MECHANISM OF HEAT TRANSFER OF THIN INDIUM FILMS

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Abstract:

Lattice, electronic and radiative components of thermal conductivity are calculated for thin indium films. The effect of thickness of the indium thin film on the estimated values of thermal conductivity are considered. It was found that the main contribution of heat transfer mechanism is due to both phonons and electrons, whereas that due to photons is very small indeed.

Introduction:

The effect of structural parameters on electrical properties of thin indium films on glass substrates has been investigated in [1]. Where it was found that the electrical behaviour showed discontinuety at about 70 nm. It was found that almost optical properties follow the same pattern [2,3].

In the previous articles [2,3] this behaviour was attributed to the discontinuous-continuous film transition. At the same time optical constants and the energy loss functions of thin indium films on mica were reported [4]. It was generally observed that a resonable values of bulk properties could be obtained by investigating the continuous films (films of thicknesses higher than 70 nm).

On the other hand the thermal properties of conducting and semiconducting materials have been reported [5-8]. According to our knowledge these data for thin In films are almost absent.

The aim of this article is to investigate the electrical and thermal properties of thin In films on mica substrate, and discuss the mechanisms of thermal conductivity in these films.

Experimental:

In thin films of different thicknesses in the range from 15 to 100 nm were prepared by thermal evaporation. The pressure before evaporation was 1.33×10^{-3} Pa, and the purity of indium was 99.999%. The deposition rate was 0.31 nm/s approximatly. The thickness of In films was measured by the multiple beam Fizeau fringe method[9]. The resistivity was measured by obtaining I-V curves.

Results and Discussions

The dependence of resistivity (ρ) on thickness (t) is given in Fig. 1 where it decreases by increasing the film thickness as the usual behaviour.

However, it reveals that this dependence for thicknesses less and higher than 66 nm follow different patterns.

In other words In films on mica and glass substrates have a common behaviour. To clarify this behaviour ρ vs $\frac{1}{t}$ was plotted as shown in Fig. 2, in which it is clear that the separation between the two thickness regions is sharply observed. The obtained results are found to fit with [F-S] theory [10]. The busk properties obtained by extrapolation of the two thickness regions are given in table 1.

Table 1: Values of bulk resistivity (ρ_o) and the mean free path (l_o)

Bulk resistivity (ρ_o) in Ωm		Mean free path (l_o) in A°	
curve (a)	curve (b)	curve (a)	curve (b)
45×10^{-8}	125×10^{-8}	1388	2666

It was clear that the values of region a (contineous films) are more acceptable than that obtained in region b (discontineous films).

The electronic part of thermal conductivity (λ_e) was calculated according to Wiedmann-Franz relation [1].

$$\lambda_e = L_o \sigma T$$

where L_o-Lorenz number, σ-the electrical conductivity and T-absolute temperature.

The caucluation of λ_e is complicated due to the fact that the exact value of L_o is not always available. But at temperatures higher than 300 K, the above relation could be applied, where L_o is constant and the scattering is elastic [12].

Fig. 3 reveals the increase of λ_e with thickness. However it follows a given pattern in thickness range a and different pattern-range b. This behaviour is in fair agreement with the data obtained by El-Ocker [3] and El-Ocker et-al [4], for the same samples, where it was concluded that it was not possible to obtain reasonable results using Drude theory for any thickness less than 66 nm. In such a case they concluded that the conditions of Drude which should be obeyed by bulk solids are not satisfied in films of low thickness. This is in agreement with the enhanced metalic behaviour for indium films of thicknesses higher than 66 nm on mica substrate.

