Research Letter

Growth and Characterization of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ -Sintered Films

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The II-VI polycrystalline semiconducting materials have come under increased scrutiny because of their wide use in the cost reduction of devices for photovoltaic applications. $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ is one of the II-VI ternary semiconductor materials whose bandgap can be tailored to any value between 1.48–2.26 eV as X varies from 0 to 1. It is promising material for high-efficiency solar cells, switching, and other optoelectronic devices. Polycrystalline thin film of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ with variable composition ($0 \leq X \leq 1$) has been deposited on ultraclean glass substrates by screen printing method followed by sintering process. The optical and structural properties of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ thin films have been examined. The optical bandgap of these films is studied using reflection spectra in wavelength range of 350–900 nm by using double beam spectrophotometer. The structure of sample was determined from X-ray diffraction patterns. The films were polycrystalline in nature having wurtzite (Hexagonal) structure over the whole range studied. The lattice parameters vary almost linearly with the composition parameter X , following Vegard's law. Sintering is a very simple and viable method compared to other cost-intensive methods. The results of the present investigation will be useful in characterizing the material CdZnTe for its applications in photovoltaics.

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1. INTRODUCTION

In recent years, II-VI compound semiconductors are attracting a great deal of attention because of their potential abilities in a wide spectrum of optoelectronic devices [1–6]. Ternary materials provide a possibility of tailoring their properties as per requirements and hence project themselves, as important semiconducting material, for future advancements in the field of device fabrication. The $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ ($0 < X < 1$) ternary semiconductor with Zinc blende-type structure has many applications for its various desirable properties such as the tunability of bandgap and lattice parameter with alloy composition, high optical absorption coefficient above the bandgap energy, and high value of optical transmittance below the bandgap. These favourable properties have attracted many people to work with this material [7–15].

A $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ thin film is very useful in high-efficiency tandem solar cell fabrication [7] because of the ease in tuning its bandgap in visible region (between 1.48–2.26 eV) [16].

$\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ is also used as the most suitable substrate material for epitaxial growth of $\text{Hg}_{1-X}\text{Cd}_X\text{Te}$ which is the leading infrared detector material [8, 9].

It is generally recognized that any large-scale applications must rely on cheap polycrystalline materials. The use of thin-film polycrystalline semiconductors has attracted much interest in an expanding variety of applications in various electronic and optoelectronic devices. The technological interest in polycrystalline-based devices is mainly caused by their very low production costs. Thin film of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ was prepared by variety of techniques, such as two-source vacuum evaporation [16, 17], molecular beam epitaxy [18], chemical vapour deposition [19], metal organic chemical vapour deposition [20], two-stage process [21], and thermal evaporation [22].

In the present investigation, we have prepared $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ thin films by screen printing method followed by sintering process. The optical and structural properties of these polycrystalline-sintered films were studied in relation to the composition (X) of the films.

Sintering is one of the best techniques allowing the preparation of polycrystalline semiconducting films with ease, low costs, and large-area applications. It is extremely simple and viable compared to other cost-intensive methods [23–26].

2. EXPERIMENTAL DETAILS

In the present investigation, the films of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ ($X = 0, 0.2, 0.4, 0.6, 0.8, 1$) were prepared by screen printing followed by sintering process. To make different compositions of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$, we used CdTe and ZnTe of high purity (99.999%). In fact, $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ alloy was prepared by taking the stoichiometric ratio of CdTe and ZnTe compounds.

