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ELECTRICAL RESISTIVITY OF THIN SAMARIUM FILMS

ЭЛЕКТРИЧЕСКОЕ УДЕЛЬНОЕ СОПРОТИВЛЕНИЕ ТОНКИХ САМАРИЕВЫХ ПЛИНОК

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The electrical properties of thin metal films of noble metals such as Au, Ag and Cu and transition ferromagnetic metals Fe, Ni and Co have been studied extensively in recent years [1, 2]. Thin metallic films of the rare-earth metals exhibit a great variety of physical properties. However, rare-earth metals have been studied in bulk form samples [3, 4], and only in some cases studies of the electrical resistivity [5—12] and optical absorption have been carried out [13]. The thickness dependences of the electrical resistivity of samarium and ytterbium films have been investigated and the electron mean free paths (e.m.f.p.) in these metals have been determined to be about 400 Å and 500 Å, respectively [7, 8].

Using the Boltzmann transport equation, a spherical Fermi surface, an isotropic e.m.f.p. and a random scattering of electrons from the surface of a film, the resistivity of a thin film can be expressed as [14]

$$\frac{\varrho_b}{\varrho_f}=1-\frac{3}{4}\left(k-\frac{k^3}{12}\right)E_i(-k)-\frac{3}{8k}\,1-\exp[-k])-$$
$$-\left(\frac{5}{8}+\frac{k}{16}-\frac{k^2}{16}\right)\exp[-k], \tag{1}$$

where ϱ_b is the electrical resistivity of the bulk sample, ϱ_f is the electrical resistivity of the thin film, k is the ratio of the film thickness d to the e.m.f.p. l in the bulk sample, and

$$-E_i(-k)=\int_k^\infty(\exp[-t]/t)\,dt.$$

The limiting form of this expression is given by [15, 16]

$$\frac{\varrho_f}{\varrho_b}=1+\frac{3}{8}\frac{l}{d}(1-p),\qquad d>l, \tag{2}$$

and

$$\frac{\varrho_f}{\varrho_b}=\frac{4}{3}\left(\frac{l}{d}\right)\left(\frac{1-p}{1+p}\right)\frac{1}{\ln\frac{l}{d}},\qquad d\ll l, \tag{3}$$

where p is the specularity parameter.

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The temperature coefficient of the resistivity $\frac{1}{\varrho}\frac{d\varrho}{dT}$ of a thin film is given by

$$\frac{\alpha_f}{\alpha_b}=1-\frac{3}{8}\frac{l}{d}(1-p),\qquad d>l, \tag{4}$$

$$\frac{\alpha_f}{\alpha_b}=\left\{\ln\left(\frac{l}{d}\right)\right\}^{-1},\qquad d\ll l. \tag{5}$$

In this paper we report the results of our studies on the electrical resistivity in thin samarium films over a thickness range from 700 Å to 2000 Å and for temperatures between 77—300 K.

The aim of our measurements was: 1. the calculation of the e.m.f.p., 2. the determination of the Néel temperature, 3. the determination of the spin-disorder resistivity ϱ_m. As far as we know, no other measurements of the kind seem to be available.

Samarium films of various thickness were prepared by vacuum evaporation of the bulk material (containing the following impurities in weight % : La (0,03), Nd (0,01), Eu (0,01), Gd (0,01), Fe (0,01), Cu (0,01) onto pre-cleaned microscope glass slides of 6 mm × 20 mm at room temperature in a high vacuum coating unit at a pressure of 5×10^{-6} torr. The resistance measurements have been carried out potentiometrically (sensitivity 10^{-8} V) using the four-probe technique. The thickness of the films were determined to an accuracy of 50 Å by Tolansky's method. Prior to the film preparation, silver electrical contacts were evaporated onto glass slides, and silver wire leads were cemented with silver conducting paint at required positions.

In order to reach higher electrical stability of the samarium films, thin films of SiO were evaporated onto samarium film surfaces. Thus, for a required thickness usually three thin films were prepared — one for thickness determination (without SiO) and two for electrical resistivity measurements (to check reproducibility).