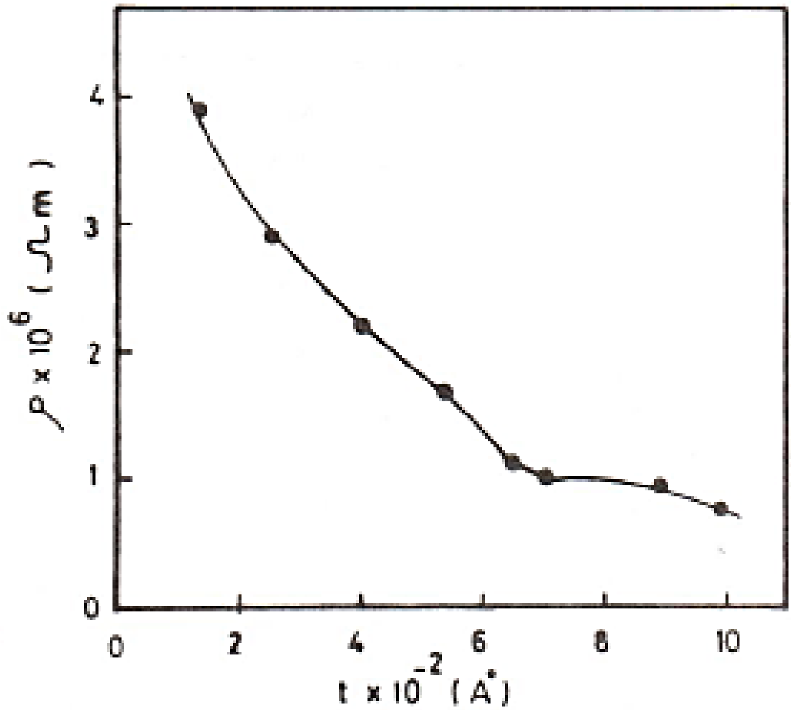

Fig.(1): Relation between the resistivity ρ and the film thickness (t).

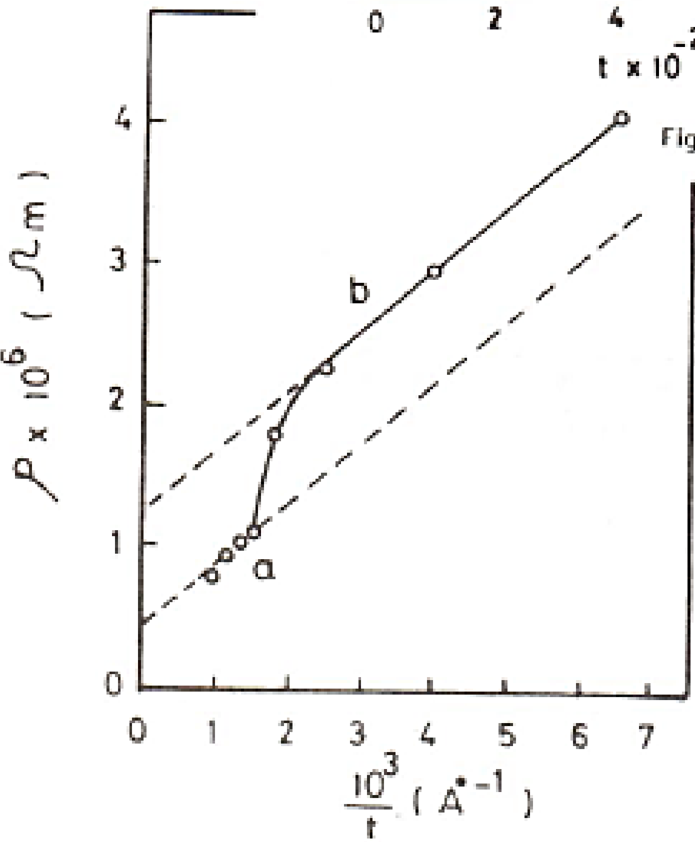

Fig.(2): Relation between the resistivity ρ and the reciprocal of film thickness $(\frac{1}{t})$.

