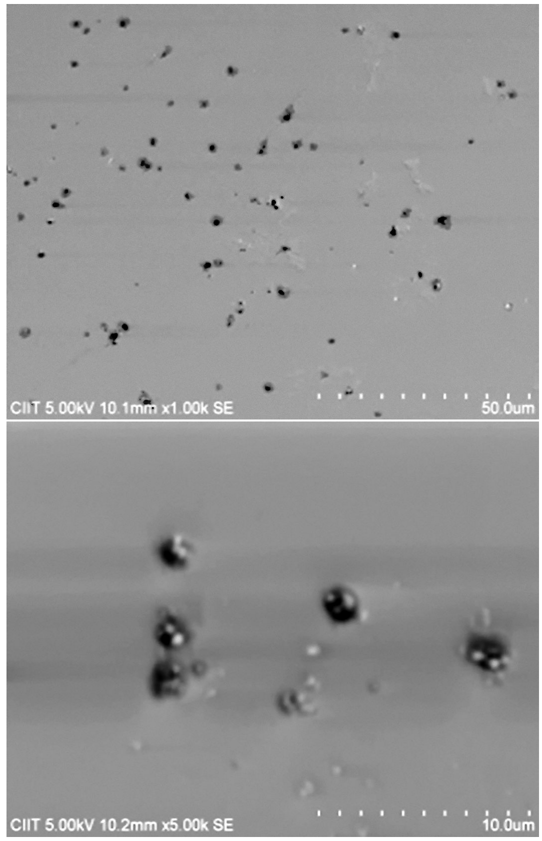

Fig. 8. SEM micrographs of sample 6 at different magnifications.

4. Conclusions

On the basis of experimental results and characterizations, it is concluded that vacuum evaporation is a simple and convenient way for depositing high quality ZnTe thin films. The XRD results show a strong influence of the substrate temperature and thickness on the structure of the samples. The XRD result of ZnTe sample 1 shows that the film is amorphous as it was deposited at room temperature. All other films evaporated at different substrate temperatures, rates of evaporation, and thicknesses have a preferential orientation in the [1 1 1] direction with a cubic structure. It was observed that the samples that were deposited at higher substrate temperatures have low resistivity, high mobility and large carrier concentrations. Optical study revealed that ZnTe samples are highly transparent in visible and NIR regions. More than 80 % light is transmitted in these regions. The energy gap of this material lies between 2.15 eV and 2.25 eV. The SEM image of ZnTe sample shows that owning to high substrate temperature, the ZnTe particles arranged themselves during the deposition which resulted in a very smooth surface. Some of the particles with slightly bigger grain sizes are also observed in the samples. The electrical resistivity, mobility and carrier concentration are strongly influenced by substrate temperature. Good quality films in terms of low resistivity, higher bulk concentration and higher mobility can be deposited at substrate temperature ranging from 200 °C to 375 °C. Hall effect measurements show that the properties of ZnTe samples depend on the rate of evaporation and film thickness.

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