AC and dielectric properties of vacuum evaporated InTe bilayer thin films

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1. Introduction

III–VI semiconducting compounds are receiving great technological interest because of their interesting electrical and optical properties [1–5]. Among these compounds, indium telluride (In2Te3) is a well known semiconductor for radiation detector, switching and photovoltaics [6–9]. Indium telluride is a direct band gap semiconductor with the band gap energy of 1.1 eV. In2Te3 is a well known semiconductor for radiation detector, switching devices, gas sensors, hybrid solar cells, etc. InTe thin films were prepared by sequential thermal evaporation of In and Te at Ar atmosphere. X-ray diffraction pattern of the films shows that the films posses mixed phase of In2Te5 and In2Te3. Grain size (D) and dislocation density were calculated by using Scherer’s formula. Surface morphology of the film is analyzed by SEM and the surface is found to be agglomeration of well defined grains. EDS analysis reveals that elemental composition is in right stoichiometry. The value of capacitance and tanδ was recorded with respect to different frequencies and at different temperatures. It is observed that the capacitance decreases with increase in frequency at all temperatures. The observed nature of the capacitance is due to the inability of the dipoles to orient in a rapidly varying electric field. The pronounced increase in capacitance toward the low frequency region may be attributed to the blocking of charge carriers at the electrodes which leads to space charge layer resulting in the increase of capacitance. The mechanism responsible for AC conduction is found to be electronic hopping. TCC and TCP values were calculated and the results are discussed.

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2. Experimental details

In2Te3 bilayer thin films were prepared on to well cleaned glass substrates by sequential thermal evaporation of In and Te using 5N pure powder materials (Sigma–Aldrich Chemicals, US) under a base pressure of 1 × 10−5 mbar in Ar atmosphere. The thickness of both layers In and Te was chosen in order to get effective mixing with atomic proportions. In order to compensate the re-evaporation of chalcogenide during annealing, we have taken the thickness ratio of Te/In was slightly higher than 3/2 to form In2Te3. The thickness of the films was monitored and controlled by Quartz Crystal thickness monitor. Bottom and top electrode is used to sandwich the InTe thin film with Al as the electrode material. Al/InTe sandwich thin film system was annealed at 300 °C in Ar atmosphere for half an hour in order to form InTe. Complete system of Al/InTe/Al is prepared by thermal evaporation technique with individual elements. Temperature was measured by chromel–alumel thermocouple. X-ray diffraction studies were carried out using PANalytical instrument with CuKα radiation in order to get structural information. Surface morphology and elemental composition of the films were analyzed by scanning electron microscopy and energy dispersive X-ray spectroscopy, respectively. With the help of digital LCR meter (LCR-819, GW Insteck, Good will Instrument Ltd., Taiwan), measurements of series capacitance and the dissipation factor for different frequen-
cies were carried out at various temperatures (291–448 K) under vacuum of $10^{-3}$ mbar. All the experiments were repeated three times in order to check the reproducibility and the error bar was about ±2%. The dielectric constant ($\varepsilon'$) was evaluated from the observed capacitance data. The parallel equivalent conductance ($G_p = \omega C_p \tan \delta$) was calculated at different temperatures.

3. Results and discussion

3.1. Structural properties

Fig. 1 represents the XRD spectra of indium telluride thin film of typical thickness 4000 Å. From Fig. 1, it is observed that the structure of the film contains the mixed phase of In$_2$Te$_3$ and In$_2$Te$_5$ (JCPDS 16-0445 & 71-0109). In$_2$Te$_3$ phase of the film exhibits with the preferential orientation along (5 1 1), (6 6 0) and (7 7 1) plane at $2\theta$ equal to 23°, 40.3° and 49°, respectively, whereas In$_2$Te$_5$ phase exhibits with the preferential orientation along (4 4 0) plane and (6 2 2) plane at $2\theta$ equal to 27° and 33°, respectively. From Fig. 1, it is inferred that the films contain mixed phase of In$_2$Te$_3$ and In$_2$Te$_5$; whereas In$_2$Te$_5$ phase is dominant when it is compared with In$_2$Te$_3$ phase. The electronegativity difference between the metal and the chalcogene is quite small, since the electronegativity of tellurium and indium is 2.1 and 1.7, respectively. This small electronegativity difference induces a poor stability of such compounds, whose composition that depends strongly on preparation condition and annealing temperature. The grain size ($D$) of the dominant phase was calculated by using Scherer's formula and it is given in Table 1.

Fig. 2 represents the SEM image of InTe thin film. The SEM images clearly denote that the film have homogeneous surface without any pinhole. The grains tend to agglomerate with nearer grains to form bigger grains, which supports the XRD result [16]. Spherical geometry of the grains was vanished due to agglomeration of grains, thereby reducing grain boundaries. Table 2 shows the elemental composition of the InTe thin film. It is observed that excess in tellurium content implies that the possibility of existence of In$_2$Te$_5$ phase along with In$_2$Te$_3$ phase [1]. This also supports the XRD results.