The different compounds have been taken as follows:

$$\begin{aligned} \text{weight of CdTe} &= 240(1 - X) \text{ g,} \\ \text{weight of ZnTe} &= 192.97 X \text{ g,} \\ \text{weight of ZnCl}_2 \cdot \text{H}_2\text{O} &= 10\% \text{ wt. of (CdTe + ZnTe) g.} \end{aligned} \quad (1)$$

As these weights were very large, we reduce them in the same proportion. All the three compounds are mixed thoroughly and few drops of ethylene glycol are added to make it a paste. Zinc chloride was used as an adhesive (cadmium chloride was used as adhesive when $X = 0$, i.e., in case of CdTe film) and ethylene glycol as a binder. The paste thus prepared was screen printed on ultraclean glass substrates, which has been cleaned by embryo powder and acetone, and finally washed with distilled water. The samples thus prepared were dried at 120°C for 4 hours in nitrogen atmosphere. The reason of drying the sample at lower temperature was to avoid the cracks in the samples. The removal of organic materials takes place at about 400°C , so sintering temperature cannot be less than 400°C . Zinc chloride is hygroscopic and its melting point is 283°C . To get stable sintered films, zinc chloride and ethylene glycol should not remain in the samples. We optimized the sintering temperature and sintering time by performing the experimental process for different values of these two parameters and concluded that the samples would be sintered at 500°C for 10 min in a temperature-controlled furnace in nitrogen atmosphere. For drying and sintering of sample, nitrogen atmosphere is used as formation of ZnO occurs in air atmosphere; but in nitrogen, this problem does not exist. All the films were synthesized under the same experimental conditions [27].

3. TECHNIQUES OF CHARACTERIZATION

The thicknesses of films were determined by an optical interference technique. The thickness of various films was found of the order of $1 \mu\text{m}$. The optical reflectance versus wavelength traces of all the films was recorded from 350–900 nm wavelength range using a double beam spectrophotometer (Hitachi U-3400). The XRD traces were obtained using a Philips PW 1140/09 X-ray diffractometer with $\text{CuK}\alpha$ ($\lambda = 1.5405$) radiation.

1	$X = 0$	4	$X = 0.6$
2	$X = 0.2$	5	$X = 0.8$
3	$X = 0.4$	6	$X = 1$

FIGURE 1: Reflection spectra of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ -sintered films.

4. RESULT AND DISCUSSION

4.1. Optical studies

The optical reflectance measurements of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ ($X = 0, 0.2, 0.4, 0.6, 0.8, 1$) sintered films were recorded at room temperature from 350 to 900 nm wavelength range using a Hitachi U-3400 UV-VIS-NIR double beam spectrophotometer. The optical bandgap of these films was determined with the help of reflection spectra. Almost all the II-VI compounds are direct bandgap semiconductors. According to Tauc relation [28], the absorption coefficient for direct bandgap material is given by

$$\alpha h\nu = A(h\nu - E_g)^n, \quad (2)$$

where $h\nu$ is photon energy, A is constant which is different for different transitions, E_g is the bandgap, and $n = 1/2$ for direct bandgap material. The absorption coefficient may be written in terms of reflectance as [29]

$$2\alpha t = \text{Ln} \left[\frac{(R_{\max} - R_{\min})}{(R - R_{\min})} \right], \quad (3)$$

where t is the thickness of the film and R is reflectance for any intermediate photon energy, where reflectance falls from $R_{\max}$ to $R_{\min}$ due to absorption of light by the material.

We plot a graph between $(\alpha h\nu)^2$ or the square of $h\nu \text{Ln}[(R_{\max} - R_{\min})/(R - R_{\min})]$ (as ordinate) and $h\nu$ (as abscissa) a straight line is obtained. The extrapolation of straight line to $(\alpha h\nu)^2 = 0$ axis gives the value of energy bandgap of film material. Figure 1 represents the reflection spectra of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ -sintered films. In Figure 2 we plotted a graph between the square of $h\nu \text{Ln}[(R_{\max} - R_{\min})/(R - R_{\min})]$ and $h\nu$ for the determination of bandgap. The bandgap of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ -sintered films varies between 1.48–2.26 eV as composition X varies from 0 to 1. The decrease in

1 $X = 0$	4 $X = 0.6$
2 $X = 0.2$	5 $X = 0.8$
3 $X = 0.4$	6 $X = 1$

FIGURE 2: Energy bandgap determination of $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$ -sintered films from reflectance measurement. (A plot of $[\ln\{(R_{\max} - R_{\min})/(R - R_{\min})\}]^2$ Vs. $h\nu$.)

