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PYROELECTRICITY OF Cd-DOPED TELLURIDE THIN FILM

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The crystalline structure, electrical conductivity and pyroelecricity of freshly prepared $Hg_{0.7}Cd_{0.3}Te$ thin film have been investigated in detail.

It is of interest to note that HgTe and CdTe have the zinc blende structure and form a continuous series of alloys [1–3] denoted by $Hg_{(1-x)}Cd_xTe$, where x is the mole fraction of CdTe in the alloy. These alloys are a mixture of a semimetal (HgTe) with a semiconductor (CdTe); the energy gap E_c in these alloys varies continuously [4, 5] between the "negative gap" of -0.30 eV found in HgTe [6] to the positive gap of 1.60 eV found in CdTe [7, 8]. Narrow-gap semiconducting alloys in this system have proved useful as infrared detectors [9].

Experimental

HgTe and CdTe were prepared by direct melting of equimolecular ratios of the two component elements under vacuum (10^{-5} mmHg) in quartz capsules [10]. The crystalline structures of the prepared $Hg_{0.7}Cd_{0.3}Te$ thin film were measured before and after heating, using a Shimatzu (Japan) X-ray diffractometer, Cu–K_α radiation and a Ni-filter. The DC electrical resistivity and I–V characteristics were measured. The pyroelectric current generated was measured after poling with a K.T.V. electrometer, type TR 1501, from Orion, Budapest (Hungary).

Results and discussion

Figure 1 shows the Cu–K_α relative intensity (I/I_0) and interplanar spacings of the characteristic X-ray diffractograms of unheated (A, 20°) and preheated (B, 150°) HgCdTe thin films. From the results obtained, it can readily be seen that the X-ray

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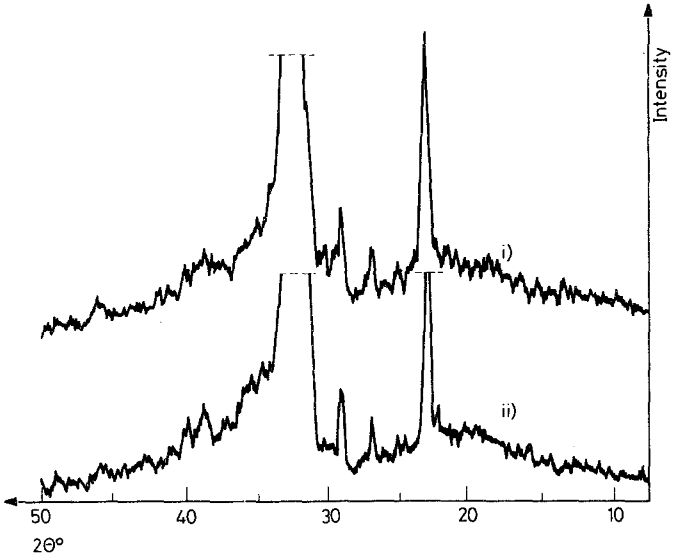

Fig. 1 A diagram showing the Cu–K_α X-ray diffraction pattern of $Hg_{0.7}Cd_{0.3}$ vacuum evaporated thin films: i) unheated sample, ii) sample preheated at 150 °C

diffraction peaks have a general trend in common, viz. the deflection peaks sharpen and their intensities are increased by preheating of the thin film at 150°. This could be correlated with further crystallization and an increased degree of crystallinity, together with cubic structure improvements. This indicates that the number of non-stoichiometric atoms or the non-stoichiometry decreased and the degree of crystallinity increased for the p4eheated sample (150°).

In this respect, the composition was chosen to evaluate the effect of Hg migration and non-stoichiometry on the electrical characteristics of the test sample. The activation energy for the process of electric conduction was calculated in the low and high-temperature regions, as in Table 1 and Fig. 2. From Fig. 2, it can be seen that the electrical conductivity becomes considerable higher with voltage rise from

Table 1 Activation energies and energy gaps (eV) obtained for Cd-modified HgTe thin film under applied voltages of 15 and 20 volts (A and B)

(A) 15 volts		(B) 20 volts	
Activation energy, eV	Energy gap, eV	Activation energy, eV	Energy gap eV
0.2	0.10	0.03	0.10
0.08	—	0.08	—

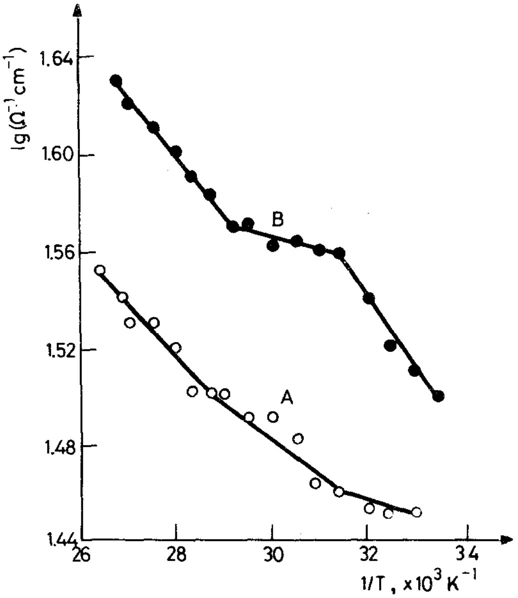

Fig. 2 A schematical representation showing the variation of logarithmic electrical conductivity as a function of reciprocal temperature: a – applied field = 15 V, b – applied field = 20 V