A usual way to discuss the total electrical resistivity of thin films is the well-known Matthiesen rule. The total resistivity ϱ of a film is given by the equation

$$\varrho=\varrho_d+\varrho_f+\varrho_m+\varrho_i(T), \tag{6}$$

where $\varrho_i(T)$ represents the resistivity corresponding to the scattering of conduction electrons due to thermal vibration, ϱ_d scattering of conduction electrons from defects, ϱ_f scattering of conduction electrons from film surfaces and ϱ_m scattering of conduction electrons due to disordered spins (this term is present only in magnetic materials). The increase in the resistivity of a film due to surface scattering (ϱ_f) can be calculated from the Fuchs—Sondheimer theory if the e.m.f.p. is known (equation 1—3)). Exact variation of ϱ_m with film thickness for samarium is not known. It is expected that ϱ_m decreases below about 500 Å—600 Å and approaches zero for zero thickness. However, our measurements were performed with thicker films and thickness dependence of the spin-disorder resistivity ϱ_m could not be determined reliably.

In the vicinity of 100.5 K—102 K we observed a marked change in the slope of the temperature dependence of the electrical resistivity, which is an indication of transition from the paramagnetic to the antiferromagnetic state. Polycrystalline susceptibility results revealed an anomalous kink near 106 K and a sharp decrease in susceptibility beginning at 14 K [17]. Neutron diffraction results confirm that the spins on hexagonal sites only are ordered antiferromagnetically at 106 K and at 14 K the cubic sites are ordered into ferromagnetic layers [4]. Our measurements show quite clearly a suppression of the Néel temperature to lower temperature (approximately 2.5 K for 700 Å film thickness).

Our values of the electrical resistivity at room temperature are not in agreement with the results of other authors [7], where a constant value of $\varrho_f=50$ μΩcm for thickness above 600 Å was observed. This value is much lower than the room temperature value of the bulk samarium metal (≈ 92 μΩcm). We also observed an approximately constant value of the electrical resistivity at room temperature for thicknesses above 1000 Å, but with a value of $\varrho_f=94\div96$ μΩcm, which is very close to the bulk value.

Using Eq. (4) and assuming that the surface scattering is completely diffuse ($p = 0$), the calculated values of e.m.f.p. are in the region from 375 Å to 450 Å, which is in good agreement with other measurements. The phonom resistivity term $\varrho_i(T)$ in (6) has a linear temperature dependence with the coefficient of proportionality from 0.125 μΩcm K^{-1} to 0.12 μΩcm K^{-1}. Below the Néel temperature a decrease of the electrical resistivity with temperature is higher, approximately linear near 77 K with the coefficient 0.24 μΩcm K^{-1}.

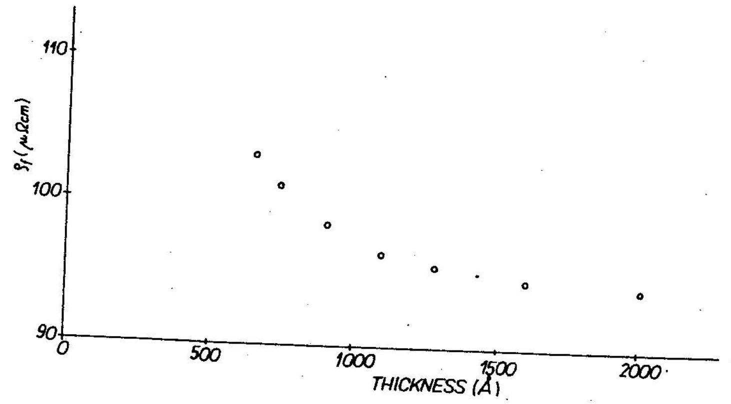

Fig. 1. Electrical resistivity of thin samarium films.

The spin-disordered resistivity ϱ_m can be obtained in the following way: The linear high temperature resistivity curve should be extrapolated back to zero temperature and then the resistivity intercept minus the residual resistivity will be approximately the desired ϱ_m. The obtained values of ϱ_m are in range from 50 to 55 μΩcm. Paper [18] gives for the samarium spin-disorder bulk resistivity the value of 46 μΩcm. A detailed study of the spin-disorder resistivity and magnetoresistance at low temperature at our laboratory is in progress.

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