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MAGNETORESISTANCE OF THIN PALLADIUM FILMS*

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We have measured the temperature and magnetic field dependence of the resistivity of palladium films of ∿ 25 Å thickness. We find a logarithmic temperature increase with decreasing temperature and a large, positive, isotropic, temperature dependent magnetoresistance. Similar results with PdAu films show that the effect is not magnetic in origin. The temperature coefficient and positive magnetoresistance are consistent with an interpretation in terms of the interaction picture rather than localization effects.

There has been a great deal of interest in the transport properties of thin films since the scaling argument prediction that all states in two dimensions are localized.[1] Measurements of both pure[2] and alloy[3] films and inversion layers[4] show logarithmic temperature dependences which, however, can also be explained by a model including scattering and electron-electron interactions.[5] On the other hand, there have been measurements on quenched Pd films which show a resistivity minimum[6] which is enhanced by application of a magnetic field.[7] It had been suggested that this effect was related to two dimensional magnetism.[7]

The samples were prepared by room temperature evaporation of "marz" grade palladium in a vacuum of 10^{-7} - 10^{-6} Torr onto a glass substrate. Electron micrographs of 30 Å films deposited on a carbon-coated microscope grid show uniform thickness films with some narrow cracks on a 100 Å scale and homogeneity on a micron scale. Films down to 20 Å are continuous.

In Fig. 1 we show the resistance (normalized to the 3 K value) as a function of the logarithm of the temperature for a Pd film of ∿25 Å. Over one and a half decades of temperature, the resistivity is well represented by a logarithmic dependence.

For films with resistivities from 500 Ω/□ to 10 K Ω/□, we find that the low temperature resistivity may be written as

$$R_\square(T) = R_\square(1 - S_T \ln T) \qquad (1)$$

with $S_T \approx 10^{-5}\ \Omega^{-1} R_\square$ or $S'_T \equiv S_T(\hbar\pi^2/e^2 R_\square) \approx 0.4$. This value of S_T is comparable to what has been found in PdAu films[3] and silicon inversion layers[4] but is about a factor of 2 to 3 smaller than the value seen in clean Cu films.[2] The value that we find is close to that predicted by the interaction theory,[5] $S'_T = 0.5$ (without the Hartree correction), or by the localization theory[1] with a linear exponent

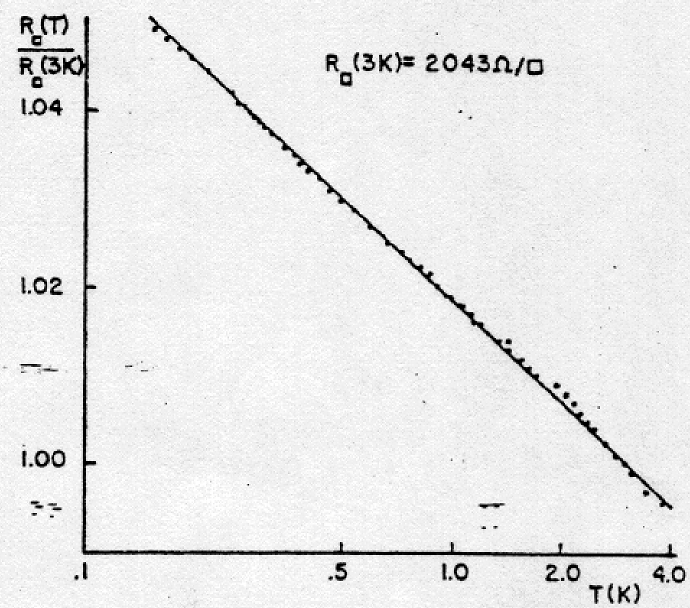

Figure 1. Normalized resistivity as a function of temperature (plotted on a logarithmic scale).

for the temperature dependence of the inelastic scattering.

In the published literature, the only discussion of magnetoresistance in the localization problem suggests a negative magnetoresistance for the localization picture and no magnetoresistance for the interaction picture.[5] The magnetoresistance of a Pd film with $R_\square$ ∿ 4000 Ω/□ is shown in Fig. 2. There is a positive magnetoresistance which is two or three orders of magnitude larger than what one expects from conventional orbital magnetoresistance effects in a film with a mean free path of ∿ 25 Å.

