Физика твердого тела, 1997, том 39, № 1

Electrical conductivity of PbTe thin films

© *M.I. Abd El-Ati*

Physics Department, Faculty of Science, Tanta University, Egypt

(Поступила в Редакцию 2 сентября 1996 г.)

PbTe thin films were prepared by vacuum technique with different thicknesses ranged from 550 to 3000 Å. The electrical resistivity as a function of the film thickness and mobility was measured. The dependence of log (resistivity) and log (current) were studied as a function of the universal of temperature. The activation energies were estimated before and after the break. The transition of conductivity from n-type to p-type is attributed to the tincrease of migrating lead vacancies. An increase of the applied voltages on the thin films caused the shift of breaking temperature to higher temperatures. This is attributed to creation of Pb vacancies which retard the break.

PbTe has been of technological interest because PbTe films can be used as high sensitive infrared detectors [1].

In past eyars, further work was motivated by the possible use of PbTe films in thin film transistors [2]. More recently, PbTe was found to be a suitable semiconductor for producing laser action [3]. Extensive studies on the electrical and optical properties of PbTe have been made [4,5]. The low mobility and the increase of the activation energy with increasing temperature suggest that more than one conduction mechanism is involved [6]. The high density of acceptor centres in the thin layer of HgTe may affect the conduction current in certain temperature ranges. The electrical conductivity increases with voltage rise in Cd doped HgTe thin films [7]. This could probably correlate with a greater rate of movement of Hg to the edges of crystallites. The observed increase of the activation energies at higher temperatures is a further support for a change from extrinsic to intrinsic conduction mechanisms. The mobility of charge carriers was determined to be $1.97 \cdot 10^{-7}\,\mathrm{cm}^2 \cdot \mathrm{V}^{-1} \cdot \mathrm{s}^{-1}$ associated with a donor concentration of $4.5 \cdot 10^{18}\,\mathrm{cm}^{-3}$ and a high temperature activation energy of 0.078 eV, these are indicative of a localized-state conduction (hopping) mechanism [7].

PbTe films grow almost always n-type independently of temperature and type of the substrate [8]. In the present investigation, the film thickness versus resistivity dependences of PbTe thin films are examined. Another purpose was to study the effect of universal temperature on the log (d.c. current) passing through the PbTe thin film in order to evaluate the mobility of charge carriers besides the shift of the breaking resistivity against universal temperature at different applied voltages. All of these are good semiconductor parameters.

1. Experimental procedure

1) Film preparation. In order to produce high quality of PbTe thin films by evaporization in vacuum, the glass substrates were carefully cleaned using hot water, NaOH solution, distilled water and isopropyl alcohol sequentially. A quartz boat was charged with PbTe in granular form, of purity 99.999 % from Koch-Light Laboratories Ltd (England). The vacuum chamber was pumped down to 10^{-5}Torr. The boat was gradually heated until the material started to evaporate. The vapour molecules leaving the source were deposited onto the substrate surface. The substrate temperature was held at room temperature during the deposition process. The film was electroded by indium of distance separation 1 cm.

2) Measurements. Electrical measurements were performed under normal atmosphere. For the current measurements, the d.c. bias voltage was provided by power supply and the current was recorded by digital TRMS MULTIME TER 179 A (KEITHLEY). For the measurements of resistivity of the PbTe thin film, the voltage across the sample was monitored by digital voltameter. Sample temperature was monitored using thermocouple of accuracy ±0.1°C attached to the film substrate. The thickness of deposited on films was determined using a quartz crystal monitor.

2. Results and discussion

1) Identification of the prepared PbTe thin film. The X-ray diffraction pattern of PbTe thin film was recorded using a Shimadzu X-ray diffractometer, model (XD-3) with Cu K_α-radiation, and is shown in Fig. 1. The Bragg angle 2θ, the corresponding spacing d and the refractive intensities of the diffraction lines are listed in Table. The results confirm the preparation of cubic crystals of PbTe which are consistent with the ASTM card data. Table represent Bragg angles and the corresponding intensities of reffractions for PbTe thin film.

2) Resistance thickness dependence. The variation of the electrical resistivity ρ with film thickness t for PbTe films is noticed in Fig. 2. It is observed that the resistivity decreases with increasing film thickness. The high resistivity of thin films with small thicknesses is attributed to the existence of an island structure which contain many defect sites. These islands increase in area with the increase of the film thickness leading to the formation of a continous film. This suggests that the defect density is much smaller for films deposited with

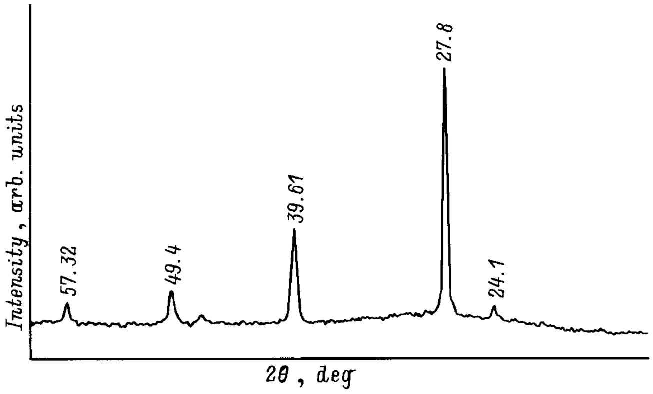

Fig. 1. X-ray diffraction pattern of PbTe Thin film.