15 to 20 volts (curves A and B, respectively). This could probably be correlated with more mobilization of Hg to the edges of crystallites under 20 volts than under 15 volts. Thus, mercury migration may lead to a decreased potential barrier between the crystallites. Again, the observed increase in the activation energies at higher temperatures is further support of the passage from extrinsic to intrinsic conduction mechanisms (Fig. 2). Since the high-temperature activation energy remains constant (0.01 eV), this corresponds to the intrinsic conduction mechanism as well as to an energy gap for the test specimen. For the relatively low-temperature region, the activation energies could be accounted for by an extrinsic conduction mechanism. This is further supported by their values being interchangeable, caused by migration of Hg from the bulk of the material to the crystallite edges. A typical I–V characteristic curve is shown in Fig. 3, which is ohmic up to $\simeq$20 volts. The current at low field varies with temperature in accordance with the equation [11]:

$$I_c = I_0 \exp(-\Delta E/2KT) \tag{1}$$

where ΔE is the activation energy for donors or traps, and

$$I_0 = q\mu N_d \frac{V_b}{d} A \tag{2}$$

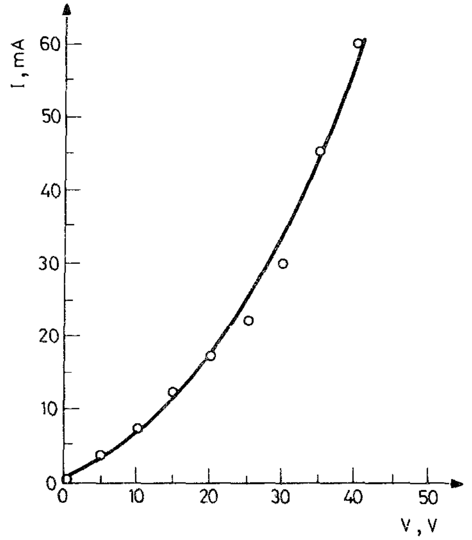

Fig. 3 A typical I–V characteristic curve for the investigated $Hg_{0.7}Cd_{0.3}Te$ thin film

where q is the electronic charge, μ is the mobility, N_d is the impurity density, V_b is the bias voltage, d is the effective electrode separation and A is the effective area. Normally, the current carriers in this material are of electronic and/or hole type. It is known that Hg/Cd and Te are weakly bound through intermetallic bonds. Thus, it was first suggested that the non-linearity in the I–V curve of this compound is due to the space charge of unneutralized carriers [12] when a relatively high electric field (300 volts as a poling field) is applied. The non-linearity in I–V above 20 volts (Fig. 3) is due to the domain structure of the material investigated. Thus, the onset of non-linear conduction would require current and power densities so high that power dissipation under continuous operation is destructive [13]. Plots of log I_c against $1000/T$ according to Eq. (1) have gradients which yield a consistent value of activation energy $\Delta E \simeq 0.1$ eV at different voltages (15 V and 20 V). With N_d (in Eq. (2)) $\simeq 6\times 10^{18}$ cm^{-1}, the mobility was estimated to be 1.28×10^{-2} cm^{2} V^{-1} sec^{-1}. This relatively low value of mobility and activation energy with an ohmic I_c–V_c characteristic ($\simeq 20$ V) are indicative of a localized state conduction (hopping) at relatively low field and high temperature. Consequently, the estimated hopping mobility of 1.28×10^{-2} cm^{-1} V^{-1} sec^{-1} is associated with a 0.01 eV activation energy at higher temperature (see Fig. 2 and Table 1). The breakthrough voltage is inversely proportional to the donor density and the density of surface states. Accordingly, these features are important in the fabrication of microelectronic circuits. Figure 4 illustrates the variation of pyroelectric current (amp.) as a function of temperature at heating rates of 2, 5 and 10 deg min^{-1} for

