Indian J. Phys. 49, 783–790 (1975)

Galvanomagnetic properties of evaporated tellurium films

A. K Chaudhuri and H. N Bose

Department of Physics Indian Institute of Technology, Kharagpur

(*Received* 14 *April* 1975, *revised* 30 *June* 1975)

Temperature variation of Hall coefficient and Hall mobility for different thickness of tellurium films have been measured, films were deposited keeping all other evaporation parameters constant. Results of the present measurement show that the nature of variation of Hall coefficient and Hall mobility with temperature is qualitatively different for thick and thin films The Hall coefficient and mobility of tellurium films seem to obey approximately the relations;

$$R_H = \frac{A}{p_0 + p_1 e^{\epsilon/KT}} \quad \text{and} \quad \mu = \frac{CT^{5/2}}{p_0 + p_1 e^{-\epsilon/KT}}$$

respectively, where A, p_0, p_1 and C are constants for a particular film. Suitable scattering mechanisms have been suggested to account for the results. Structural defects and impurities like oxygen appear to control the galvanomagnetic properties of tellurium films

1. Introduction

Many workers (Scanlon *et al* 1947, Sakurai *et al* 1952; Yin Shu-Duan *et al* 1961; Schwartz *et al* 1964) have investigated the galvanomagnetic properties of tellurium films and have explained those results in terms of the surface states or film structure Ghosh (1959) observed that the values of Hall mobility in these films are much smaller than that of the bulk and the Hall mobility decreases with decrease of the film thickness. Goswami & Jog (1968) have observed that the activation energy depends on the thickness and the rate of deposition of the film. Yin tuan & Regel (1961) have observed that when tellurium fims, 300μ thick, are properly annealed, it is possible to obtain specimens in which the Hall coefficient changes from positive to negative value. It has been reported by Caper & White (1973) that the Hall mobility of tellurium films increases with crystallite size and range of deposition; according to their results the carrier concentration of such films is also increased with increase in the rate of deposition. These results are in agreement with those of Dinno *et al* (1974). who have recently reported that the conductivity of thin films of tellurium in vacuum can be explained in terms of carrier concentration and mobility presumably on the assumption that the carrier concentration increases with increasing defects and mobility increases as the grains grow in size but may decrease with increase in defect concentration

The electrical properties of tellurium films are known to be affected by absorption and diffusion of oxygen, when such films after deposition in vacuum are exposed to atmospheric air. Despite a large accumulation of work on tellurium films there has been as yet very limited investigations which can be considered as a comprehensive study of the nature and concentration of defects in the same film along with its carrier concentration and mobility for a satisfactory understanding of its galvanomagnetic properties. The present paper forms a part of such a programme of study of tellurium films

Chaudhury (1974) has studied the temperature variation of the electrical conductivity of the tellurium films of different thickness in vacuum along with electron microscopic examination of the films The variation in the concentration of lattice defects of the specimens, determined by X-ray diffraction methods have been reported by Mitra & Chowdhury (1974). The present paper reports the temperature variation of Hall coefficient and Hall mobility of the same specimens of tellurium films; the aim of the investigation was to study the influence of structural defects and diffused oxygen on the galvanomagnetic properties of the film

2 Experimental Procedure

Tellurium films on glass substrate were prepared with the help of a conventional vacuum coating unit. Experimental conditions for the preparation of the films were the same as that reported by Chaudhuri (1974).

The voltage and current measuring circuits were constructed following the standard circuit given by Pugh & Foner (1953) The Hall and resistive voltage were measured with a microvolt potentiometer with a Liston-Becker chopper amplifier and a wide scale millivoltmeter as output meter. In this arrangement a voltage of the order of $0.1\mu V$ could be measured. The design and construction of a suitable samlple holder constitute the major difficulty in the measurement of Hall effects; the trouble is mainly due to the contact probes, which have a tendency to scratch out the film After preliminary trials the difficulties were finally removed by making a sample holder from thick mica sheet fitted with phosphor bronze springs at predetermined distances. These springs not only made automatic electrical contacts for current and Hall probes but also kept the sample rigidly in position However, to ensure good electrical contacts, traces of aquadag were also used at the contact points.

