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Letter

Electrical properties of thin terbium films

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Electrical conduction in thin films has been of interest for many years. Most data analyses of experimental measurements have been carried out according to the following expressions [1, 2]

$$\rho_f=\rho_\infty\left(1+S\frac{l_b}{d}\right) \tag{1}$$

$$\alpha_f=\alpha_\infty\left(1+S\frac{l_b}{d}\right)^{-1} \tag{2}$$

where ρ_f is the resistivity of the film of thickness d, ρ_∞ is the resistivity of thick (bulk) film, l_b is the electron mean free path in the bulk, α_f is the temperature coefficient of resistance (TCR) of the film, and α_∞ is the TCR of thick (bulk) film. $S=\frac{3}{8}(1-p)$, where p is the specularity parameter according to the FS [1] approximation in which $0.1l_b<d<10l_b$ [3]. $S=\frac{3}{2}R/(1-R)$, where R is the reflection coefficient at grain boundaries according to the MS [4] approximation in which $Sl_b/d<1$ and the average grain size is equal to the film thickness [5].

Polycrystalline terbium films were prepared by thermal evaporation and condensation onto an optically flat glass substrate held at 20 °C in a vacuum of about 10^{-6} Torr. We used the four-probe method to measure the resistance and a copper–constantan thermocouple to measure the temperature of the samples.

Figure 1 shows the resistivity measured at 200 K as a function of thickness d in the range 14–50 nm. For thicknesses below 40 nm the resistivity increases markedly with decreasing thickness. For films thicker than 40 nm the dependence of the resistivity on thickness obeys eqn. (1). In Fig. 1 we also show a plot of ρ_f *vs.* $1/d$ which gives $\rho_\infty=45.2$ μΩ cm and $Sl_b=567$ Å. The full curve $\rho_f(d)$ drawn in Fig. 1 was calculated from the linear relation given by eqn. (1). The value of ρ_∞ is 52% smaller than the value for bulk undisturbed terbium [6]. It has also been reported for gadolinium

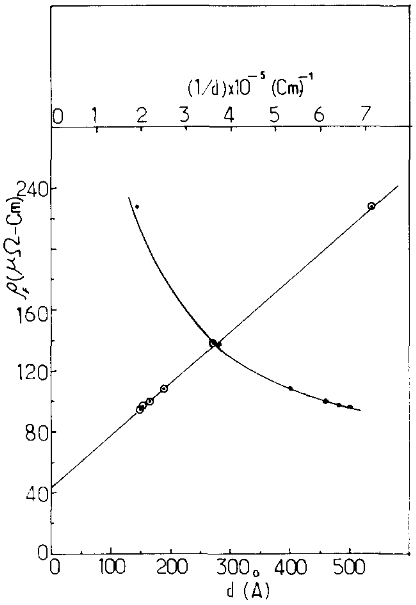

Fig. 1. The thickness dependence of the resistivity at 200 K of thin terbium films: ● experimental points of a ρ_f *vs.* d curve; ⊙ experimental points of a ρ_f *vs.* $1/d$ graph.

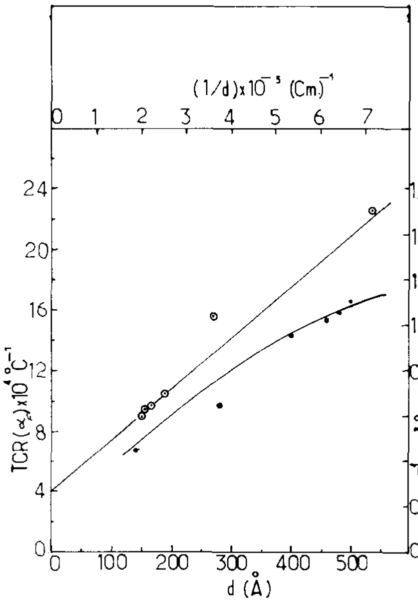

Fig. 2. The thickness dependence of the TCR(α_f) at 200 K of thin terbium films: ● experimental points of a α_f *vs.* d curve; ⊙ experimental points of a $1/\alpha_f$ *vs.* $1/d$ graph.

[7] and samarium [3] that for higher thicknesses the film resistivity is much smaller than the bulk resistivity.

Equation (2) can be used to describe the experimental results, as can be seen from Fig. 2 in which $1/\rho_f$ is plotted as a function of $1/d$. This linear relationship holds quite well for thicknesses greater than 40 nm, which gives $\alpha_\infty = 35.7 \times 10\ °\mathrm{C}^{-1}$ and $Sl_b = 590$ Å. The full curve $\alpha_f(d)$ in Fig. 2 was calculated from the above linear relationship. The value of α_∞ is 39% smaller than the TCR (α_b) of bulk terbium [6]. This may be attributed to the high density of structural imperfections in the films, so that the value of α_∞ approaches the value of α_b when high annealing temperatures are used [8, 9]. The Sl_b value obtained from the TCR measurements differs from the value obtained from the resistivity measurements. This difference has also been observed with copper [10], nickel [8], and palladium [11].

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