JOURNAL OF MATERIALS SCIENCE 25 (1990) 585–588

Electrical properties of thin metal zinc films

M. EL SHABASY
Department of Physics, Faculty of Science, Minia University, Minia, Egypt

M. A. EL HITI, M. A. AHMED
Department of Physics, Faculty of Science, Tanta University, Tanta, Egypt

Thin metal zinc films 40 to 200 nm thick are deposited by thermal evaporation at room temperature onto glass substrates with a deposition rate of 0.2 to 0.7 nm sec^{-1}. The electrical resistivity is measured as a function of film thickness, deposition rate and annealing temperature. The experimental results show that electrical resistivity decreases as the film thickness, deposition rate and annealing temperature increase, while the temperature coefficient of resistivity increases with the increase in the film thickness. The calculated values of the activation energy for the conduction electrons increases as the film thickness and deposition rate increase. The well known Fuchs–Sondheimer model is applied for zinc films. The theoretically calculated values for the electrical resistivity and the temperature coefficient of resistivity are in good agreement with the experimental results.

1. Introduction

The electrical resistivity and the temperature coefficient of resistivity of thin metallic films vary markedly from those of their bulk specimens, and this variation increases as the film thickness decreases. The electrical resistivity and the temperature coefficient of resistivity of zinc films deposited by r.f. (radio frequency) sputtering at room temperature were studied [1, 2]. In another study the electrical resistivity and the temperature coefficient of resistivity of zinc films deposited at room temperature onto glass substrates [3] have been studied as a function of film thickness and annealing temperature. The measurements of the electrical resistivity on annealing show irreversible change. This electrical stabilization was found for zinc films deposited by sputtering [4]. All the experimental results show that the electrical resistivity of zinc films is many orders of magnitude higher than the bulk value.

The well known Fuchs–Sondheimer model [5, 6] has been used successfully by many authors to calculate the electrical resistivity and temperature coefficient of the resistivity of thin films.

The aim of this work is to study the effect of film thickness, annealing temperature and deposition rate on the electrical resistivity and temperature coefficient of the resistivity of zinc films deposited on glass substrates at room temperature in a high vacuum. Also we aim to show the dependence of the activation energy of the conduction electrons on the film thickness and deposition rate.

The theoretical values of electrical resistivity and temperature coefficient of the resistivity of zinc films are calculated using the Fuchs–Sondheimer model, to show the degree of agreement between the experimental and theoretical values.

2. Experimental procedure

Zinc thin films were deposited in a vacuum of 10^{-3} Pa onto glass substrates at room temperature, by thermal evaporation. Zinc material of 99.99% purity from Balzers was evaporated from a molybdenum boat. The temperature of the substrate and overgrowth were measured and controlled using Ni–CrNi thermocouples stuck onto glass substrates, while the evaporation rate and film thickness were measured by a quartz crystal thickness monitor. Four indium electrodes were welded to the substrates for electrical measurements.

The electrical resistivity was measured *in situ* for a series of zinc films 40 to 200 nm thick, deposited at 0.5 nm sec^{-1}.

A second series of experiments was carried out to study the effect of annealing temperature on the electrical resistivity. The films were annealed in the temperature range of 50 to 150° C.

A further series of experiments was carried out to show the dependence of electrical resistivity on the deposition rate. Zinc films 180 nm thick were deposited with 0.2, 0.4 and 0.7 nm sec^{-1}. This work was carried out at Minia University, using a coating unit of the type E 306 A, from Edwards.

3. Results and discussion

The electrical resistivity ϱ as a function of the thickness t of zinc thin films is shown in Fig. 1, for various annealing temperatures. The effect of annealing temperature on the electrical resistivity of zinc films is presented in Fig. 2 for various thicknesses. The relationship between electrical resistivity and annealing temperature for a series of zinc films 180 nm thick deposited with 0.2, 0.4 and 0.7 nm sec^{-1} is given in Fig. 3, to show the role of the deposition rate on electrical resistivity. The dependence of the temperature coefficient of resistivity on film thickness is illustrated in Fig. 4.