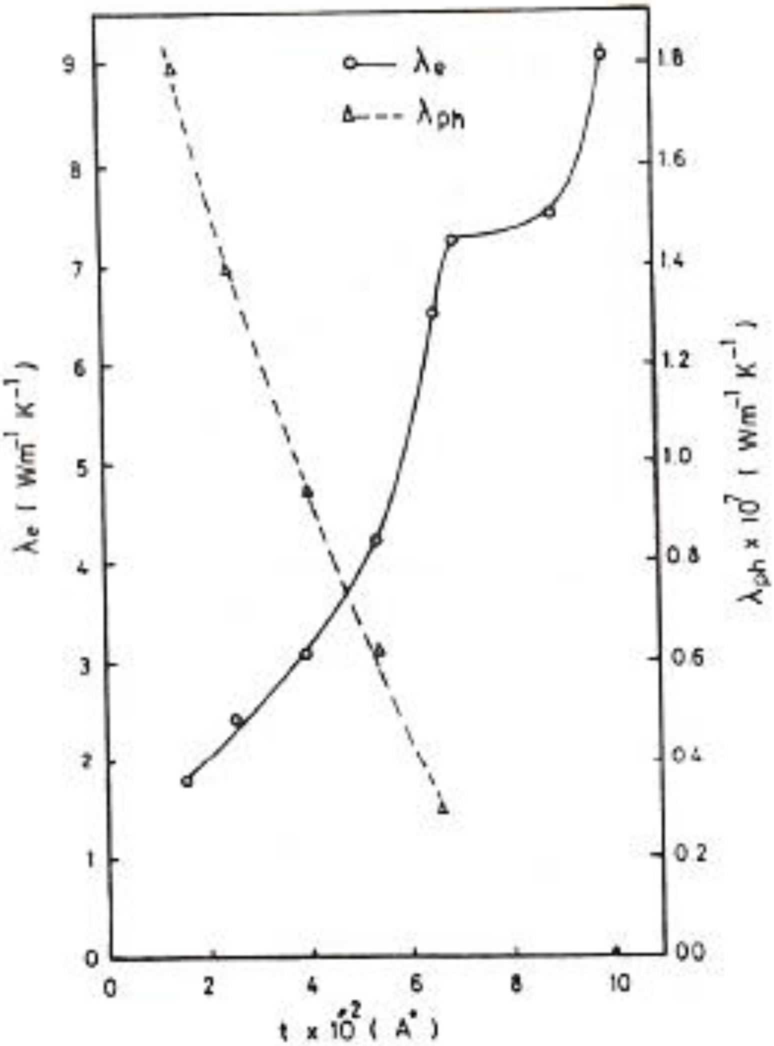

Fig.(3): Relation between thermal conductivity (λ) and the film thickness (t).

The lattice thermal conductivity (λ_ℓ) was determined according to the relation.

$$\lambda_\ell = \frac{1}{3} C_v V \ell$$

where

C_v - specific heat capacity at constant volume

V - velocity of sound

and ℓ - phonon mean free path.

The values of λ_ℓ was obtained using the data of [13]. The estimation of l was found to be about 5.5 A° which gives phonon thermal conductivity of 1.88 Wm^{-1} K^{-1}. This acceptable value shows that the sharing of phonons in thermal conductivity cannot be neglected in In thin films.

The contribution of photons in thermal conductivity in these films was calculated using the data reported in [4] for the complex refractive index. The formula used [14]

$$\lambda_{photon} = \frac{4\, \sigma n^2\, T^3\, t}{1 + \frac{3}{4}\alpha t}$$, for opticaly thin samples

where α - optical absorption coefficient

σ - Stefan-Boltzman constant

n - refractive index

T - absolute temperature,

and t - thickness

The dependence of λ_{ph} on thickness is shown in Fig. 3. It is clear that the radiative part of thermal conductivity is quite small with respect to the contributions of λ_e and λ_ℓ. λ_{ph} decreases rapidly with thickness and can be neglected at thickness of region a i.e. the samples become opaque at about 66 nm.

The above arguments make it possible to assume that the thermal properties as long as optical and electrical properties follow common pattern. In other words it is more likely to assume that the physical properties of thin In films show drastic variation at about 66 nm. These variations should be correlated with the discontineous-contineous film transition. A conclusion which was obtained for thin In films on amorphous glass substrate.

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