Since it has previously been suggested that Pd films are magnetic due to the large exchange enhancement in pure Pd,[7] we have also performed measurements on PdAu films (Pd, 42 wt%; Au, 58 wt%). The magnetic field and temperature

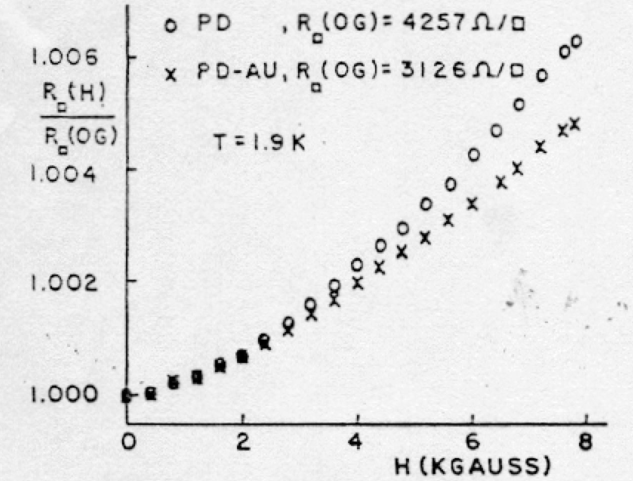

Figure 2. Normalized resistivity as a function of magnetic field for Pd and PdAu films.

dependence of the resistance of these films is compared in Figs. 2 and 3. The concentration of Au is sufficient to fill the d band and to strongly suppress the exchange enhancement. We therefore conclude that the resistivity minima and magnetoresistance in Pd films is not associated with a magnetic transition. Previous measurements on quenched Pd films have the same form that we have found when the percentage change in resistance is scaled by $R_{\square}$.[7]

The positive magnetoresistance we find is very temperature dependent, as has been found by Bergmann.[7] The field dependence appears to scale as H/T. The magnetoresistance is independent of magnetic field orientation with respect to the film and hence is almost certainly a spin effect rather than an orbital effect.

In the localization picture, a positive magnetoresistance may result from alignment of impurity spins. An electron becomes delocalized (loses phase coherence) by either an inelastic scattering or a spin flip scattering process.[6] A very small concentration of Fe (of order 5 ppm) is sufficient at ~ 1 K to result in spin flip scattering comparable to the inelastic scattering. Application of a magnetic field aligns the impurity spins and reduces spin flip processes, producing more highly localized states and increased resistivity. The characteristic field for the usual negative magnetoresistance scales with the inverse of the elastic mean free path. Thus, the relative importance of the two mechanisms depends on resistivity and number of magnetic impurities.

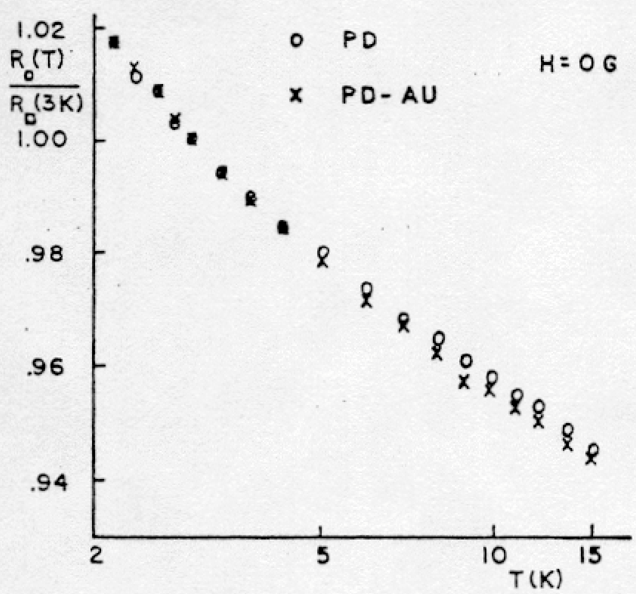

Figure 3. Normalized resistivity as a function of temperature (logarithm scale) for the same films as in Figure 2.

In the interaction picture, it has been recently suggested[9] that the screening correction to the Hartree term may be magnetic field dependent. In this model, the limiting high field behavior should be that predicted for no screening. It is interesting to note that in our case, the extrapolated high field saturation of the magnetoresistance would contribute less than 0.1 to our value of S'_T. In previous work, the limiting high field, temperature dependent resistivity approaches that expected from the interaction picture.

In conclusion, we find a low temperature logarithmic increase in the resistivity of thin pure Pd and PdAu films which is consistent with the interaction picture. We also find a large positive magnetoresistance which we suggest is associated with the anomalous resistance and not with a magnetic transition. The magnetic field dependence is a part of the localization and interaction pictures which clearly needs more theoretical work. We have mentioned ways in which a positive magnetoresistance may occur in either model.

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