Resistivity and temperature coefficient of resistance of chromium–copper alloy films

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Measurements of electrical resistivity and the temperature coefficient of resistance of vacuum deposited chromium–copper alloy films are reported. The mean freepath of the conduction electrons calculated from resistivity data and TCR data is 37.6 and 36.3 nm, respectively. The resistivity and TCR of an infinitely thick film have been computed to be 3.83 $\mu\Omega$ cm and 2.886×10^{-3} ° C^{-1}, respectively. The experimental data can be satisfactorily explained on the basis of Fuchs–Sondheimer theory assuming a total diffuse scattering.

1. Introduction

The possibility of utilizing chromium–copper alloys in place of copper as a contact material in resistance heaters and structural elements carrying current has led to intensive studies on the alloying behaviour of chromium with copper. Addition of chromium has been found to modify the properties of copper considerably. It increases the resistivity in bulk form [1–3]. Studies have been reported on the annealing and oxidation characteristics of copper–chromium–copper sandwiches [4]. There are no studies on the properties of chromium–copper alloys in thin film form. Recently, growth of alloy films with a chromium content of 0.8 wt% has been reported and their electrical resistivity has been measured as a function of temperature and thickness of the deposit [5]. Effect of annealing on the electrical resistivity of these films is also reported [6]. The present paper reports the electrical resitivity and temperature coefficient of resistance and an analysis of the experimental data using the Fuchs–Sondheimer theory [7].

2. Experimental details

Chromium (0.8 wt%)–copper alloy obtained from the Indian Smelting and Refining Company, Bombay, was evaporated from a tungsten filament at a residual air pressure of 10^{-6} torr onto glass substrates at room temperature (33° C). The rate of deposition was maintained at 1.5 nm $\sec^{-1}$ for all depositions. The films were annealed at a temperature of 190° C for two hours before making electrical measurements. The thickness of the films were measured with a quartz crystal monitor. The films were subjected to heating and cooling cycles in the temperature interval 33 to 190° C and resistance measurements made were reproducible within an experimental error of 5%.

3. Results and discussion

The thick film approximation of the Fuchs–Sondheimer theory [7] can be expressed in the form,

$$\rho = \rho_0[1 + 3(1 - p)/8k] \qquad \text{for } k > 1 \quad (1)$$

where ρ is the film resistivity, ρ_0 is the resistivity of an infinitely thick film, p is the specularity parameter and k is the ratio of film thickness to the mean freepath of the conduction electrons. Fig. 1 shows the thickness dependence of resistiv-

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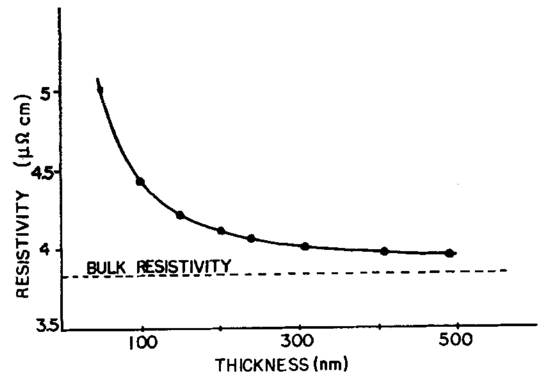

Figure 1 Variation of resistivity with the thickness of the deposit.

ity of the alloy films in the thickness range 50 to 490 nm. The resistivities mentioned are essentially of films annealed at 190° C. The resistivity decreases with increases in thickness reaching an almost constant value for higher thicknesses as predicted by Equation 1. The best fit to our experimental data on the basis of the Fuchs–Sondheimer theory was obtained for $p = 0$, suggesting that the resistivity arises through a total diffuse scattering of the conduction electrons. Equation 1 also suggests a linear dependence of ρt on the thickness t. A graph of ρt against t is shown in Fig. 2, where the straight line has been drawn to a least square fit of the values. The intercept and the slope of the straight line gives the mean freepath of the conduction electrons and the resistivity of an infinitely thick film as 37.6 nm and 3.83 $\mu\Omega$ cm, respectively. Fig. 3 shows the plot of $\log(\rho/\rho_0)$ against $\log k$. The full line indicates the theoretical curve corresponding to Equation 1. The deviation of the experimental values from the theoretical ones has been verified [8] to be due to the approximate nature of Equation 1.

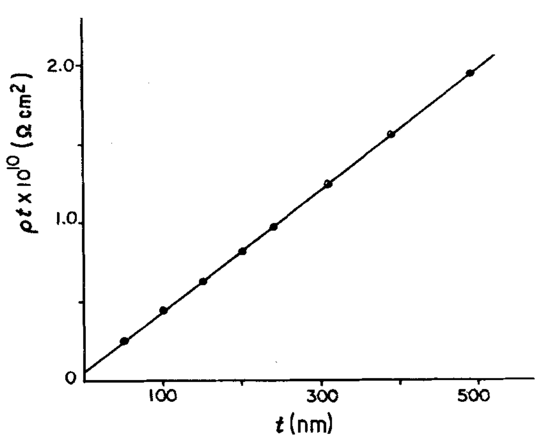

Figure 2 Variation of ρt with the thickness t.