FIGURE 3: The compositional dependence of bandgap of $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$ -sintered films.

bandgap is attributed to the basic properties of these compounds. The compositional dependence of the bandgap is shown in Figure 3. The variation of E_g with X is almost linear for this system. These results are in good agreement with the reported values [16, 22].

The mode of optical transitions in these films is of band-to-band direct type. This has also been confirmed by plotting $\ln(\alpha h\nu)$ versus $\ln(h\nu - E_g)$ for direct, allowed type transitions [30]. The variation yields a straight line with slope almost 1/2. The electronic transitions between the valence and conduction band start at the absorption edge corresponding to the minimum energy difference between the lowest energy of the conduction band and the highest energy of the valence band in the crystalline materials. In case of cadmium and zinc salts, the plot of electron energy E as a function of electron wave vector k (E - k band diagram) indicates that the top of the valence band has the same k value as the bottom of conduction band and hence the transitions are of direct type. As given above, the absorption coefficient α of the film

FIGURE 4: X-ray diffraction pattern of CdTe-sintered film.

FIGURE 5: X-ray diffraction pattern of $\text{Cd}_{0.4}\text{Zn}_{0.6}\text{Te}$ -sintered film.

material is proportional to $\ln[(R_{\max} - R_{\min})/(R - R_{\min})]$. The absorption coefficient for all the $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$ composition is high. The absorption coefficient increases sharply with photon energy beyond the fundamental absorption edge. The high absorption coefficient and tunable bandgap of $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$ -sintered films will be an added advantage in respect of their applications in photovoltaic devices.

4.2. XRD studies

X-ray diffraction (XRD) studies were carried out on these samples and diffractograms were analyzed to obtain information about various crystallographic aspects. XRD traces of all samples were taken at room temperature and found to show almost similar trends. We have shown here the XRD traces of CdTe and $\text{Cd}_{0.4}\text{Zn}_{0.6}\text{Te}$ in Figures 4 and 5, respectively. These traces confirmed the formation of alloys of $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$. The presence of sharp structural peaks in these XRD patterns confirmed the polycrystalline nature of the films. The XRD peaks show no peaks of CdTe or ZnTe Oxidation.

FIGURE 6: The variation of lattice parameter with composition for $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ -sintered films.

The experimental d-values for different compositions of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ system are calculated from Bragg's relation

$$2d_{hkl} \sin \theta = n\lambda, \quad (4)$$

by taking θ values from the peaks of XRD patterns; these d-values are compared with the standard ASTM data (d^*) for the confirmation of the structure of the film material. The experimental d-values and ASTM (d^* values) are in good agreement and show hexagonal (wurtzite) structure of each composition. Various workers [16–22] have prepared the films of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ system by different techniques other than sintering; and their investigations revealed the presence of cubic zinc blende or mixed phase depending on the composition of the system. The lattice parameter “a” as a function of composition x is plotted in Figure 6. The lattice parameter varies almost linearly with composition parameter x , following Vegard's law. A decrease in lattice parameter was observed with the increase of zinc content in the films.

5. CONCLUSION

The optical, structural properties of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ pseudobinary-sintered films were investigated. The absorption coefficient of the films of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ system is high, and varying X from 0 to 1 can engineer their bandgap from 1.48 to 2.26 eV, which are suitable for efficient absorption in the visible region of the solar spectrum. All the films of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ system are found to be polycrystalline in nature and have hexagonal (wurtzite) structure over entire composition range. The lattice parameters vary almost linearly with the composition parameter X , following Vegard's law.

Due to optimum band gap, large absorption coefficient, polycrystalline nature, and stability, these sintered films may be suitable for use in solar cells, wide band gap window material, and other photovoltaic devices. The sintering technique is simple, inexpensive, viable, and attractive means of obtaining films of II-VI semiconductors and offers a wide flexibility for their use in a variety of applications.