The electrical resistivity decreases (Fig. 1) and the

0022–2461/90 $03.00 + .12

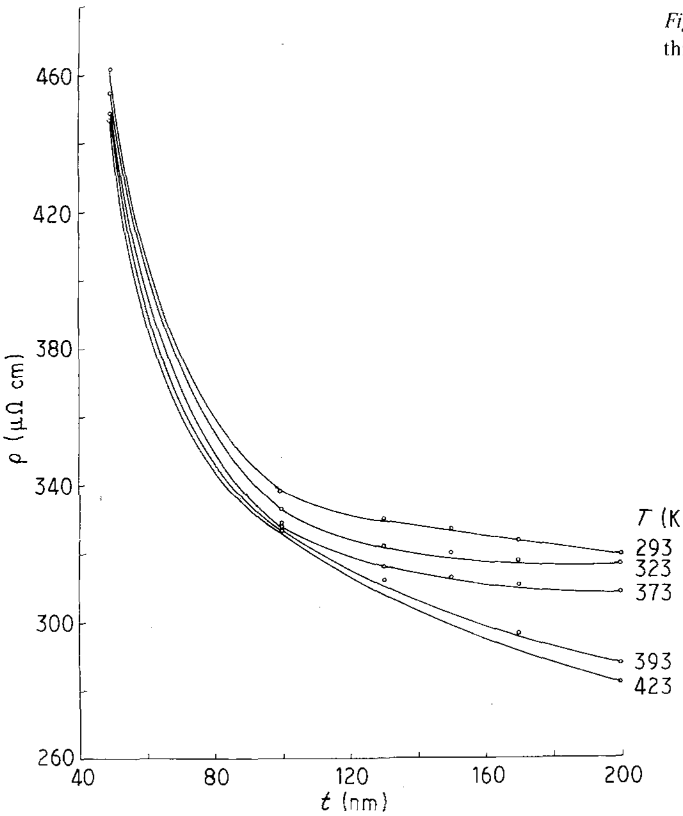

Figure 1 The thickness dependence of the electrical resistivity of zinc thin films for various annealing temperatures.

temperature coefficient of resistivity increases (Fig. 4) as the film thickness increases. This is due to the filling of the empty channels between the isolated islands of very thin zinc films and the transformation of zinc films from discontinuous to continuous films, where the conduction is also changed from conduction through the substrate in the empty channels, to the conduction through the metallic zinc film material itself. The zinc films studied here have a polycrystalline structure, as previously found [3].

The annealing process causes the rearrangement of the film crystallites, decreasing the porosity of the film and leading to the formation of a continuous polycrystalline film, which has lower values of electrical resistivity. This effect is clearly shown in Fig. 2.

As the deposition rate increases, the rate of filling of the empty channels between the isolated islands increases, thus the electrical resistivity decreases as seen in Fig. 3.

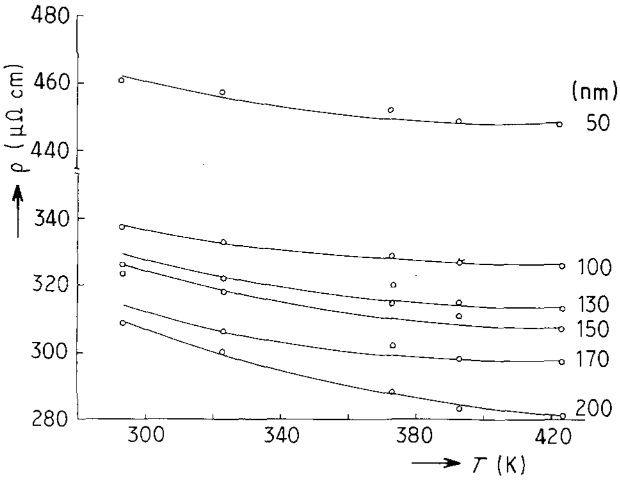

Figure 2 The relationship between annealing temperature and electrical resistivity of zinc thin films of various thicknesses.

The conductivity of the film σ_f is given by the relation:

$$\sigma_f = \sigma_0 \exp(-E/KT) \quad (1)$$

where σ_0 is the bulk conductivity, K is Boltzman's constant, T is the absolute temperature of the film and E the activation energy for the conduction electrons. Fig. 5 shows the relation in Equation 1. The activation energy can be calculated from the slopes of the lines presented in Fig. 5, as shown in Table I. It is clear that the activation energy increases as the deposition rate increases. Equation 1 is represented in Fig. 6 for various film thicknesses, (Fig. 5 was for various deposition rates). In the same way, the activation

