YU ISSN 0015—3206
FZKAAA 14 (3) 141 (1982)

STRUCTURAL INVESTIGATION AND ELECTRICAL PROPERTIES OF THIN INDIUM FILMS+

E. A. ABOU-SAIF*, M. M. EL-OKER**, S. A. EL-SAHHAR** and F. SULTAN**

Electron Microscope and Thin Films Laboratory, National Research Centre, Dokki, Cairo

***Physics Department, Faculty of Science, Al-Azhar University, Cairo*

Received 10 October 1981

Revised manuscript received 23 February 1982

UDC 538.975

Original scientific paper

Thin indium films of thickness ranged from 15 to 100 nm were deposited onto glass substrates with a deposition rate of 0.31 nm/s by thermal evaporation technique. The grain size increased with increasing film thickness. The resistivity decreased with increasing film thickness. The resistivity-thickness relation does not fit the theories of either Fuchs-Sondheimer or Mayadas-Shatzkes. The values of mean free path l_0 of the charge carriers were calculated.

1. Introduction

Grain size and island density variations as a function of film thicknesses and substrate temperature of vapour deposited indium and thin films were studied by Singh and Murr[1] using transmission and scanning electron microscopy. The

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[+] This is a part of Ph. D. Thesis of S. A. El.Sahhar earned in (1981) from Faculty of Science, Al-Azhar University, Cairo.

electrical resistivity of polycrystalline indium films of thicknesses from 49 to 500 nm deposited onto glass substrates have been studied in the temperature range from 30 to 90° C by Pal and Chaudhuri[2].

The aim of the present work is to study the effect of the film thickness on the structure and electrical properties of thin indium films.

2. *Experimental*

Different thicknesses of indium films in the range from 15 to 100 nm were prepared by thermal evaporation of spec pure indium (In) of 99.999% under high vacuum of 1.333×10^{-3} Pa. The films were deposited onto cleaned amorphous glass substrates with deposition rates of 0.31 nm/s. The substrates were maintained at room temperature during deposition. The thickness of the In films was measured by multiple beam Fizeau fringes method[3]. The structural investigation* was carried out by *ELMI D*2 transmission electron microscope (at 45 KV). The electrical measurements** were done by using a potentiometric circuit and the films were contacted with gold electrodes.

3. *Results and discussion*

From the investigation of In films in the range from 15 to 100 nm by using transmission electron microscopy, it was found that the films were composed of spherical islands and then these islands coalesced together with increasing film

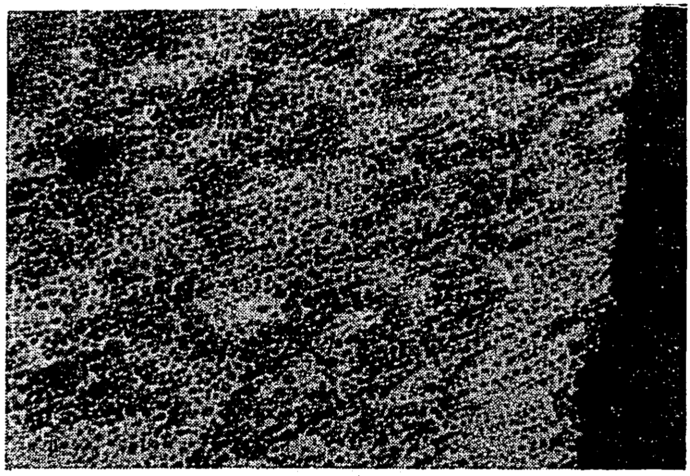

Fig. 1. Transmission micrograph of thin indium film of thickness 66 nm (1500 *X*).

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* This part was carried out in the Electron Microscope and thin films Lab. at NRC, Egypt.

** This part has been done at Physics Department, Faculty of Science Al-Azhar University, Egypt.

thickness (see Fig. 1 for 66 nm thick In film). Fig. 2 shows that the average grain size[4], $\overline{D}$, increases with increasing film thickness up to 40 nm and then reaches saturation in the thickness range from 40 to 66 nm, then it begins to increase again up to 100 nm. The saturation might be due to the formation of secondary and tertiary nuclei. To compare our results to those of Singh and Murr[1], the average volume growth was calculated according to the following formula:

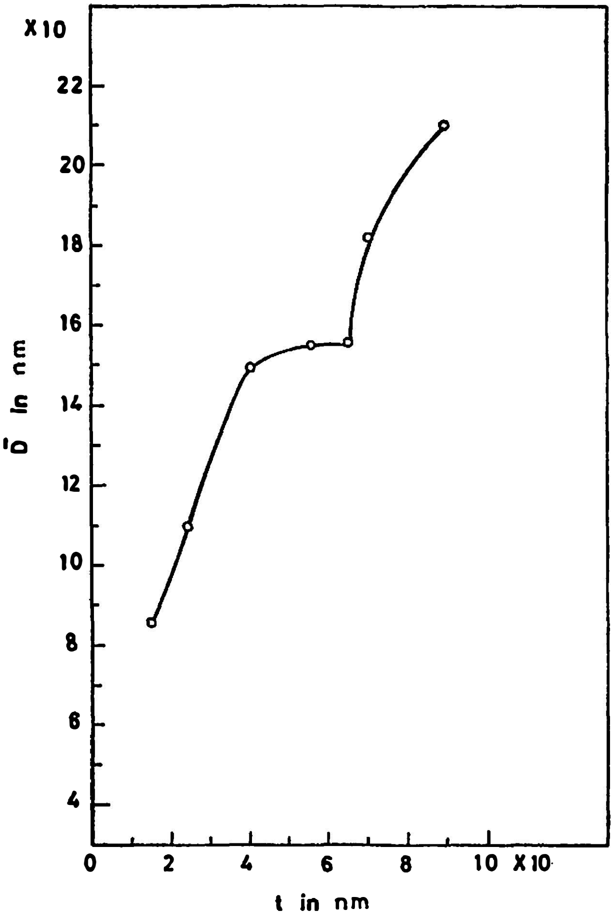

Fig. 2. Relationship between the average grain size $\overline{D}$ and the film thickness t.

$$S = \frac{D_2^3 - D_1^3}{t_2 - t_1} \qquad (1)$$

where D is the size of the nuclei and t is the time of deposition in seconds. It was found that from 15 to 55 nm $S = 6.25 \times 10^{-14}$ cm^3/s, while from 55 to 100 nm,

$S = 8.43 \times 10^{-17}$ cm^3/s. On the other hand, Singh and Murr[1] found that for tin films $S = 1.4 \times 10^{-14}$ cm^3/s in the range from 2 to 100 nm, while $S = 2 \times 10^{-17}$ cm^3/s in the range from 2 to 10 nm. The discrepancy may be due to differences in the type of substrates and other deposition parameters.

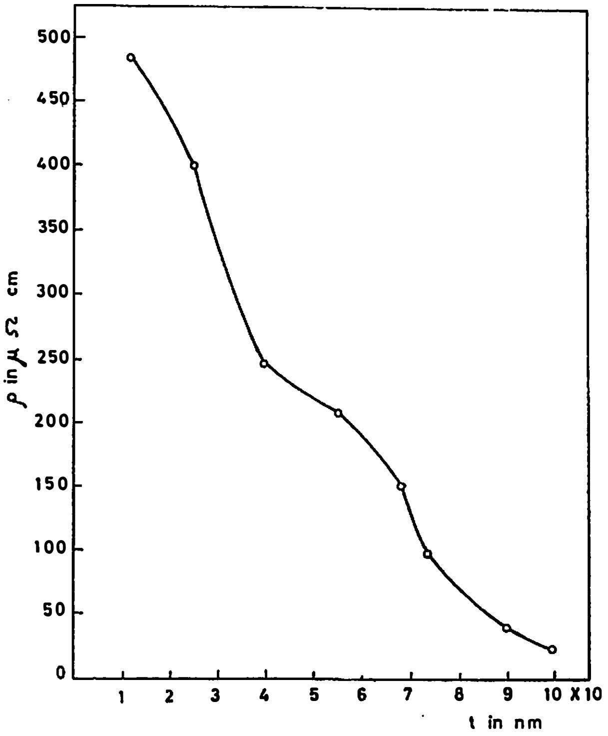

Fig. 3. Relationship between the resistivity ϱ_F and the film thickness t.

With respect to the electrical measurements of In films, it was found that the resistivity decreased with increasing film thickness (see Fig. 3). The bulk resistivity ϱ_B and the mean free path l_0 were calculated according to the following equation of Fuchs-Sondheimer[5-7]

$$\frac{\varrho_F}{\varrho_B} = 1 + \frac{3\, l_0}{8\, t}(1 - P) \quad (t/l_0 > 1). \tag{2}$$

Therefore, it was necessary to plot a relation between ϱ_F and $1/t$ (Fig. 4), and a relation between $\varrho_F t$ and t (Fig. 5). From the slopes and intercepts (according to equation 2), the values of ϱ_B and l_0 were obtained and listed in the following table.

TABLE 1.

Bulk resistivity ϱ_B in $\mu\Omega$ cm				Mean free path l_0 in nm			
Curve *a*	Curve *b*	Curve *c*	Curve *d*	Curve *a*	Curve *b*	Curve *c*	Curve *d*
12	68	14.2	93	141.4	249.5	108.9	266.6

The values of bulk resistivity and mean free path of In films.

