Structural properties of electron-beam evaporated CdTe films

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CdTe thin films were deposited on glass substrates using electron beam evaporation technique. The cadmium enriched starting materials, as (1-x)% Cd and x% Te where x varies from 20% to 45%, were used for fabrication of thin films. The variation of structural properties with composition of Cd and Te in starting materials have been studied. Films were characterised by using XRD and SEM techniques. In the composition range 20% ≤ x ≤ 45% CdTe films are n-type and polycrystalline. Scanning electron microscopic studies of the films indicate that the grains are fine and with small size of crystallites. X-ray diffractograms show that the grain size of CdTe films varies from 1.33 to 1.57 Å. It has been observed that the cubic structure of CdTe films is more responsible for their high conductivity.

The narrow band gap semiconductor of the II-IV compounds, CdTe has good prospects for applications in photoconductive and photovoltaic cell, thin films diode and transistor. The deviation from stoichiometry of CdTe in films i.e. the tellurium and cadmium vacancies are responsible for n-type and p-type semiconductivities respectively1. The n-type and p-type semiconductivities of CdTe films were obtained by vacuum evaporation of single crystal or polycrystalline CdTe with Cd or Te respectively in excess i.e. CdTe+Cd or CdTe+Te at controlled rates2.

In this paper n-type CdTe films have been prepared using electron beam evaporation technique with a new starting material - (1-x)% Cd and x% Te. The variation of structural properties of n-type CdTe thin films with compositions of Cd and Te in starting material, are reported here.

Experimental Procedure

The desired amount of cadmium (99.99%) and tellurium (99.99%), for particular composition in (1-x)% Cd and x% Te, were premixed and sealed in evacuated corning glass ampoules at a pressure of 10⁻² torr. The glass ampoules were fired in a furnace at different temperatures between 700-800°C, below the melting point for a particular composition7 for approximately 50 h, to allow the cadmium and tellurium to react in solid form. After 50 h, the ampoules were cooled, broken and compounds were found to be semipowdered. The semipowdered materials were again sealed in glass ampoules at pressure of 10⁻² torr and heated at the same temperatures to ensure the homogeneity of product materials.

The CdTe films were fabricated from starting materials on glass substrates kept at room temperature in vacuum using electron beam evaporation system, evacuated by a diffusion oil pump with liquid nitrogen trap. The obtained lowest pressure was 10⁻⁵ torr, but during evaporation it was below 10⁻⁵ torr. The deposition rate and thickness of the films were measured during deposition by using digital thickness monitor (HITECH, DTM-101). The deposition rate was in the range between 6-8 Å per second. The resistivity of the CdTe films was measured at room temperature by four point probe technique. The conventional van der Pauw method was used for Hall coefficient measurement at 7k gauss at room temperature. The electrical ohmic contacts to the samples were made by evaporating Indium on both ends of the surface for the measurements of activation energy and thermoelectric power. The X-ray diffraction of the films were measured by diffractometer (SIEMENS DIFRAKTOMETER, D-5000) at school of Physics, Devi Ahilya Viswavidyalaya, Indore, India and scanning electron micrographs of the CdTe films were taken by electron microscope (PHILLIPS, SEM-515) at Central Drug Research Institute, Lucknow, India.
Results and Discussion

The surfaces of the fabricated films were smooth and brown in colour. The films were firmly adhered to glass substrates. The crystallography structures of the films were analyzed by X-ray diffraction (Cu $K_{\alpha}$ radiation). The X-ray diffraction patterns of CdTe films of the thickness 300 nm as samples, SR-I, SR-II, SR-III, SR-IV and SR-V are given in Figs 1a-e respectively. The Fig. 1a corresponds to X-ray diffractogram of CdTe film fabricated from starting material as 80% Cd and 20% Te. The (111), (200) and (101) peaks were observed, side by side one peak of Cd was also observed. The structure of this film was cubic (111) and tetragonal (200) and (101) with a preferred orientation of the (111) planes parallel to the substrate. The Fig. 1b represents the X-ray diffraction pattern of CdTe films fabricated from starting material as 75% Cd and 25% Te. The (111), (220) and (311) peaks of CdTe were observed and one peak of Cd was also observed. The crystallinity of the film was good and the structure of the films was cubic [(111), (220), (311)] with a preferred orientation of the (111)
Table I—Electrical measurement on CdTe films of thickness 300 nm with different compositions of Cd & Te