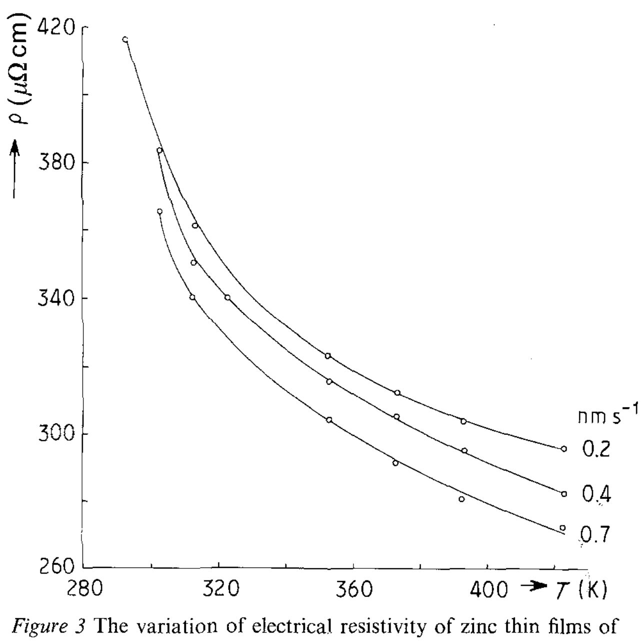

Figure 3 The variation of electrical resistivity of zinc thin films of thickness 180 nm with annealing temperature. Films deposited at 0.2, 0.4 and 0.7 nm sec^{-1}.

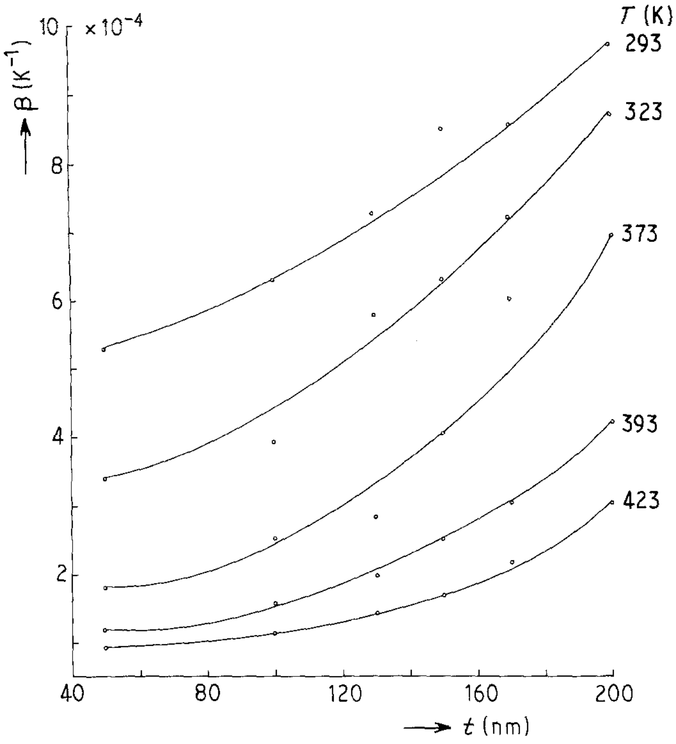

Figure 4 The relation between temperature coefficient of resistivity and thickness of zinc films at various annealing temperatures.

energy was calculated from Fig. 6 as a function of the film thickness, as shown in Table II. The results show that the activation energy increases as the film thickness increases, which is in agreement with results found previously [3] for zinc films deposited by thermal evaporation.

According to the Fuchs–Sondheimer model, the electrical conductivity and the temperature coefficient of resistivity β_f are given by the following relations:

$$\sigma_f/\sigma_0 = \begin{cases} 1 - \dfrac{3}{8\lambda}(1 - P) & \text{for } \lambda \gg 1 \\ \frac{3}{4}\lambda \dfrac{(1 + P)}{(1 - P)} \ln [1/\lambda] & \text{for } \lambda < 1 \end{cases} \quad (2)$$

and

$$\beta_f/\beta_0 = 1 - \frac{3}{8\lambda}(1 - P) \quad \text{for } \lambda \gg 1 \quad (3)$$

where β_0 is the temperature coefficient of resistivity of the bulk material, λ is the reduced thickness of the film, $\lambda = t/L_0$, L_0 is the mean free path of the conduction electrons. P is the specularity parameter, taking values from 0 to 1.

