II. MICROWAVE SPECTROSCOPY*

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A. WORK COMPLETED

1. SURFACE EFFECTS IN THE MAGNETO-SURFACE IMPEDANCE OF METALS

This research has been completed by J. B. Barton, and submitted to the Department of Physics, M.I.T., August 1971, in partial fulfillment of the requirements for the degree of Doctor of Philosophy. A summary of the thesis follows.

The classical theory of the surface impedance of a metal at low temperatures is reviewed for the case in which there is no externally applied magnetic field. Then the effects of applying a magnetic field are discussed. We used a simple trajectory model for electronic conduction. In our model surface scattering effects were approximated by an angle-dependent probability of specular reflection. We found evidence for a simple relation between the rf surface impedance and the nonlocal conductivity of a metal, and used this relation in conjunction with the trajectory model to predict the qualitative dependence of the low magnetic field surface impedance line shape on the type of surface scattering present.

We discussed procedures for measuring the absolute value of the real part R_s of the rf surface impedance. As a prerequisite for this discussion, the subject of impedance relationships along a transmission line was dealt with in some detail. A method was described for eliminating most of the effects of a line on measurements of R_s, and for accurately computing the remaining influences of the line.

We described techniques for increasing the speed of a marginal oscillator's response to changes in the impedance of its tank circuit, and analyzed, to a limited extent, the relationship between the response time and the sensitivity of the oscillator. For a large enough sample signal, increasing the response speed of the oscillator permitted us to make a real-time display of the low-field line shape.

We tabulated results of static and dynamic measurements of R_s for single-crystal

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disks of gallium. The absolute values measured for R_s are compared with values for X_s cited by Cochran and Shiffman,[1] and the line shapes observed in the dynamic measurements are also compared with data obtained by those researchers. We found that the line shape exhibits a strong peak at $B = 0$ in all the crystal orientations which we studied. Its width, however, exhibited no measurable dependence on parameters such as temperature and surface roughness, so positive comparison with the theoretical model was not possible.

In an appendix, we explored a quasi-classical theory for scattering of a wave packet from a statistically defined rough surface. An enhancement of specular reflection was found to occur when the diameter of the wave packet becomes smaller than the correlation length for surface irregularities.

M. W. P. Strandberg

References

1. J. F. Cochran and C. A. Shiffman, Phys. Rev. 140, A-1678 (1965).

B. CRITICAL-POINT FLUCTUATIONS IN SUPERCONDUCTING THIN FILMS

Further study has been made on the noise properties of superconducting thin films near the transition temperature. Excess noise (noise not caused by ordinary temperature fluctuations) has been observed in both tin and indium films when those films were placed in a perpendicular magnetic field and biased by a current source. These films, deposited on sapphire disks one inch in diameter, were photo-etched using master drawings so that the final film geometry could be accurately controlled. In this way we could study the dependence of the excess noise on such parameters as film width, length, thickness, current density, magnetic field, and temperature.

The usual procedure for studying the excess noise is the following. The superconducting film, held at some temperature and biased by a fixed current density, is swept through the transition region by the application of a perpendicular magnetic field. The excess noise is observed only in this transition region, and this noise peaks typically when the film reaches 1/10 of the full normal resistance. When the film has reached 1/2 normal resistance or greater, the excess noise is negligible.

The peak-integrated noise power for a film swept through the transition region is roughly proportional to $(J-J_o)^2$, where J is the bias current density, and J_o is a parameter that increases almost linearly with decreasing temperature. For $J < J_o$ no excess noise is observed. The value of J_o depends greatly on film thickness, and, in general, the thinner the film the smaller will be J_o for a fixed temperature.

The noise power spectrum from 10 kHz to 200 kHz follows roughly a $1/f^{\alpha}$ dependence where α is close to unity. A high-frequency tail with a more gradual falloff is also observed at the higher frequencies (from 200 kHz to 50 MHz). Below 10 kHz bubble noise with its $1/f^2$ dependence dominates. This noise, caused by the boiling of liquid helium producing temperature fluctuations in the film, prevents the accurate study of the excess noise below 10 kHz.

There are several reasons why we believe the observed excess noise is caused by a flux-flow mechanism. The peaking of the noise in the lower part of the transition region is characteristic of flux flow in type I superconductors. The existence of the parameter J_o is consistent with general flux-flow arguments describing the stability of the intermediate superconducting state. The observed noise spectrum with its $1/f$ dependence agrees with the flux-flow model which assumes that the flux bundles are stopped many times on their passage from one side of the film to the next. The magnitude of the observed noise is reasonably close to the predicted level. The lack of any other simple mechanism that could produce the observed noise characteristics supports our conclusion that flux-flow noise is being observed.

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