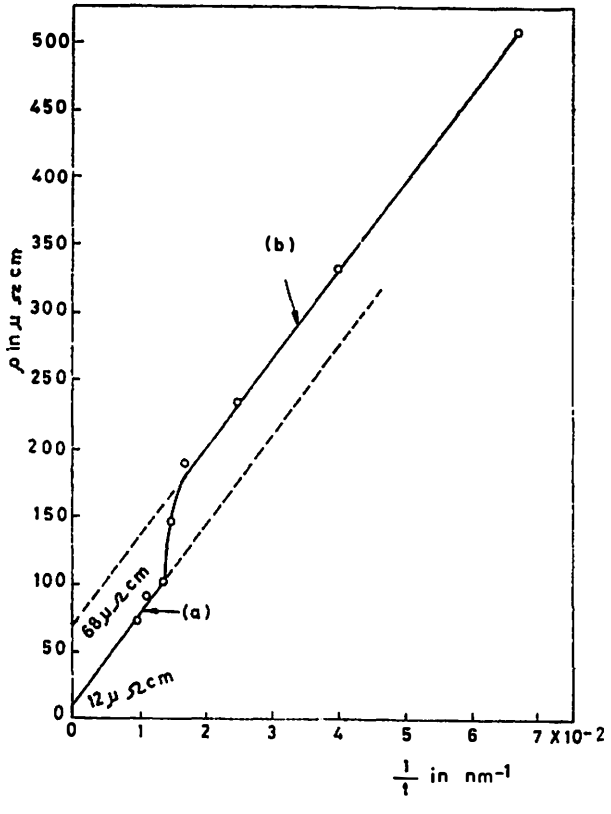

Fig. 4. Relationship between the resistivity ϱ_F and the reciprocal of the thickness $1/t$.

The results indicate a decrease in resistivity with increasing thickness as expected for thin metallic films. However, a singularity was observed at $t = 70$ nm. Such anomalous behaviour was also observed on thin films of bismuth by Jogleker, Kareker and Sathianadan[8]. This singularity is shown in Fig. 4. It is clear that for $t < 70$ nm the relation between the resistivity ϱ_F against $1/t$ follows a linear behaviour with a specific slope, while for $t > 70$ nm the ϱ_F vs. l/t, although still linear, has a different slope. The same singularity is also observed in Fig. 5 curves *c* and *d*. With reference to our data in Table 1 of l_0 and ϱ_B, Pal and Chaudhuri[2] found that the values of l_0 and ϱ_B for In films were 99.5 nm and 11.87 $\mu\,\Omega$ cm.

The difference between these values and that obtained in the present work could be attributed to the fact that the work done by Pal and Chaudhuri was reported on In films of thickness in the range from 50 to 600 nm. The fitting of resistivity thickness relation of In films was carried out in the light of Fuchs-Sondheimer[5-7] and Mayadas-Shatzkes[9] theories.

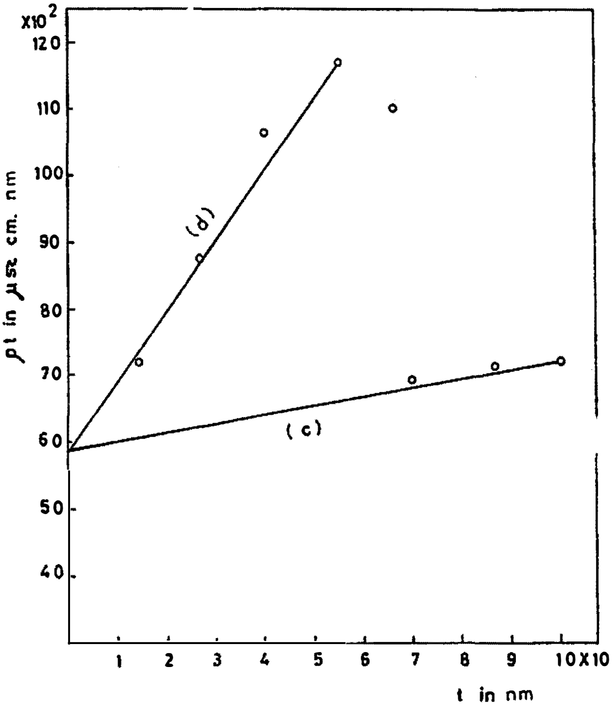

Fig. 5. Relationship between the product of resistivity and thickness $\varrho_F\, t$ and the correspoding values of the film thickness t.

Fig. 6 shows the relation between ϱ/ϱ_0 and film thickness. Curve a represents the data of present experimental results, while the curves b and c represent that according to Fuchs-Sondheimer theory (at $P = 0$ and $R = 0$).

