Study of disorder effects on titanium films resistivity

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Abstract

The resistivity of titanium (Ti) films has been measured between 4.2 and 273 K . Samples with different residual resistivity, residual resistivity ratio, and temperature behavior have been obtained. The results are investigated in the framework of the electron-phonon-impurity interference theory of Reizer and Sergeev. The T^2 behavior predicted by such theory is found in the temperature range between 4.6 and 30 K. Some samples also show an increase of resistivity for temperature lower than 12 K due to the Kondo effect.

Key words: Titanium; resistivity

1. Introduction

Reizer and Sergeev [1] showed that the interference between electron-phonon and electron-impurity scattering gives rise to a contribution to the metal resistivity which is proportional to T^2 and to the residual resistivity ρ_0. Such result is valid in the "clean" limit $ql > 1$ (q is the thermal phonon wave number and l is the electron mean free path) and for $T \leq \Theta_\mathrm{D}/10$ where Θ_D is the Debye temperature. In this work we show that such theory can be applied to the low temperature resistivity of Ti films produced in our laboratory with different values of l, i.e. different degrees of disorder.

2. Experiment

Ti films have been deposited by e-gun at the base pressure of about $2 \cdot 10^{-5}$ Pa on silicon nitrite (SiN) substrates. The substrate temperature, monitored by a thermocouple, was varied between 400 °C and 500 °C. The Ti films have been prepared starting from two materials of different purity: one with 99.6+ % purity (A) and the other with 99.99+ % (B). Films were patterned for resistance measurements by standard photolithographic process and chemical etching. All samples were 3.5 mm long and 50 μm wide.

The electrical resistance has been measured as a function of temperature by using a four-probe AC resistance technique at 13 Hz. The sample temperature has been controlled by dipping a cryogenic insert in liquid helium and varying the power dissipated on a manganin heater. In table 1 the measured parameters of the Ti films are reported: d is the film thickness and RRR is the Residual Resistance Ratio between R(273 K) and R(4.6 K).

3. Results and discussion

The resistivity of a metallic film can be fitted by the equation

$$\rho = \rho_0 + \Delta\rho_\mathrm{lk} + \Delta\rho_\mathrm{epi} + \Delta\rho_\mathrm{ep}, \tag{1}$$

where ρ_0 is the residual resistivity which is indipendent from temperature, $\Delta\rho_\mathrm{lk}$ is the term related to weak localization and Kondo effect with a logaritmic temperature behaviour, $\Delta\rho_\mathrm{epi}$ is the contribution due to the in-

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Sample	d	RRR	ρ_0	a	b	c	l
	nm		$\mu\Omega$·cm	$\mu\Omega$·cm	$\mu\Omega$·cm·K^{-2}	$\mu\Omega$·cm·K^{-5}	Å
A1	58	2.46	39.4	-3.49E-2	2.46E-5	1.34E-10	28
A2	310	6.18	10.99	0	1.38E-5	1.27E-8	102
A3	310	5.25	14.29	-9.9E-3	4.22E-5	1.24E-8	78
B1	63	2.48	33.18	-1.52E-2	7.30E-5	1.12E-8	34
B2	90	3.88	20.92	0	3.86E-5	1.44E-8	54
B3	100	4.71	15.34	0	3.89E-5	1.36E-8	73
B4	130	3.66	21.98	0	6.12E-5	1.07E-8	51
B5	151	4.5	16.25	0	4.82E-5	1.25E-8	69

Table 1
Experimental and fit parameters of the Ti films studied

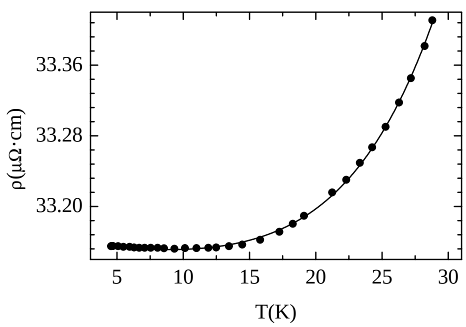

Fig. 1. Experimental resistivity data (dot) and fit following equation (3) (solid line) for the sample B1.