Experiments on the measurement of Hall coefficient and conductivity of the films exposed to outside atmosphere were performed in a vacuum chamber which could be evacuated to about 10^{-4} to 10^{-5} torr. The sample was removed to this vacuum chamber in order to avoid the disturbances that may arise due to variations in atmospheric condition. A heater and a copper-constantan thermocouple were provided in the experimental chamber in order to measure the temperature and also to keep the sample at different temperatures of the bath.

3. Results and Discussions

Figure 1 shows the variation of Hall mobility with K' at a constant temperature where K' is the ratio of thickness of the film and the mean free path of the carriers. The value of mean free path obtained from the measured value of mobility of the order of 4.2×10^{-6}cm. It is observed that Hall mobility of the film is decreasing with the decreasing value of K'. This result agrees well with the theoretical prediction by Amith (1960) The variation of Hall coefficient with magnetic field is shown in figure 2 There is no appreciable change in Hall coefficient within the range 0 7 to 6 0 kilogauss of magnetic field So it can be

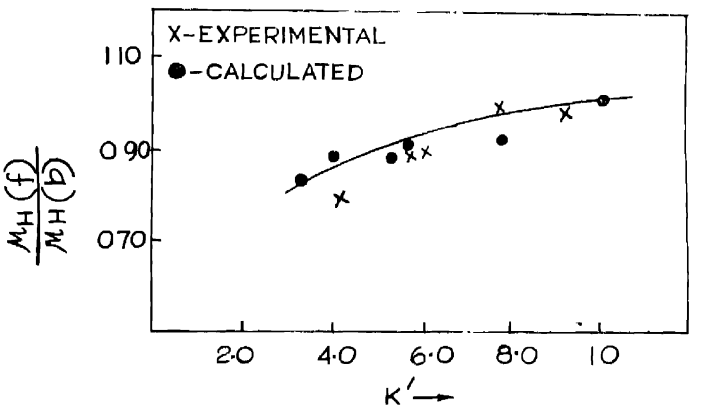

Fig 1 Variation of Hall mobility with K'

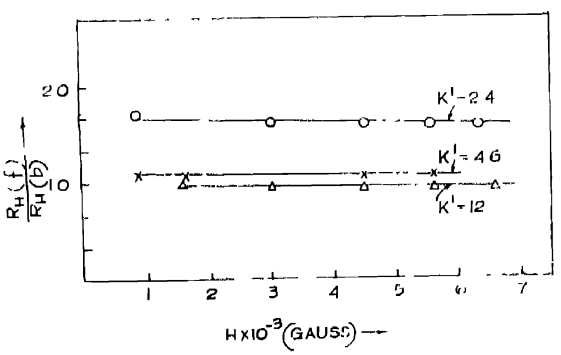

Fig 2 Variation of Hall coefficient with magnetic field

said that the Hall coefficient is measured in the limit of small magnetic field. The observed variation in Hall mobility with K' should thus be attributed to the effect of scattering of carriers in the relevant region of the film. Therefore the ratio $R_H(f)/R_H(b)$ and $\mu_H(f)/\mu_H(b)$ should give only the scattering correction factors

for different thickness of the film, $R_H(f)$ and $\mu_H(f)$ are the values of Hall coefficient and Hall mobility respectively for thin films and $R_H(b)$ and $\mu_H(b)$ are the corresponding values for the bulk. Assuming space charge layers on either side of the film to be identical, the Hall coefficient of the film can be expressed (Chaudhuri 1974) as,