The numerical values of σ_f and β_f are calculated using Equations 2 and 3, respectively, and the following values are listed in [7]: $\sigma_0 = 1.69 \times 10^5$,

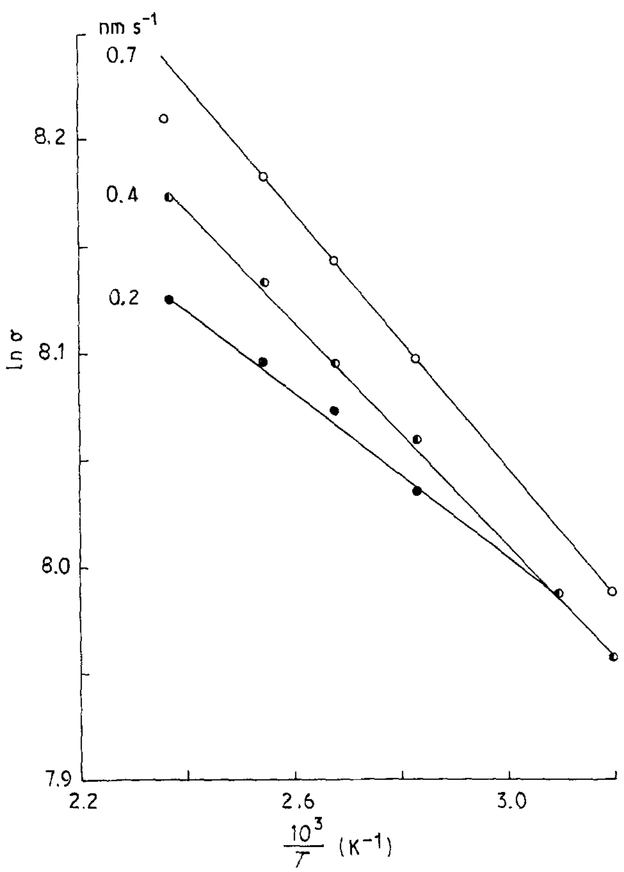

Figure 5 The dependence of the electrical conductivity on annealing temperature for 180 nm thick zinc films deposited with 0.2, 0.4 and 0.7 nm sec^{-1}, respectively.

TABLE I The relation between activation energy for the conduction electrons and the deposition rate of zinc thin films

Deposition rate (nm sec^{-1})	Activation energy (eV)
0.2	0.016
0.4	0.022
0.7	0.026

TABLE II The dependence of the activation energy for the conduction electrons on the thickness of zinc films

Film thickness (nm)	Activation energy (eV)
50	0.0029
100	0.0031
130	0.0058
150	0.0073
170	0.0095
200	0.0112

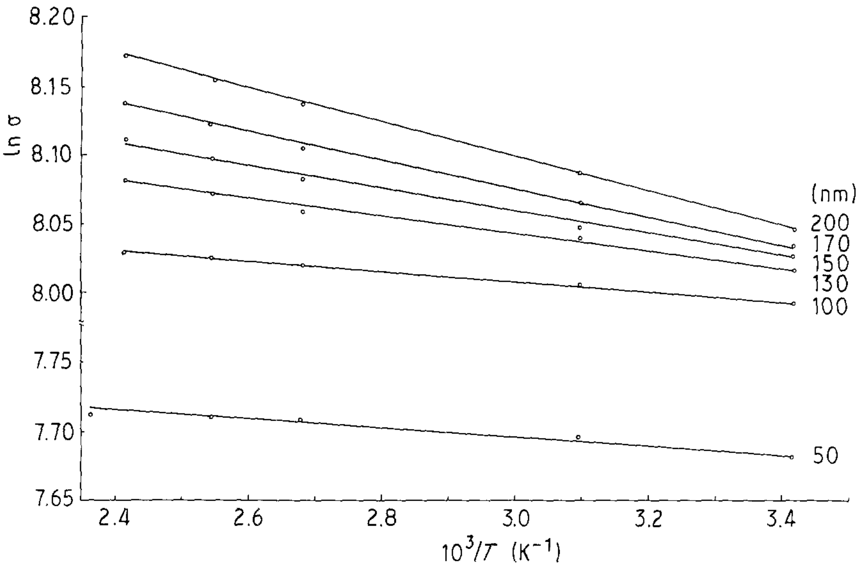

Figure 6 The relation between electrical conductivity and annealing temperature for zinc films of various thicknesses deposited with $0.5\,\text{nm sec}^{-1}$.