It is clear that our experimental data do not fit the theory of Fuchs-Sondheimer. Fitting of the resistivity-thickness relation with Mayadas-Shatzkes was carried out using the following equation[9,10]:

$$\frac{\varrho}{\varrho_0} = \frac{1}{f(\alpha)} + \frac{3}{8}\frac{l_0(1-P)}{t}. \tag{3}$$

Consequently, $f(\alpha)$ was determined for each film thickness, and the curves between the values of ϱ/ϱ_0 and the corresponding values of thickness t were plotted. Fig. 7 shows the relation between ϱ/ϱ_0 and thickness t. It is obvious that our experimental data (curve a) do no fit the data of Mayadas-Shatzkes theory

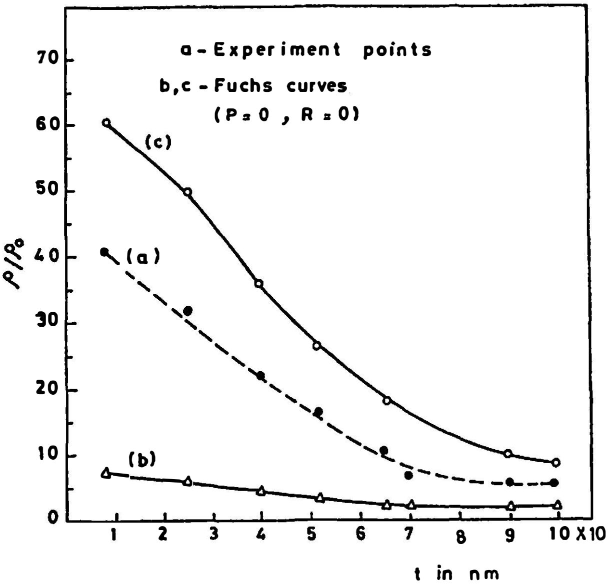

Fig. 6. Relationship between the ratio ϱ/ϱ_0 and the corresponding values of the film thickness t. (Fitting with F-S theory)

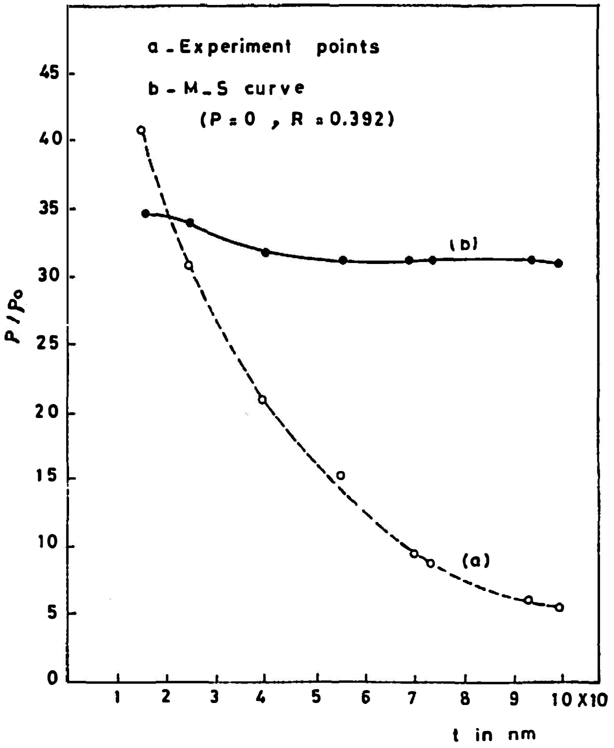

Fig. 7. Relationship between the ratio ϱ/ϱ_0 and the corresponding values of the film thickness t. (Fitting with M-S theory)

(curve *b*). The values of α and R, (where R is the reflection coefficient at a grain boundary) were estimated from the value of $f(\alpha) = 0.0320$ applying the following equations[9,10]:

$$f(\alpha) = 1 - \frac{3}{2}\alpha \text{ and } = \frac{l_0}{a_g}\frac{R}{1-R} \tag{4}$$

where a_g is the grain size for film thickness of 25 nm and found to be 109 ± 0.284 nm. Hence $\alpha = 0.6450$ and $R = 0.3920$.

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STRUKTURNA ISTRAŽIVANJA I ELEKTRIČNA SVOJSTVA TANKIH FILMOVA INDIJA

E. A. ABOU-SAIF+, M. M. El-OKER++, S. A. El-SAHHAR++ i F. SULTAN++

+*Electron Microscope and Thin Films Laboratory, National Research Centre, Dokki, Cairo, Egipat*

++*Physics Department, Faculty of Science, Al-Azhar University, Cairo, Egipat*

UDK 538.975

Originalni znanstveni rad

Izvršena su mjerenja strukturnih i električnih svojstava tankih slojeva indija, debljine 15—100 nm pripremljenih termičkim naparivanjem na sobnoj temperaturi. Iz dobivenih podataka o prosječnoj veličini zrna i specifičnom otporu kao funkciji debljine filma izračunat je srednji slobodni put elektrona u filmu. Rezultati mjerenja uspoređeni su s teorijskim istraživanjima.