$$\frac{R_H(f)}{R_H(b)} = \frac{1+\dfrac{2d_s}{d-2d_s}}{1+\dfrac{2\sigma_s}{\sigma_b}\dfrac{d_s}{d-2d_s}} \cdot \frac{\mu_H(f)}{\mu_H(b)}, \qquad \ldots \quad (1)$$

where σ_b and σ_s are the bulk and surface conductivities, d_s and d are the thickness of the surface layer and total thickness of the film respectively. Here d_s is taken to be equal to the Debye screening length, the value of which is about 300Å for the films used. From the above relation the ratio $\mu_H(f)/\mu_H(b)$ was found to increase with the decreasing value of K'. The value of $\mu_H(f)/\mu_H(b)$ were calculated from eq. (1) with the estimated value of $\sigma_s/\sigma_b = 0.5$; this particular value for the ratio σ_s/σ_b was chosen because of the fact that the variation of thermal activation energies with the thickness of tellurium films determined with this value of σ_s/σ_b showed (Chaudhuri 1974) satisfactory agreement with that observed experimentally.

The temperature dependence of Hall coefficient is shown in figure 3. The variation of Hall coefficient with temperature is quite appreciable in thick films ($d \sim 3000$ Å or more) but for thin films ($d \sim 1000$ Å or less) the Hall coefficient is comparatively insensitive to temperature. Throghout the temperature range

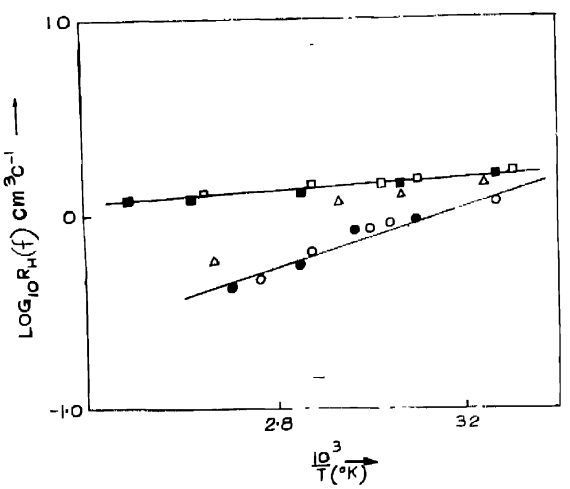

Fig 3 Variation of Hall coefficient with temperature for different thicknesses of the films. Film thickness 0-3394Å, ●-3247Å, Δ-1722Å, □-1222Å and ■-979Å.

300-420°K the sample is found to remain p-type which indicates that the sample is highly extrinsic. Another interesting observation is that the nature of variation of Hall mobility with temperature (figures 4 and 5) is quite different for thick and thin films. For thick films the Hall mobility decreases with increasing temperature (figure 4), whereas in case of thin films it increases with temperature (figure 5). These observations indicate the distinctive difference in the relative importance of the mechanisms of scattering in the two cases

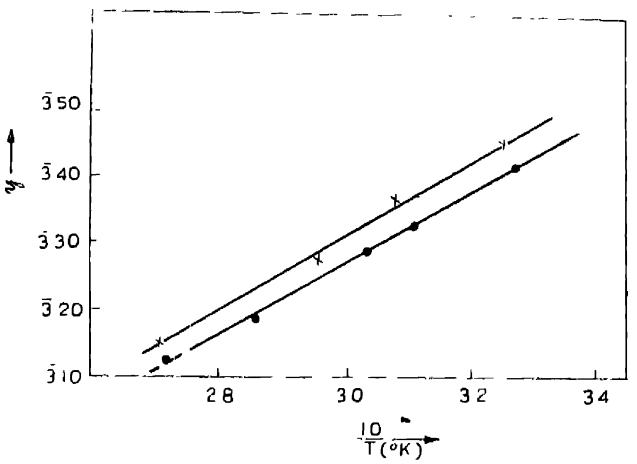

Fig 4 Variation of y with temperature for thick films Film thickness X-2722Å, ●-2347Å and y $\log_{10}(\mu_H\ T^{-3/2})\text{cm}^2\ \text{volt}^{-1}\text{sec}^{-1}\ °K^{-1}$