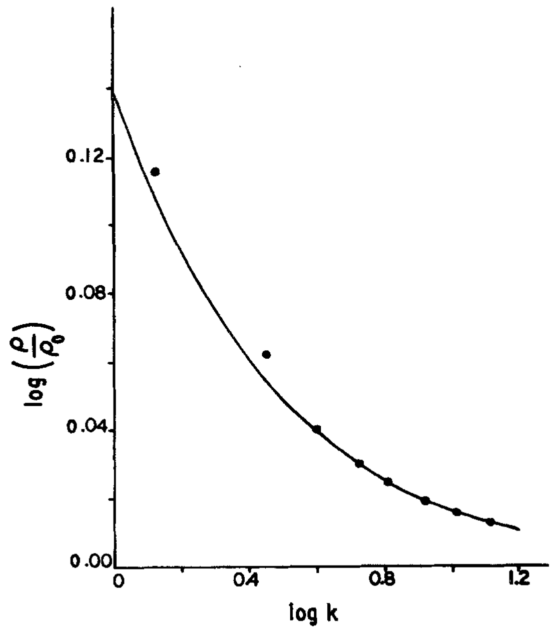

Figure 3 Plot of $\log(\rho/\rho_0)$ against $\log k$. The full line indicates the theoretical curve corresponding to Equation 1 and the points indicate the experimental values.

A graph of the temperature coefficient of resistance (TCR), α, against film thickness t is shown in Fig. 4. The TCR is positive, characteristic of continuous metallic films, and increases with thickness. Based on the Fuchs–Sondheimer theory, the dependence of TCR on film thickness can be written in the form,

$$\alpha = \alpha_0[1 - 3(1-p)/8k] \qquad \text{for } k > 1. \qquad (2)$$

This equation suggests a linear dependence of αt on the film thickness t. Thus, the straight line drawn for a least square fit (Fig. 5) yields the

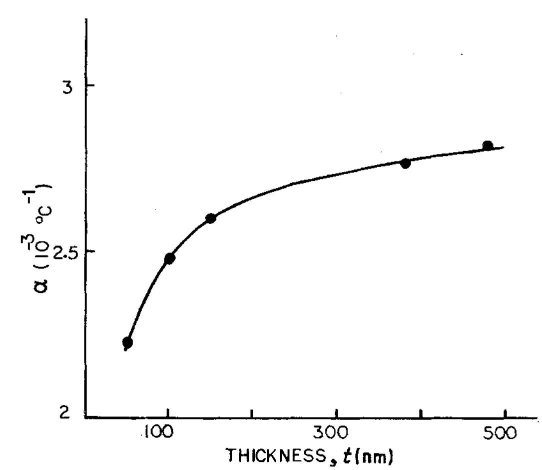

Figure 4 Variation of TCR with thickness at 33° C.

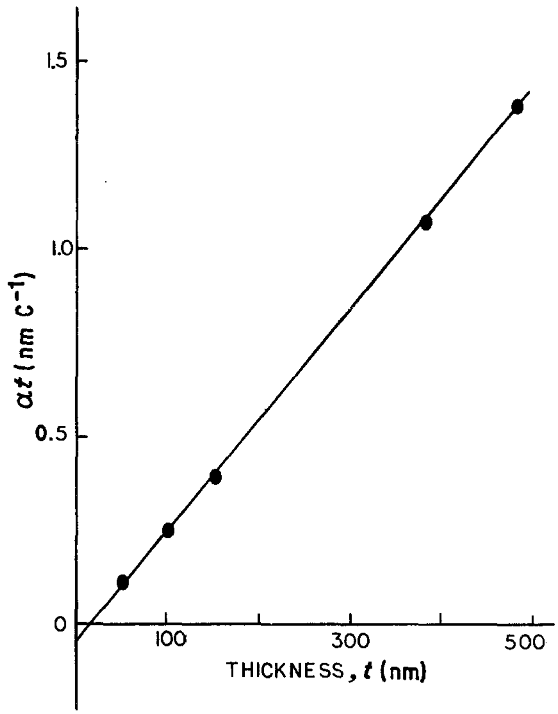

Figure 5 Plot of αt against thickness at 33° C.

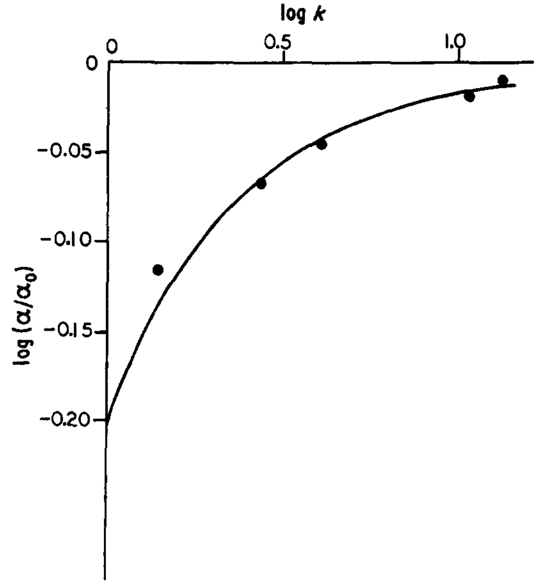

Figure 6 Plot of log (α/α_0) against log k. The full line indicates the theoretical curve corresponding to Equation 2 and the points indicate the experimental values.

mean freepath of the conduction electrons and the TCR of an infinitely thick film, α_0, as 36.3 nm and 2.886×10^{-3} ° C^{-1}, respectively. A comparison of the experimental values with the theoretical values obtained from Equation 2 is shown in Fig. 6.

From the resistivity and TCR data, it is observed that $\alpha\rho$ is a constant thereby showing that Matthiessen's rule is valid for the alloy films.

4. Conclusions

The resistivity and the TCR of chromium–copper alloy films can be explained satisfactorily on the basis of the Fuchs–Sondheimer theory. The theory also predicts a total diffuse scattering with a mean freepath for the conduction electrons 37.6 nm from the resistivity data which is in excellent agreement with the value 36.3 nm obtained from TCR data.

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