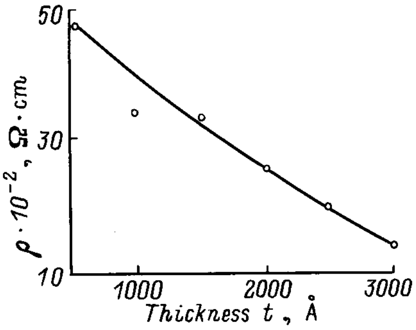

Fig. 2. Effect of film thickness on the electrical resistivity ρ.

larger thickness. As a result, the electrical resistivity decreases with rising film thickness.

In conclusion, the increase of the film thickness decreases the empty channels between the isolated islands of PbTe leading to creation of continuous film structure caused the increase of the charge carriers through the film. The decrease of the resistivity as the film thickness increase is similar to previous work [4,7].

3) Temperature dependence of current of PbTe thin film. The logarithm of current is plotted against the reciprocal of absolute temperature at 20 V for different film thicknesses as shown in Fig. 3. The current varies with temperature in accordance with the relation

$$I = I_0 \exp(-\Delta E/kT), \qquad (1)$$

where ΔE is the activation energy for donors. According to eq. (1), the gradients for these slopes yield a consistent value of activation energy. Before the transition temperature (break of $\log I$), $\Delta E = 0.0696 \rightarrow 0.124$ eV for different thicknesses, while for higher temperature (after break), $\Delta E = 0.0397 \rightarrow 0.205$ eV.

The break through current, or transition from a straight line with a low gradient to one with a higher gradient as the temperature is increased, suggest that more than one conduction mechanism is involved. The high density of acceptor centres in the PbTe thin film may affect the conduction at the transition temperature. A possible explanation of the results obtained of the PbTe thin film is n-type which is correlated to interdiffusion of native defects when raising its temperature. In the present work, materials with an impurity density $\cong 10^{18}\,\mathrm{cm}^{-3}$ were used [18]. Thus, the carrier type and concentration are primarily determined by the presence of electrically-active native point defects which are mainly metal and Te vacancies. The metal vacancies

Bragg angles θ, the corresponding spacings d, and the diffraction line intensities I/I_0

Prepared Samples			ASTM data		
2θ, deg	I/I_0	d, Å	2θ, deg	I/I_0	d, Å
24.1	8	3.6926	23.8	10	3.74
27.8	100	3.209	27.6	100	3.23
39.61	38	2.2758	39.5	80	2.28
49.4	14	1.8448	48.95	30	1.858
57.32	10	1.6073	57.2	20	1.609