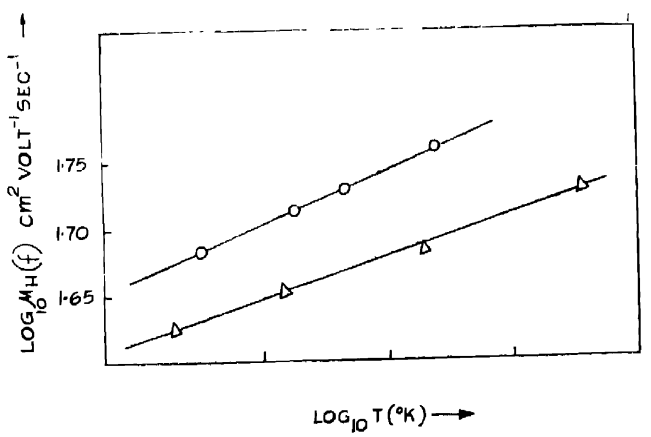

Fig 5 Variation of Hall mobility with temperature for thin films O-1272Å, and Δ-979Å

In such extrinsic cases, the Hall coefficient R_H can be taken to be

$$R_H =$$

where A is a constant and p is the carrier concentration. The temperature dependence of the Hall coefficient (figure 3) indicates that for thin films the hole concentration is relatively temperature independent in the range of 300-420°K. On the other hand for thick films, the hole concentration seems to increase with rise of temperature. Further, for few intermediate thickness hole concentration tends to become temperature independent comparatively at low temperatures. It is thus possible to indicate the temperature variation of Hall coefficient for tellurium films used and for the range of temperature of the present investigation by a relation of the type

$$R_H = \frac{A}{p_0 + p_1 \exp(-\epsilon/kT)} \quad \ldots (2)$$

where A, p_0 and p_1 are constants depending on thickness and the nature of material of the films. Thus for thin films the second term in the denominator is negligible while it predominates for thick films; for intermediate thickness, $p_1 \exp(-\epsilon/kT)$ becomes negligible only at comparatively low temperature.

The origin of the two terms in the expression for hole concentration can be tentatively interpreted as being due to two types of acceptor levels. The impurity levels of shallow depths possibly due to the diffused oxygen should be considered as completely ionised in this temperature range leading to the constant term p_0 while the acceptor levels of comparatively large depth, possibly due to structural defects are expected to be incompletely ionised leading to an approximate term $p_1 \exp(-c/kT)$ in the expression for the hole concentration. In this expression, p_1 should represent the concentration of such acceptor states and ϵ the corresponding trap depth. The value of c determined from figure 3 is found to be 0.14 eV which is slightly below the mid-gap position of tellurium. The value of p_1 is found to be of the order of 10^{18} per c.c. The density of lattice defects is also found to be of the same order (Mitra & Chaudhuri 1974). Moreover it is observed by them that the number of defects decreases with decrease of thickness. So X-ray study also supports the view that the diffused oxygen present in the material play an important role in very thin film while in thick films structural defects control the galvanomagnetic properties.

The mobility of carriers is determined by two primary processes—thermal scattering and impurity scattering. The magnitude of μ due solely to thermal scattering is expected to be comparatively large and can thus be ignored for the samples under investigation. The mobility of carriers controlled mostly by impurity scattering process can be written as (Shockley 1959)