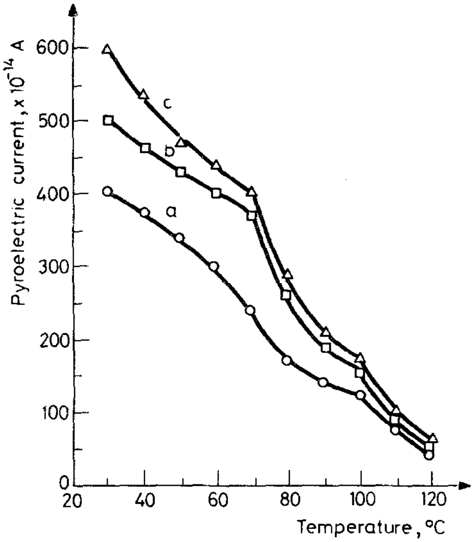

Fig. 4 A diagrammatical representation for the variation of the generated pyroelectric current (in Ampere) as a function of temperature

curves a, b and c, respectively. From this Figure it can readily be deduced that a higher generated pyroelectric current could be obtained at an increased rate of heating. This could be explained by the action of the heating rate in accelerating the mobilization of Hg to the edges of crystallites, leading to higher accumulation of pyroelectric charges at the surface of the specimen. Figure 5 illustrates the variation

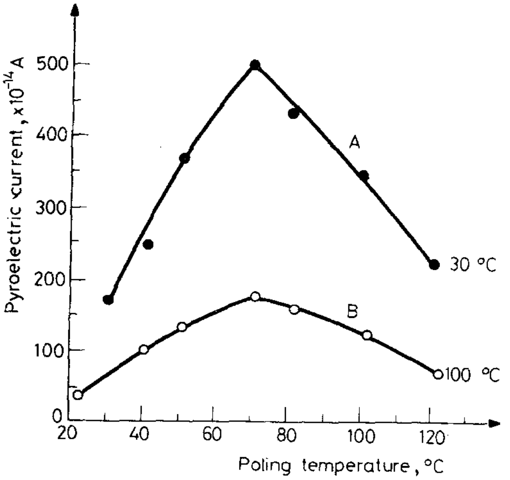

Fig. 5 A representation showing the variation of the generated pyroelectric current (in Ampere) as a function of poling temperature at various working temperatures: a – –30 °C, b – –100 °C

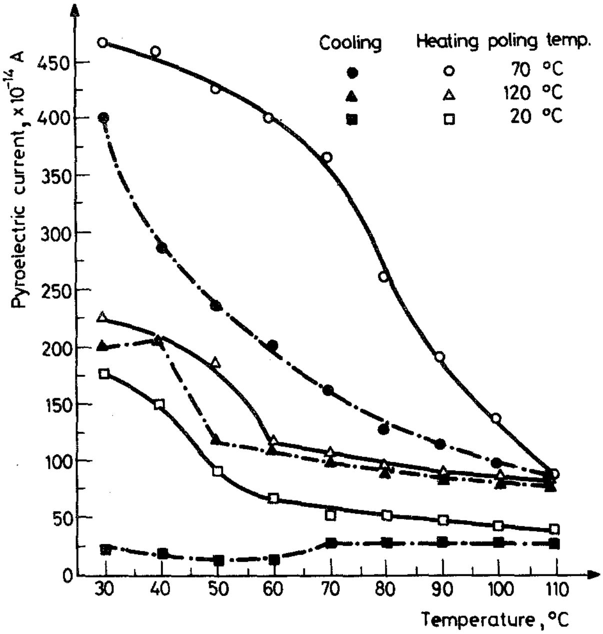

Fig. 6 A correlation showing the variation of the generated pyroelectric current (in Ampere) as a function of temperature at various poling temperatures as well as an cooling.

Cooling	Heating	Poling temp.
✓● -.-.-	○——	70 °C
✓▲ -.-.-	△——	120 °C
✓■-.-.-	□——	20 °C

of the generated pyroelectric current as a function of the poling temperature (°C) at working temperatures of 30° (curve a) and 100° (curve b). Both curves are characterized by an initial rise in pyroelectric current with poling temperature, at a rate depending on the experimental (working) temperature, leaving behind a peak value situated at constant temperature (T). The critical temperature (T_c) could probably be ascribed to some change in the electronic band structure of the specimen under investigation. This leads us to conclude that a poling temperature of 70° and a final working temperature of 30° are the optimum conditions for attaining maximum pyroelectric current. Thus, in confirmity with the X-ray data (see Fig. 1), the increased degree of crystallinity (for a sample preheated at 150°) will offer additional resistance or barrier energy for pyroelectric charge release. Accordingly, the results of X-ray diffraction analysis conform with those of pyroelectric measurements. In the initial heating stages, the pyroelectric current slowly falls, followed by abrupt decreases corresponding to the breaks in the curves at temperatures depending on the poling temperature, as a general trend in common

(Fig. 6). Alternately, 70° is the best poling temperature for attainment of a high generated pyroelectric current, holding up to relatively high working temperatures for the investigated HgCdTe films in the electronic and engineering industries.

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Zusammenfassung — Kristallstruktur, elektrische Leitfähigkeit und Pyroelektrizität einer frisch präparierten $Hg_{0.7}Cd_{0.3}Te$ Filmschicht wurden ausführlich untersucht.

Резюме — Детально исследована кристаллическая структура, электропроводность и пироэлектрические свойства свежеполученного тонкопленочного $Hg_{0.7}Cd_{0.3}Te$.