terference between electron-phonon and electron- impurity scattering and $\Delta\rho_{\rm ep}$ is the Bloch-Gruneisen law related to the pure electron-phonon interaction. At low temperatures ($T \leq \Theta_{\rm D}/10$) the last term is proportional to T^5, whereas the interference term obtained by Reizer and Sergeev [1] is

$$\frac{\Delta\rho_{\rm epi}}{\rho_0} \approx \frac{4\pi^2\beta_{\rm t}}{3\epsilon_{\rm F} p_{\rm F} u_{\rm t}}(k_{\rm B}T)^2 = BT^2, \tag{2}$$

where $\epsilon_{\rm F}$ and $p_{\rm F}$ are the Fermi energy and momentum, $u_{\rm t}$ is the propagation velocity of transverse phonons, $\beta_{\rm t}$ is the constant of interaction with transverse phonons, and $k_{\rm B}$ is the Boltzmann constant. With this assumption equation (1) can be written as

$$\rho(T) = \rho_0 + a\ln T + bT^2 + cT^5. \tag{3}$$

The resistivity behaviour of different Ti films has been fitted with this equation in the temperature range 4.6-30 K when the Kondo effect was present in the experimental data. Otherwise parameter a was set equal to zero. The fit parameters are reported in table 1. The last column reports the l values for our samples at 4.6 K, obtained assuming a constant value of the product $\rho l = 1.12\cdot 10^{-5}\mu\Omega\cdot{\rm cm}^2$ [2]. As an example of the best fit in Fig. 1 are reported the experimental data and the curve fit for sample B1.

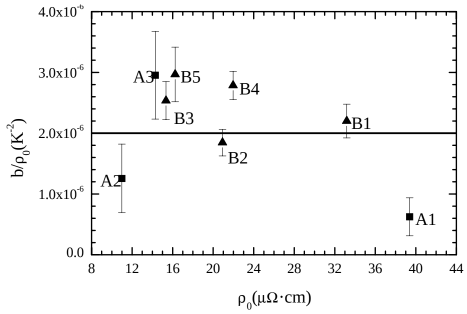

Fig. 2. The fit parameter b of equation (3) divided by ρ_0 as a function of ρ_0. The solid line is the theoretical value.

The theory of Reizer and Sergeev predicts that the resistivity contribution $\Delta\rho_{\rm epi}$ is proportional to ρ_0 as stated by equation (2). This means that the coefficents b reported in table 1 divided by ρ_0 should be constant. The theoretical value predicted for Ti from equation (2) is $B \approx 2\cdot 10^{-6}$ K^{-2}, obtained with the following parameters taken from literatures: $\epsilon_{\rm F} = 9.07$ eV, $p_{\rm F} = 1.46\cdot 10^{-19}$ g·cm/s, $u_{\rm t} = 3.13\cdot 10^3$ m/s, $\beta_{\rm t} = 5.28$. In Fig. 2 is plotted the fitting parameter b divided by ρ_0 as a function of ρ_0. These values are spread around $2.1\cdot 10^{-6}$ K^{-2} which agrees with the theoretical prediction within the experimental uncertainty.

For $T < 12$ K, in three of our samples, the resistivity slope is negative. Such behaviour can be fitted with the logarithmic term associated with the Kondo effect due to the presence of residual ferromagnetic impurities. The samples A1 and B1 have an experimental resistivity rise of $15.8\cdot 10^{-3}$ and $3.1\cdot 10^{-3}\mu\Omega$·cm respectively; this is in agreement with the results of Vangrunderbeek et al. [3], which found a rise of $7.6\cdot 10^{-3}\mu\Omega$·cm using the Kondo theory. The sample A3, instead, has a rise of $0.5\cdot 10^{-3}\mu\Omega$·cm, which is an order of magnitude smaller than expected. Since the value of the resistivity rise depends strongly on the film fabrication process, further investigations on the Kondo effect are in progress.

In conclusion the resistivity of Ti films with different degrees of disorder has been considered. The resistivity temperature behaviour has been studied in the framework of the electron-phonon-impurity interference theory [1]. The fit of the experimental data between 4.6 and 30 K are in good agreement with the theory and confirm the presence of a T^2 term proportional to ρ_0 .

References

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