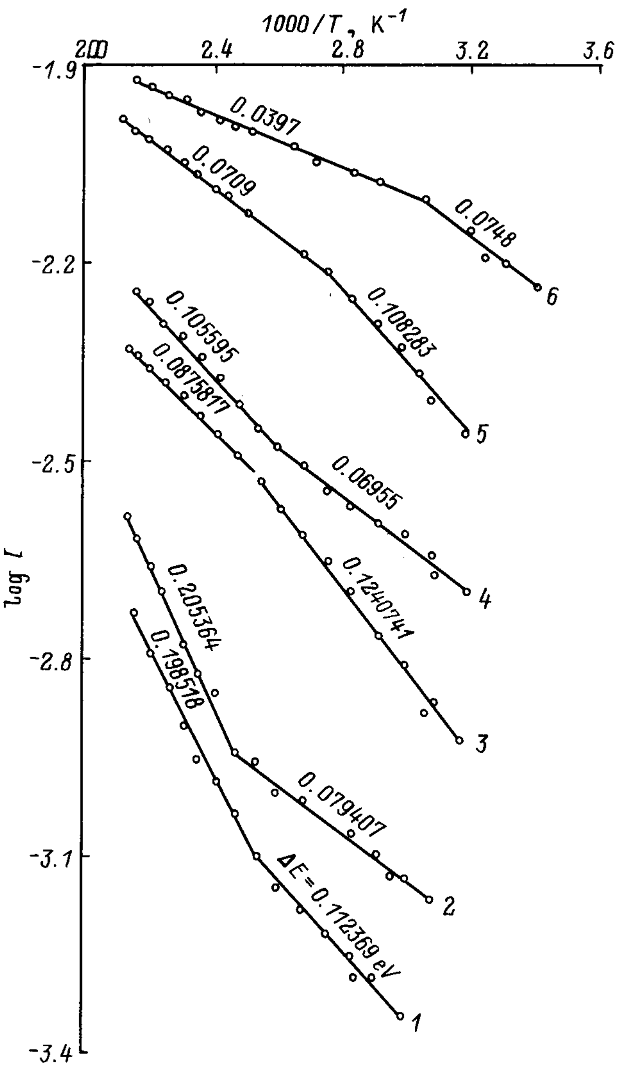

Fig. 3. Temperature dependence of current of PbTe thin films. t (A): *1* — 550, *2* — 1000, *3* — 1500, *4* — 2000, *5* — 2500, *6* — 3000.

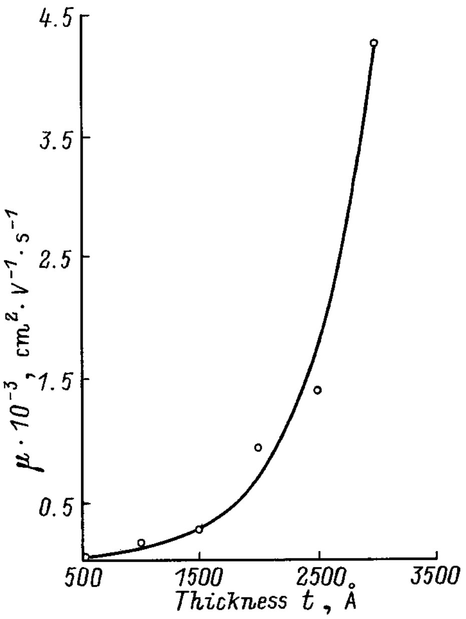

Fig. 4. Effect of film thickness on the mobility of charge carriers for PbTe thin film.

behave as acceptors and the Te vacancies behave as donors. When the n-type PbTe is heated to the breaking temperature, the lage interdiffusion coefficient of metal vacancies in PbTe [9,10] which are substitutional metal vacance flow into the PbTe possible. This flow increases the acceptor concentratin and reduced electron concentratin at the critical temperature leading to the creation of the p-type conduction of PbTe thin film. This is in a good agrement with previous work on HgCdTe thin film [11] and CdSe thin films [12].

4) Mobility of electrons as a function of PbTe thin film thickness. The mobility of electrons in PbTe thin film was estimated from the relation [6].

$$I_0 = q\mu N_d \frac{V}{d} A, \qquad (2)$$

where q is the electronic charge, μ is the mobility, N_d is the donor (or acceptor) density $\cong 10^{18}\,\mathrm{cm}^{-3}$, U is the voltage, d is the effective electrode separation, A is the effective area, and I_0 is the current at zero temperature determined from Fig. 3.

The mobility of the electrons increases exponentially as the film thickness increases as in Fig. 4. These low values of mobility are an indication of a localized state conduction (hopping), which is limited by the scattering on the barriers among crystallites. The increase of film thickness increases the mobility because the energy gap decreases due to increasing the size of island leading to formation of continuous n-type PbTe film. This is confirmed presently by decreasing the activation energy with increasing thickness.

5) Temperature dependence of electrical resistivity of PbTe thin film. The temperature dependence of the electrical resistivity ρ of PbTe thin film (3000 Å) at different applied voltages (20, 30, 40 and 50 V) is noticed in Fig. 5. The logarithmic relation between the electrical resistivity and $1000/T$ is linear with a negative slope, controlled by the relation

$$\rho = \rho_0 exp(-E/kT),$$

where ρ_0 is the resistivity at zero temperature, k is the Boltzmann constant, and E is the activation energy.

