



Doctoral Thesis

Weak localization and oscillatory magnetoresistance in cylindrical metal films

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WEAK LOCALIZATION AND OSCILLATORY MAGNETORESISTANCE IN
CYLINDRICAL METAL FILMS

A dissertation submitted to the
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presented by
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6. SUMMARY AND CONCLUSIONS

The magnetoresistance of thin cylindrical Mg and Ag films (diameter $\approx 1 - 2 \mu\text{m}$) in the weakly localized regime has been investigated in the temperature range between 1.3 and 4.2 K and in a longitudinal magnetic field up to 0.3 T. The measurements were carefully analyzed in terms of the recent theories of weak electron localization. The observed magnetoresistance oscillations are periodic in the magnetic flux quantum $h/2e$ and in excellent agreement with the Altshuler-Aronov-Spivak (AAS) theory. In the Mg sample as well as in the two Ag samples the phase of the oscillations corresponds to the case where scattering processes with strong spin-orbit coupling dominate. This is consistent with the behaviour of the monotonic magnetoresistance.

In order to obtain the different scattering times the theory was fitted over the full field and temperature range to the magnetoresistance data including the oscillations at low fields. We note that a simultaneous fit of the low and high field data is necessary for obtaining a uniquely defined set of parameters. In all samples a good agreement with theory was found in the temperature and field range studied by multiplying the theoretical expressions for the magnetoresistance by a factor of 0.3 to 0.5. We attribute this reduction of localization effects to structural inhomogeneities in our films. The resulting phase-breaking times $\tau_{\phi}(T)$ in the Ag films were almost independent of the sample properties and showed a temperature dependence as $\tau_{\phi}(T) \propto T^{-1.55}$ below 3 K. This is probably due to the interplay of inelastic electron-phonon scattering with impurity induced electron-electron scattering. The values of the spin-orbit scattering time τ_{SO} were always smaller than τ_{ϕ} and in good agreement with those obtained in planar films. The experimental results

also suggest that in our Ag films the magnetic scattering time τ_s is much larger than τ_ϕ at $T > 1.3$ K. The large scattering times found in these films may be explained with the high purity of the initial metal. The temperature dependence of the resistance in the Ag films at higher fields where localization effects are saturated is essentially caused by electron-electron interaction effects with a screening parameter $F < 0.1$.

Our main interest was concentrated on the AAS oscillations. Additional information was expected from the application of the magnetic field modulation technique, which enabled us to record up to 19 oscillations. From a fit of this data to the AAS theory the distribution of the cylinder radii was obtained and compared to the results of a scanning electron microscope analysis. This variation of the cylinder radius is mainly responsible for the damping of the oscillation amplitude with increasing field. We emphasize that the field modulation data is consistent with the direct measurements of the magnetoresistance, in particular the AAS oscillations. We also performed a Fourier analysis of the oscillations in order to study the harmonics of the fundamental $h/2e$ oscillation. As expected from the AAS theory, higher harmonics are strongly attenuated due to the long perimeter of the cylinders compared to the diffusion length L_ϕ over which the electron phase is coherent. In sample Ag2 we can not exclude the existence of oscillations with periodicity h/e .

In conclusion, this work demonstrates that the oscillatory magnetoresistance in weakly localized cylindrical films of Ag is well described by the existing theories. We have also shown that reliable values of the phase-breaking and the spin-orbit interaction times can be obtained from a detailed analysis of the experimental data.