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REFERENCES

- [1] P. Gupta, B. Maiti, A. B. Maity, S. Chaudhuri, and A. K. Pal, “Optical properties of $\text{Zn}_X\text{Cd}_{1-X}\text{Se}$ films,” *Thin Solid Films*, vol. 260, no. 1, pp. 75–85, 1995.
- [2] A. S. Nasibov, Yu. V. Korostelin, P. V. Shapkin, L. G. Suslina, D. L. Fedorov, and L. S. Markov, “Exciton luminescence in ideal solid solutions ($\text{Zn}_X\text{Cd}_{1-X}\text{Se}$ system, $0 < X < 1$),” *Solid State Communications*, vol. 71, no. 10, pp. 867–869, 1989.
- [3] A. Al Bassam, A. W. Brinkman, G. J. Russell, and J. Woods, “Electrical properties of $\text{Zn}_X\text{Cd}_{1-X}\text{Se}$,” *Journal of Crystal Growth*, vol. 86, no. 1–4, pp. 667–672, 1990.
- [4] A. Burger and M. Roth, “Temperature gradient solution zoning growth and characterization of $\text{Zn}_X\text{Cd}_{1-X}\text{Se}$ single crystals,” *Journal of Crystal Growth*, vol. 70, no. 1–2, pp. 386–392, 1984.
- [5] L. P. Deshmukh, K. M. Garadkar, and D. S. Suttrave, “Studies on solution grown $\text{Hg}_X\text{Cd}_{1-X}\text{S}$ thin films,” *Materials Chemistry and Physics*, vol. 55, no. 1, pp. 30–35, 1998.
- [6] N. C. Sharma, D. K. Pandya, H. K. Sehgal, and K. L. Chopra, “Electroless deposition of epitaxial $\text{Pb}_{1-X}\text{Hg}_X\text{S}$ films,” *Thin Solid Films*, vol. 59, no. 2, pp. 157–164, 1979.
- [7] A. Rohatgi, S. A. Ringel, R. Sudharsanan, P. V. Meyers, C. H. Liu, and V. Ramanathan, “Investigation of polycrystalline CdZnTe , CdMnTe , and CdTe films for photovoltaic applications,” *Solar Cells*, vol. 27, no. 1–4, pp. 219–230, 1989.
- [8] D. Rajavel and J. J. Zinck, “Metalorganic molecular beam epitaxial growth of high-quality $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ ($0 \leq X \leq 0.27$) films,” *Applied Physics Letters*, vol. 63, no. 3, pp. 322–324, 1993.
- [9] J. S. Goela and R. L. Taylor, “Growth of CdZnTe on Si by low-pressure chemical vapor deposition,” *Applied Physics Letters*, vol. 51, no. 12, pp. 928–930, 1987.
- [10] S. Saha, U. Pal, A. K. Chaudhuri, V. V. Rao, and H. D. Banerjee, “Optical properties of CdTe thin films,” *Physica Status Solidi (a)*, vol. 114, no. 2, pp. 721–729, 1989.
- [11] U. Pal, S. Saha, A. K. Chaudhuri, V. V. Rao, and H. D. Banerjee, “Some optical properties of evaporated zinc telluride films,” *Journal of Physics D*, vol. 22, no. 7, pp. 965–970, 1989.
- [12] B. Samantha, S. L. Sharma, and A. K. Choudhuri, “Optical and micro structural properties of $\text{Cd}_{0.8}\text{Zn}_{0.2}\text{Te}$ thin films,” *Indian Journal of Pure & Applied Physics*, vol. 32, pp. 62–67, 1994.
- [13] T. L. Chu, S. S. Chu, F. Firszt, and C. Herrington, “Deposition and properties of zinc telluride and cadmium zinc telluride films,” *Journal of Applied Physics*, vol. 59, no. 4, pp. 1259–1263, 1986.
- [14] K. K. Chattopadhyay, A. Sarkar, S. Chaudhuri, and A. K. Pal, “Preparation and optical properties of $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$ films,” *Vacuum*, vol. 42, no. 17, pp. 1113–1116, 1991.
- [15] J. L. Reno and E. D. Jones, “Determination of the dependence of the band-gap energy on composition for $\text{Cd}_{1-X}\text{Zn}_X\text{Te}$,” *Physical Review B*, vol. 45, no. 3, pp. 1440–1442, 1992.