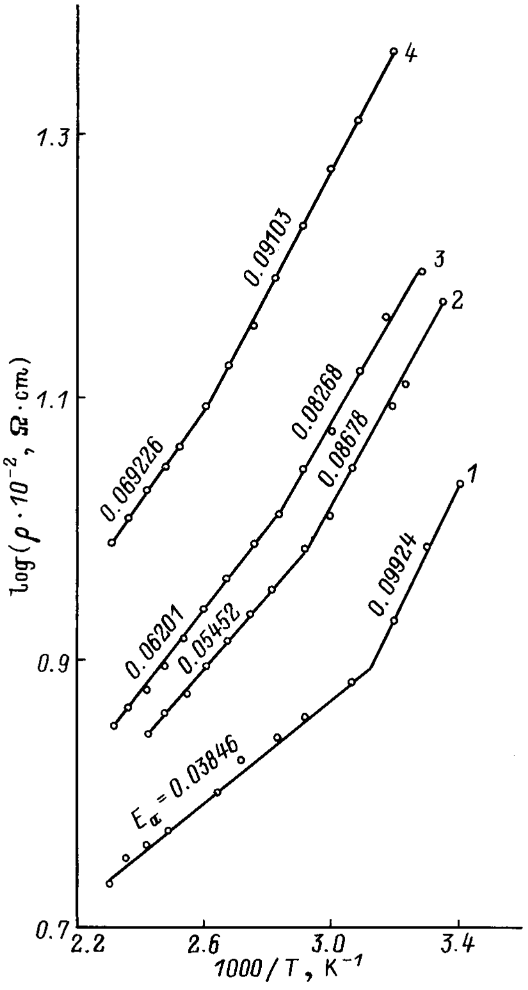

Fig. 5. Temperature dependence of the electrical resistivity ρ of PbTe thin film at different applied voltages. U (V): *1* — 20, *2* — 30, *3* — 40, *4* — 50.

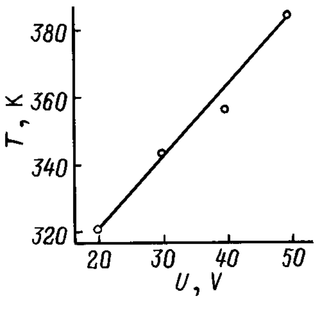

Fig. 6. Variation of the breaking temperature with the applied voltage on PbTe thin film.

The activation energy for electric conduction is calculated from the slope of the lines and was found to be in the range 0.0826–0.0992 eV before the break. The increase of conductivity may be due to the following.

The predominant point defects are Pb vacancies or Te-interstitial acceptors. It is well known that PbTe thin film always has an excess of Te and that the net hole concentration (p–n) can be altered by rising temperature. It is generally believed that the excess holes result from the ionization of acceptor defects associated with the presence of a stoichiometric excess of Te. The increase of temperature increase the ionized acceptor defects which migrate through the lattice to accumulate at the electrode surfaces. This give rise to the sample conduction as the temperature increases below breaking temperature (transition temperature). The estimated values of activation energies decrease with rising the film temperature after the break ($\Delta E = 0.038-0.069$ eV). The decrease of the gap energy is attributed to transition of conduction through the film from hole to elecftron conduction which is the predominant role after the break.

6) Effect of applied voltage on the temperature dependence of logarithm resistivity ρ. The temperature dependence of log, ρ as a function of applied voltage (20, 30, 40 and 50 V) was studied as noticed in Fig. 5. The gradients of these lines yield consistent set of activation energies over and below the break and are consistent with that estimated from $\log I$ and $1000/T$. The breaking temperature increases as the applied voltages increases, as shown in Fig. 6. This could be ascribed to the increase mobilization of Pb vacancies. Further applied voltage may increase the potential barrier which inhibits the formation of electrons and accelerates Pb-vacancy mobilization. At the break, the electrons phay the predominant role for conduction at higher temperatures for PbTe thin films.

The increase of breaking temperature at different voltages for PbTe thin films is similar to that in previous work on CdSe thin films [12].

The author wish to thank Physics Department, Faculty of Science, Qatar University, for preparation the samples.

References

[1] T.S. Moss. Optical Properties of Semiconductor. Butter Worths, London (1961). P. 181.
[2] W.B. Pennebaker. Solid State Electron. **8**, 509 (1965).
[3] J.M. Besson, W. Paul, A.R. Calawa. Phys. Rev. **173**, 599 (1965).
[4] R.B. Schoolar, J.N. Zemel. J. Appl. Phys. **35**, 1484 (1964).
[5] J.G. Simmons. J. Phys. D.: Appl. Phys. **4**, 613 (1971).
[6] A. Tawfik, M.I. Abd El-Ati. J. Therm. Anal. **31**, 509 (1986).
[7] A. Tawfik, M.I. Abd El-Ati, M.M. Abou-Sekkina. Appl. Surf. Sci. **22/23**, 7721 (1985).
[8] A. Nucciotti, P. De Stefano, P. Mascheretti, G. Samoggia. Phys. Stat. Sol. (a) **2**, 193 (1972).
[9] L. Goldstein. C.R. Acad. Sci. **B268**, 686 (1969).
[10] J.N. Walpole, R.L. Guldi. J. Nonmet. **1**, 227 (1973).
[11] A. Tawfik, M.M. Abou-Sekkina, M.I. Abd El-Ati. Appl. Surf. Sci. **22/23**, 763 (1983).
[12] M.M. Abou-Sekkina, A. Tawfik, M.I. Abd El-Ati. J. Therm. Anal. **30**. 753 (1985).