$$\mu = \frac{c_1 T^{3/2}/N}{\ln[1 + a_1 (T/N^{1/3})^2]}, \quad \ldots (3)$$

where N represents the concentration of scattering centres and c_1 and a_1 are constants. In case of complete filling up of the electron traps i.e., complete ionisation of holes from the acceptor centres, the concentration of the scattering centres N in eq. (3) should be given by p_0 and thus remain temperature independent. In case of incomplete ionisation of holes from the acceptor levels, N is expected to vary approximagely as $N_1 = P_1 \exp(-\epsilon/kT)$. Neglecting the comparatively slow temperature variation of the term in the denominator of eq. (3), we can approximately write,

$$\mu = \frac{cT^{3/2}}{p_0 + p_1 \exp(-\epsilon/kT)} \quad \ldots \quad (4)$$

Thus we can write for the two limiting cases,

$$\mu_1 \simeq \frac{cT^{3/2}}{p_0}, \quad \ldots \quad (5)$$

and

$$\mu_2 \simeq \frac{cT^{3/2}}{p_1} \exp(\epsilon/kT). \quad \ldots \quad (6)$$

In the presence of both of the scattering mechanisms the effective value of μ shosuld be given by

$$\mu = \frac{\mu_1 \mu_2}{\mu_1 + \mu_2}$$

$$= \frac{\mu_1}{1 + \mu_1/\mu_2} \simeq \mu_1 \quad \text{when} \quad \mu_2 >> \mu_1$$

and

$$\mu = \frac{\mu_2}{1 + \mu_2/\mu_2} \simeq \mu_2 \text{ when } \mu_1 >> \mu_2.$$

The results of the present investigation indicate that in the case of thin films the temperature variation of Hall mobility follows a power law relation while for thick films of tellurium the experimental results can be fitted with eq (6) Further the value of $\epsilon = 0.13$eV obtained from Figure 4 agrees within experimental error with that obtained from the temperature variation of Hall coefficient.

It is well known that, apart from structural defects and grain size, oxygen plays a vital but as yet comparatively obscure role in determining the galvanomagnetic as well as photoconducting properties of a large number of materials (viz., chalcogenides). In the present investigation the films, after deposition, have been deliberately exposed to atmosphere for a comparatively long period to obtain saturation effect, so that a comparative study of their electrical properties before and after exposure to atmosphere can bring out the relative effects of oxygen and inherent defects, structural or otherwise The results of the present investigation clearly indicate the presence of two kinds of centres with comparatively

shallow and deep acceptor levels in the films studied here; one of these, possibly that of shallow trap depth, is presumably due to oxygen. It is possible that similar work done, in details, in other materials, could help considerably in understanding the role of oxygen in process like sensitization, ageing etc

References

Amith A 1960 *J. Phys. Chem Solid* **14**, 271

Chaudhuri A K 1974 *Ind J Pure Appl Phys* **12**, 399

Capers J J & White M. 1973, *Thin Solid Films* **15**, 5

Dimo M A , Schwartz M & Ghammara B 1974 *J Appl Phys* **45**, 3328

Ghosh S K 1959 *Studies on the electrical properties of semiconductive tellurium films* Ph D thesis, Indian Institute of Technoloy, Kharagpur

Goswami A & Jog R H 1968 *Ind J Pure appl Phys* , **6**, 416

Mitra G B. & Chaudhuri A K 1974 *Proc Indo-German Seminar on Advanced Solid State Physics and Conf on Defects in Non-Metallic Solids* Madras, pae 33

Pugh E M & Foner S 1953 *Phys. Rev.* **91**, 20

Scanlong W. & Lark-Horowitz K 1947 *Phys Rev* **72**, 530

Sakurai T & Munosue S 1952 *Phys. Rev* **85**, 921

Schwartz M & Hockensmith D 1964 *Physics Letters* **11**, 11

Shockley W 1959 *Electrons and Holes in Semiconductors* D Van Nostrand Company Inc Princeton, p-287.

Yu Shih-Duan & Regal A R 191 *Soviet Physics-Solid State* **3**, 1220

Yu Shih-Duan & Regal A R 1961 *Soviet Physics-Solid State* **3**, 1224