- [16] K. Prasada Rao, O. Md. Hussain, K. T. R. Reddy, et al., "Structural and optical properties of $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$ thin films," *Journal of Alloys and Compounds*, vol. 218, no. 1, pp. 86–89, 1995.
- [17] J. Kimmerle, R. Menner, H. W. Schock, and A. Valera, "Ternary II-VI compound thin films for tandem solar cell applications," *Thin Solid Films*, vol. 126, no. 1-2, pp. 23–29, 1985.
- [18] S. A. Ringel, R. Sudharsanan, A. Rohatgi, and W. B. Carter, "Study of polycrystalline $\text{Cd}(\text{Zn}, \text{Mn})\text{Te}/\text{CdS}$ films and interfaces," *Journal of Electronic Materials*, vol. 19, no. 3, pp. 259–263, 1990.
- [19] T. M. Razykov and V. I. Vyalyi, "Structural and electrical properties of $\text{Zn}_x\text{Cd}_{1-x}\text{Te}$ films fabricated by chemical vapor deposition," *Applied Solar Energy*, vol. 24, no. 4, pp. 1–5, 1988.
- [20] T. L. Chu, S. S. Chu, C. Ferekides, and J. Britt, "Films and junctions of cadmium zinc telluride," *Journal of Applied Physics*, vol. 71, no. 11, pp. 5635–5640, 1992.
- [21] B. M. Basol, V. K. Kapur, and M. L. Ferris, "Low-cost technique for preparing $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$ films and solar cells," *Journal of Applied Physics*, vol. 66, no. 4, pp. 1816–1821, 1989.
- [22] B. Samanta, S. L. Sharma, and A. K. Chaudhuri, "Study of the microstructure and optical properties of polycrystalline $\text{Cd}_{1-x}\text{Zn}_x\text{Te}$ thin films," *Vacuum*, vol. 46, no. 7, pp. 739–743, 1995.
- [23] M. Husain, B. P. Singh, S. Kumar, T. P. Sharma, and P. J. Sebastian, "Optical, electrical and structural investigations on $\text{Cd}_{1-x}\text{Zn}_x\text{Se}$ sintered films for photovoltaic applications," *Solar Energy Materials and Solar Cells*, vol. 76, no. 3, pp. 399–415, 2003.
- [24] V. Kumar and T. P. Sharma, "Structural and optical properties of sintered $\text{CdS}_x\text{Se}_{1-x}$ films," *Journal of Physics and Chemistry of Solids*, vol. 59, no. 8, pp. 1321–1325, 1998.
- [25] V. Kumar, G. Singh, K. L. A. Khan, T. P. Sharma, and M. Husain, "ZnSe sintered films: growth and characterization," *Applied Surface Science*, vol. 253, no. 7, pp. 3543–3546, 2007.
- [26] V. Kumar, S. K. Sharma, and T. P. Sharma, "Optical and structural properties of CdZnTe sintered films," *Bulletin of Pure & Applied Sciences*, vol. 24D, no. 2, p. 115, 2005.
- [27] V. Singh, V. Kumar, S. K. Sharma, and T. P. Sharma, "Study of compositional and diffusion effect in $\text{Cd}_x\text{Zn}_{1-x}\text{S}$ sintered films," *Indian Journal of Engineering and Materials Sciences*, vol. 4, no. 4, pp. 163–165, 1997.
- [28] J. Tauc, Ed., *Amorphous & Liquid Semiconductors*, Plenum Press, New York, NY, USA, 1974.
- [29] V. Kumar, S. K. Sharma, T. P. Sharma, and V. Singh, "Band gap determination in thick films from reflectance measurements," *Optical Materials*, vol. 12, no. 1, pp. 115–119, 1999.
- [30] J. I. Pankove, *Optical Processes in Semiconductors*, Prentice-Hall, Englewood Cliffs, NJ, USA, 1997.