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Surface Scattering and DC Size Effects in Aluminium

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Abstract. *When the mean free path $\lambda_\infty(T)$ is of the order or smaller than the thickness d of the sample, the DC electrical resistivity ρ shows size effects and depends on the quality of the sample surface, polished or rough. We have performed high resolution measurements (1-10 ppm) of ρ in the temperature range 1.2 K - 9 K in Aluminium samples showing size effects. The surface was changed from rough to polished in a controlled and reproducible way by electropolishing and chemical treatments, showing that scattering at the sample surface is partially specular in contrast to the usual assumption of diffuse scattering. These results are compared with Soffer's theory.*

The first theory of size effects in DC electrical resistivity $\rho(d,T)$ was proposed by Fuchs [1] assuming as a boundary condition to solve Boltzmann equation that a constant fraction $0 \le p \le 1$, called the specularity parameter, of the incident electrons on the sample surface was specularlly scattered. A more refined model of p based on an analogy with light scattering by surfaces was proposed by Soffer [2]. In this model $p(\theta)=\exp(-16\pi^2 r^2 \cos^2\theta)$, θ being the angle between the direction of the incident electron and the surface normal and $r=h/\lambda_e$ the roughness (h the rms of the asperities and λ_e the electron wavelength). Interpreting the experimental results on $\rho(d,T)$ it has usually been assumed [3] that p=0 for Al because the oxyde formed immediately on the surface after exposure to air was supposed to yield a rough surface for the scattering of conduction electrons. This point is however questionnable and our results show that scattering is partially specular.

The $\rho(d,T)$ data are taken in a high purity monocrystal (RRR=39400). The sample preparation and the experimental setup allowing high resolution in the temperature range $1.2K \le T \le 9K$ has already been presented [4]. The state of the surface was changed from polished to etched by successsive electroplolishing and chemical treatments.

The results are presented in Fig. 1 where $\rho(d,T)$ is shown as a function of the thickness d. The are clearly distinct for polished and etched states of the surface. A fit has been made with Soffer's theory [2] and the curves are drawn with the following values of the parameters : a) T=1.2 K (residual resistivity) : $\rho_{\infty 0}(d,T)=0.70\pm0.02$ pΩm, $\lambda_{\infty 0}=1055\pm35$ μm, b) T=9 K : $\rho_\infty(9K)=1.25\pm0.04$ pΩm, $\lambda_\infty(9K)=630\pm20$ μm. In both cases the polished states are well described with r=0.30 and the etched ones with r=3.0. The $\rho_\infty\lambda_\infty$ values obtained are 0.74 ± 0.05 fΩm^2 at 1.2 K and 0.79 ± 0.05 fΩm^2 at 9 K, the small difference being insignificant.

In this representation it is difficult to decide between Soffer's and Fuchs' model for the specularity parameter. To conclude it would be necessary to examine the surface resistivity in more detail, for example its temperature dependence. Notwithstandig one fact is established : the possibility to change in a controlled way the surface specularity. So, values of p different from 0 may result from surface treatments and must be taken into account in the interpretation of experimental $\rho(d,T)$. The scatter in the $\rho_\infty\lambda_\infty$ values collected by Bass [5] is probably very often due to misinterpretation of the experimental data assuming p=0.

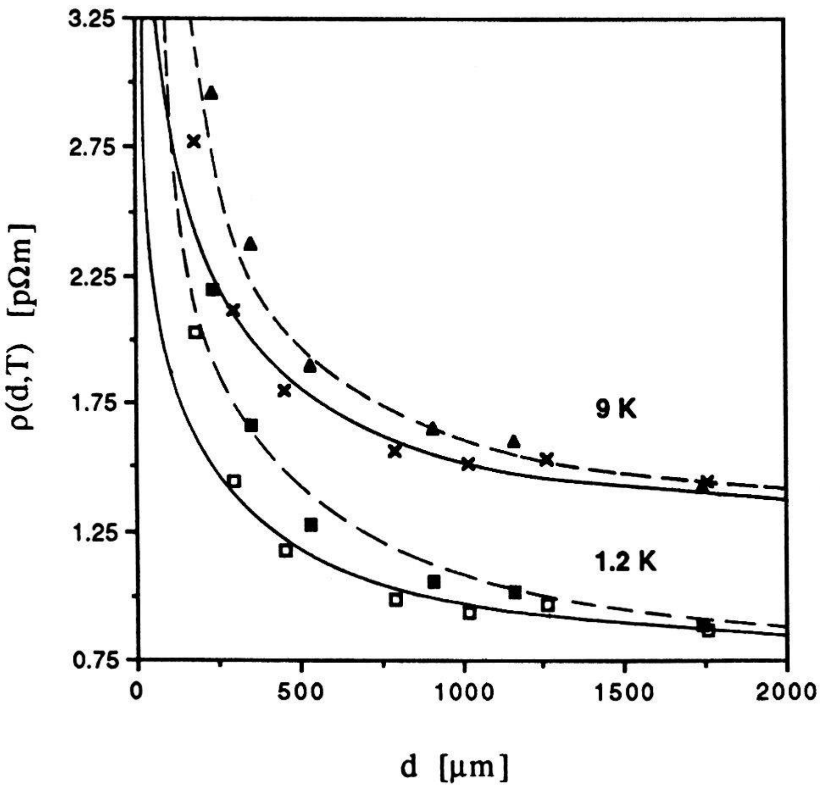

Figure 1. Resistivity $\rho(d,T)$ as a function of the thickness d for different states of the surface at T=1.2 K □ : polished, ■ : etched, and at T=9 K ✖ : polished, ▲ : etched.

The curves are fit to Soffer theory with the parameters at T=1.2 K $\rho_{\infty 0}$=0.70 pΩm, $\lambda_{\infty 0}$=1055 μm and at T=9 K ρ_∞=1.25 pΩm, $\lambda_{\infty 0}$=630 μm. At both temperatures the value of the roughness parameter is r(polished)=0.30 (full curves) and r(etched)=3.0 (broken curves).

Evidence for p≠0 in Al has also been given by Sato and Yonemitsu [6] from transverse electron focusing (TEF) experiments which give more direct information on the specularity p than the resistivity. They have shown that p also depends on the cristallographic plane forming the sample surface.

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