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Composition &amp;%</th>
<th>Resistivity $\text{ohm/m } \times 10^{-4}$</th>
<th>Carrier concentration $\text{m}^{-2} \times 10^{24}$</th>
<th>Mobility $\text{m}^2/\text{V s}$</th>
<th>Activation energy $\text{eV}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRI</td>
<td>20</td>
<td>0.50</td>
<td>1.45</td>
<td>0.076</td>
<td>0.009</td>
</tr>
<tr>
<td>SRII</td>
<td>25</td>
<td>0.30</td>
<td>2.60</td>
<td>0.080</td>
<td>0.008</td>
</tr>
<tr>
<td>SRIII</td>
<td>30</td>
<td>2.82</td>
<td>0.31</td>
<td>0.072</td>
<td>0.014</td>
</tr>
<tr>
<td>SRIV</td>
<td>35</td>
<td>4.66</td>
<td>0.20</td>
<td>0.067</td>
<td>0.015</td>
</tr>
<tr>
<td>SRV</td>
<td>40</td>
<td>6.14</td>
<td>0.19</td>
<td>0.052</td>
<td>0.017</td>
</tr>
<tr>
<td>SRIVI</td>
<td>45</td>
<td>7.19</td>
<td>0.18</td>
<td>0.046</td>
<td>0.020</td>
</tr>
</tbody>
</table>

planes parallel to the substrate. The Fig. 1c shows the X-ray diffraction pattern of CdTe films fabricated from starting material as 70% Cd and 30% Te. The (111), (220) and (311) peaks of CdTe were observed and no peak of Cd was detected. The film was crystalline, with cubic structure [(111), (220), (311)] with a preferred orientation of the (111) plane parallel to the substrate. In the Fig. 1d, the X-ray diffraction pattern of CdTe films fabricated from 65% Cd and 35% Te as starting material is shown. The crystallinity of the films was good. The (111), (101), (220) and (400) peaks of CdTe were observed and no peak of Cd was detected. The [(111), (220), (400)] peaks represent the cubic structure of CdTe and (101) peak represents the tetragonal structure of CdTe films. The intensity of all peaks except (111) peak are equal, therefore, no preferred orientation was observed. The X-ray diffraction of CdTe films deposited from 60% Cd and 40% Te as starting material is shown in Fig. 1e. The (111), (220), (311) and two (101) peaks of CdTe were observed, no peak of Cd was detected. The fabricated film was crystalline with a preferential orientation of the (220) planes parallel to the substrate. The (220) and (311) peaks represent cubic structure of CdTe although two (101) peaks represent the tetragonal structure of CdTe films. The thermo-emf measurement represents all fabricated CdTe films as n-type and the data obtained from other electrical measurements are given in Table I. X-ray diffractograms of CdTe films (Fig. 1a-e) show that peaks of Cd in Figs 1a and 1b were obtained when the concentration of Cd in starting material is very high (sample SR-I and SR-II). But no peak of Cd in Figs 1c, 1d and 1e is obtained when Cd concentration is high (sample SR-III, SR-IV and SR-V). It is clear from Figs 1a-e that the only two preferred orientations (111) in Figs 1a-c and (220)
in Fig. 1e were obtained but no preferred orientation is obtained in Fig. 1d. The cubic structure of CdTe films obtained in Figs 1b and 1c, cubic and tetragonal structures were obtained in Figs 1a, 1d and 1e, and no hexagonal structure of CdTe was obtained in any sample. It clear from Fig. 1 that if Cd concentration in starting material increases the intensity of (111) plane is increased as well as the cubic and tetragonal structure of CdTe films are changed to cubic structure. But at very high concentration of Cd in starting materials (sample SR-I), both the phases are observed. The high conductivity of CdTe films was obtained in sample SR-II and only cubic structure of CdTe films was observed in this sample, therefore, only cubic structure with preferred orientation (111) of n-type CdTe films is responsible for their high conductivity. If both phases i.e. cubic and tetragonal structures (sample SR-I, SR-IV & SR-V) were present in the CdTe films it would have low conductivity. Similar conclusions are also reported\cite{3,9,10} for highly conducting n-type CdTe films.

The grain size of CdTe films has been calculated from the X-ray diffraction peaks using the following relationship:

\[ D = \frac{0.90 \lambda}{\beta \cos \theta} \]

where D is the diameter of grain in Å, λ is wavelength in Å of X-ray beam, \( \beta \) is the full width half maximum (FWHA) and \( \theta \) is the angle of diffraction. The grain sizes were obtained as 1.42 Å, 1.57 Å, 1.38 Å, 1.33 Å, and 1.37 Å for samples SR-I, SR-II, SR-III, SR-IV and SR-V respectively. The surface morphology of polycrystalline n-type CdTe films, deposited on glass substrates at room temperature of the thickness of 300 nm, were investigated under the scanning electron microscope (SEM) and are given in Fig. 2. The Figs 2a, 2b and 2c are the scanning electron micrographs of samples SR-I, SR-II and SR-III respectively. It is clear from Fig. 2 that surfaces of polycrystalline n-type CdTe films were fine and with small size of crystallites.

**Conclusion**

The n-type CdTe thin films have been fabricated by the electron beam evaporation technique using (1-x)% Cd and x% Te as starting material. It has been found that cubic structure of CdTe films is more responsible for their high conductivity.

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**References**