Table 1

<table>
<thead>
<tr>
<th>Film thickness (Å)</th>
<th>FWHM</th>
<th>Strain ($\times 10^{-2}$ dyn/cm$^2$)</th>
<th>Dislocation density ($\times 10^{18}$)</th>
<th>Crystalline size (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>0.20468</td>
<td>5.01397</td>
<td>1.91551</td>
<td>72.2</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Film thickness (Å)</th>
<th>Element</th>
<th>Atomic %</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>In</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Te</td>
<td>66</td>
</tr>
</tbody>
</table>

3.2. Dielectric properties

The variation of capacitance with frequency in the frequency range 100 Hz to 60 kHz for different temperatures is shown in Fig. 3. The capacitance decreases with increase in frequency. It may be due to the screening of the electric field across the film by charge redistribution [17–19]. At low frequencies, the charges on neutral impurity defects are more readily redistributed, such that defects closer to the positive side of the applied field become negatively charged while the defects closer to the negative side of

Fig. 1. XRD spectra of InTe thin film.

Fig. 2. SEM image of InTe thin film.

Fig. 3. Variation of Cs with log frequency.
the field become positively charged. As the frequency is increased, the capacitance decreases to the same limit, as the charges on the defects no longer have time to rearrange in response to the applied voltage. At higher temperature, the screening is more effective, because of the increase in thermal activation of charges as observed [20].

Fig. 4 presents the dependence of dielectric constant ($\varepsilon'$) with frequency. The dielectric constant also decreases with increase in frequency at all temperatures exhibiting a similar trend as that of the capacitance. These curves closely resemble those predicted by the Debye relaxation model for orientational polarization [21]. Fig. 5 shows the typical variation of tan $\delta$ with frequency at various temperatures. The loss factor is found to increase with increase in frequency, whereas it decreases with increase in temperature, which may be due to the effect of lead resistances.

Temperature dependence of the capacitance (TCC) and temperature dependence of permittivity for different frequencies have been shown in Figs. 6 and 7, respectively. The capacitance was found to increase with increasing temperature. The temperature co-efficient of capacitance (TCC) and permittivity (TCP) have been evaluated using the expressions:

$$TCC = \left( \frac{1}{C_S} \right) \times \left( \frac{dC}{dT} \right)$$  \hspace{1cm} (1)

$$TCP = \left( \frac{1}{\varepsilon'} \right) \times \left( \frac{d\varepsilon'}{dT} \right)$$  \hspace{1cm} (2)

Table 3 summarizes the estimated values of TCC and TCP for different frequencies. It is found that the TCC values increase with frequency and TCP values decrease with increase in frequency. This effect may be attributed to the electron hopping between the pair of centres under the action of alternating current field which is equivalent to the reorientation of the dipoles. Hence the variation of TCP and TCC is attributed to the presence of dipoles [22,23].

### 3.3. AC conduction properties

The AC conductance (Gp) was calculated at different temperatures from the measured values of capacitance and loss factor.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Frequency (Hz)</th>
<th>TCC (ppm/K x 10^-4)</th>
<th>TCP (ppm/K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>5.33</td>
<td>1.51996</td>
</tr>
<tr>
<td>2</td>
<td>1000</td>
<td>1666.63</td>
<td>0.951908</td>
</tr>
<tr>
<td>3</td>
<td>2000</td>
<td>4166.70</td>
<td>0.666670</td>
</tr>
<tr>
<td>4</td>
<td>3000</td>
<td>5553.00</td>
<td>0.606078</td>
</tr>
</tbody>
</table>

Table 3 Frequency dependence of TCC and TCP.
temperatures are different, thereby resulting in the decrease of carrier movement between and within the defect wells) at different temperatures. Jonscher [28] accounted for this behavior on the basis of hopping dielectric thin films[25–27]. In the first region (<10 kHz), the behavior has been observed by various investigators on insulating solids[24].

The contributions to conductivity from the carrier movement (carrier movement between and within the defect wells) at different temperatures are different, thereby resulting in the decrease of n with increase of temperature. This phenomenon suggests that the mechanism responsible for AC conduction is electronic hopping [28,29].

Fig. 9 exhibits the temperature dependence of AC conductance and the estimated activation energy is 0.07326 eV. The observed low value of activation energy suggests that the conduction mechanism in these films may be due to the hopping of electrons, which is in accordance with earlier investigations on other semiconducting films [30,31].

4. Conclusion

Indium telluride thin film system was prepared on cleaned glass substrate by sequential thermal evaporation and post-deposition annealing at 300 °C in Ar atmosphere for half an hour. Structural analysis shows that the film contains the mixed phase of In₂Te₃ and In₄Te₅. The capacitance and loss factor are dependent on both temperature and frequency. The dielectric constant (ε'), temperature co-efficient of capacitance (TCC) and temperature co-efficient of permittivity (TCP) were estimated. The process of AC conduction has been explained on the basis of hopping mechanism. The mechanism responsible for AC conduction is electronic hopping.

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References