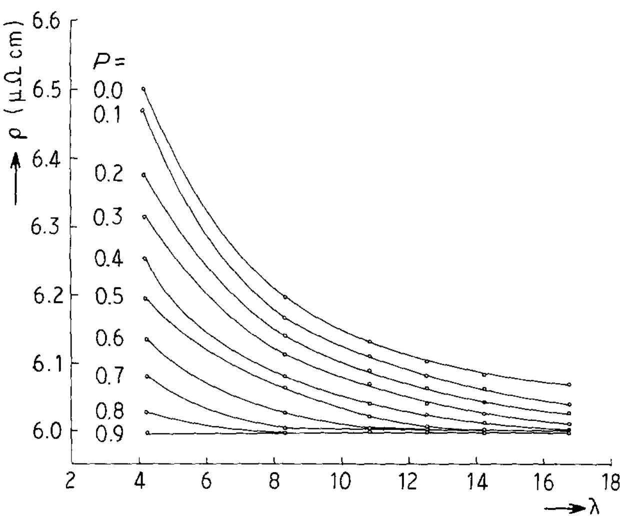

Figure 7 The theoretical relation between electrical resistivity and reduced thickness calculated according to the Fuchs–Sondheimer model for zinc films.

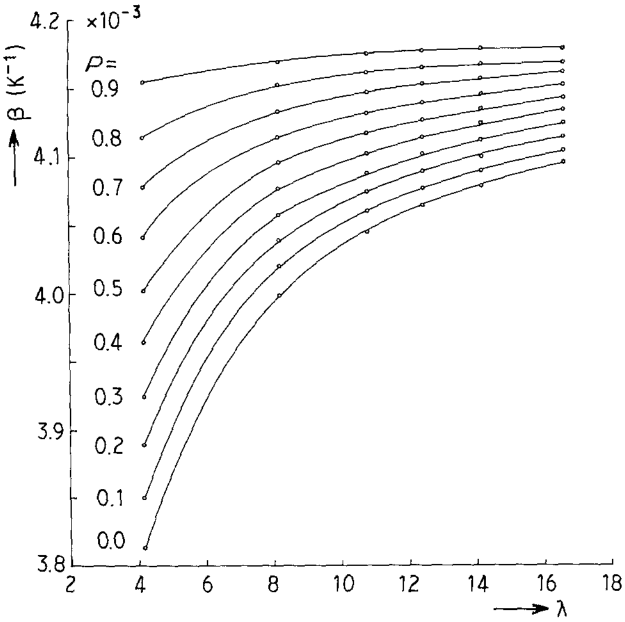

Figure 8 The dependence of temperature coefficient of resistivity on reduced thickness of zinc thin metallic films calculated according to the Fuchs–Sondheimer model.

$L_0 = 12\,\text{nm}$, $\beta_0 = 4.19 \times 10^{-3}$, for zinc. The relation between the theoretically calculated electrical resistivity and the reduced thickness according to Equation 2 is shown in Fig. 7, while Fig. 8 illustrates the relation between β_f and the reduced thickness for zinc films calculated from Equation 3. The theoretical results in Figs 7 and 8 are in good agreement with the experimental results in Figs 1 and 4, having the same character but with lower orders.

4. Conclusions

The electrical resistivity of zinc thin metallic films decreases as the film thickness, deposition rate annealing temperature increase. The temperature coefficient of resistivity increases as the film thickness and deposition rate increase. The activation energy for the conduction electrons increases as the deposition rate and the film thickness increase.

The experimental values of the electrical resistivity and the temperature coefficient of resistivity of zinc thin metallic films are in good agreement with the theoretically calculated values using the Fuchs–Sondheimer model, but the experimental values are of a higher order of magnitude.

References

1. A. J. TOSSER, C. R. TELLIER and J. LAUNEY, *Vacuum* **27** (1977) 335.
2. C. R. TELLIER, *ibid.* **28** (1978) 321.
3. E. ABU SAIF, M. EL OKER, H. ALY and A. MOHAMED, *Fizika* **15** (1983) 321.
4. A. TOSSER, G. FLUERY and H. HURRARY, *Thin Solid Films* **15** (1973) 259.
5. K. FUCHS, *Proc. Camb. Phil. Soc.* **24** (1938) 100.
6. F. SONDHEIMER, *Adv. Phys.* **1** (1952) 1.
7. C. TELLIER and A. TOSSER, "Size effects in thin films" (Elsevier, Amsterdam, 1982) p. 119.

Received 3 October 1988
and accepted 10 April 1989