Suppression of superconductivity of a tin film by microwave radiation

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A decrease of the critical magnetic field of a superconducting tin film was observed following microwave irradiation. The effect does not reduce to a simple addition of the amplitude of the high-frequency field to the external constant field.

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Much attention is being paid presently to the investigation of the nonlinear action of microwave radiation on superconductors. The interest is due both to the practical significance of the result and to the successes of theoretical physics in this direction. We have investigated the impedance of superconducting films of tin sputtered on silicon and glass substrates, at a frequency 10^9 Hz in a magnetic field.

The absorbing cell was a helical resonator. The superconducting film was placed alongside the resonator and was separated from it by a copper screen with diaphragm (of 3 mm diameter), so that the action of the microwave field did not extend to the edges of the film. The strong concentration of the field in the helical resonators makes it possible to obtain microwave magnetic field amplitudes on the order of several dozen oersteds using a generator with approximate power 1 W. We investigated the dependence of the active part of the impedance on the magnetic field at various microwave-power levels. The experimental setup is described in Ref. 1. The high-frequency and constant magnetic fields were parallel and directed along the film surface. The investigations were performed at liquid-helium temperature, below the λ point, since the boiling of the helium lowers the sensitivity of the installation. The substrate with the film and the helical resonator were immersed in the gas. The films were evaporated in a vacuum of $(5\text{–}7)\times 10^{-6}$ Torr and were 600–1000 Å thick.

Figure 1 shows a typical plot of the active part of the impedance against the magnetic field. The parameter in Fig. 1 is the relative amplitude of the high-frequency field at the film. At low power levels, the curves correspond to a transition from the superconducting state to the normal state in a parallel field. From the form of these curves we can obtain the parallel critical field of the film. At a sufficiently high irradiation level, a characteristic change takes place in the shape of the impedance plot against the magnetic field. First, the field at which the impedance begins to grow from its value in the superconducting state decreases with increasing power. Second, a change takes place in the form of the transition of the impedance from the superconducting to the normal state. As seen from Fig. 1, the transition begins jumpwise, after which a sluggish change of the impedance takes place to the fully normal state. The magnetic field at which the impedance reaches the value of the normal film also decreases with increasing power, but this decrease is much weaker than the decrease of

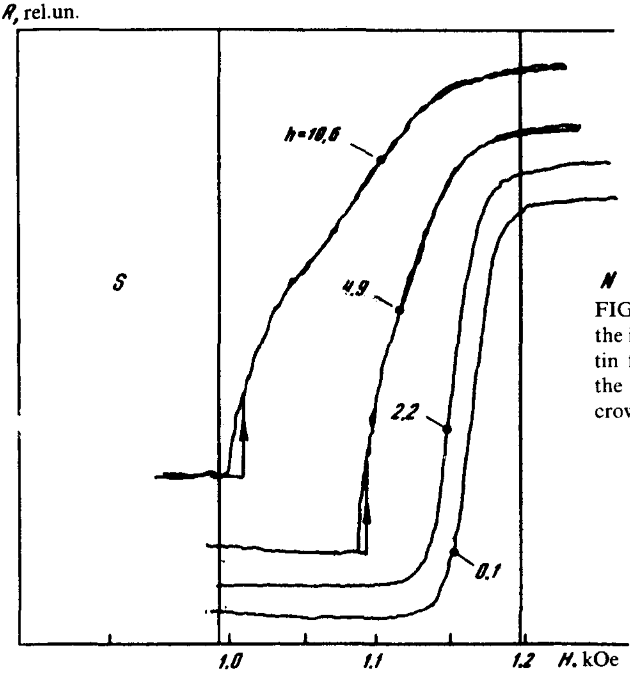

FIG. 1. Dependence of the active part of the impedance on the magnetic field for a tin film. The parameter on the curve is the relative amplitude of the applied microwave field.

the critical field. This indicates that the film was relatively little heated by the irradiation.

The dependence of the change of the critical field (of the magnetic field at which the impedance jump is observed) on the relative amplitude of the microwave field is shown in Fig. 2 for three values of the temperature. The dependence can be approxi-

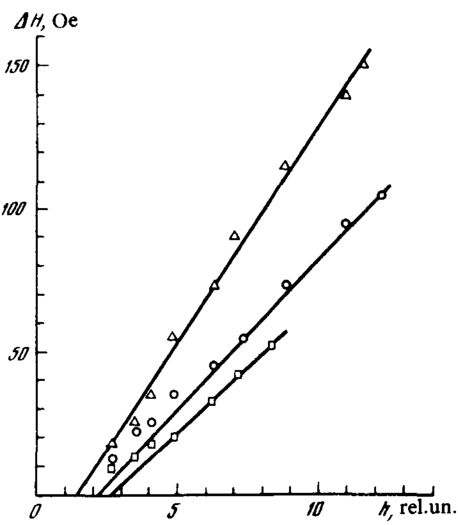

FIG. 2. Dependence of the change of the critical field of a tin film on the amplitude of the microfield at various temperatures: Δ—$T = 1.27$ K, ○—$T = 1.85$ K, □—$T = 2.14$ K.

mated by segments of straight lines that cross the abscissa at finite values. The change of the critical field is much larger than the amplitude of the microwave magnetic field (by an approximate factor of 10 at a temperature 1.3 K).

With increasing temperature, the influence of the microwave field on the transition of the tin films to the normal state in the investigated temperature region becomes weaker ($[\partial (\Delta H_c)/\partial h] \sim 1/T$). The described effect was observed in all the investigated tin films regardless of the substrate material, and also in aluminum films, which we are continuing to investigate.

The experimental results point to the existence of a mechanism of suppression of the film superconductivity by the microwave magnetic field. The behavior of the superconductors in the high-frequency field was investigated by Gor'kov and Éliashberg[2] using as an example superconductors with paramagnetic impurities. It was shown there that at sufficiently large microwave-field amplitudes an ambiguous solution is obtained for the equation for the energy gap, which becomes exponentially small at an amplitude above critical. The kinetics of this phenomenon was explained in a paper by Ivlev, Lisitsyn, and Éliashberg.[3] From the point of view of the experiment, this would correspond to the fact that an increase in the amplitudes of the microwave field would cause a jumplike change in the gap to a very small value. In Ref. 2, the effect was considered in the absence of an external constant magnetic field. The experiment was performed somewhat differently. At a constant irradiation power, the external magnetic field was varied and the change of the critical field at different irradiation levels was observed (Figs. 1 and 2). Therefore the primary result of the experiment can be the dependence of the critical amplitude on the magnetic field.

Following the jump in the impedance (in the stronger magnetic field), a certain new state is produced in the sample and can be traced on the plots of the impedance against the magnetic field (Fig. 1). According to Gor'kov and Éliashberg,[2] a state with the already mentioned exponentially small gap is established above the critical amplitude of the microwave field. We propose that in a magnetic field this state is not realized, i.e., the field should go over to the normal state. On the other hand, the normal state at these levels cannot be stable, since there is not enough power to heat the film to the critical temperature $T_{cr}(H)$, and the specific mechanism of the action of the irradiation on the superconductor is turned off. The result is thus a magnetic-field interval in which there can exist neither a pure superconducting nor a pure normal state, i.e., a certain mixed state can be produced. The structure of this state can be determined by the dependence of the suppression effect on the dimensions of the superconducting regions of the film. Such an analysis is convenient from the point of view of describing the experimental results, although there are no data that exclude the existence of a state with an exponentially small gap.

[1]S.A. Gorovkov and V.A. Tulin, Zh. Eksp. Teor. Fiz. **70**, 1044 (1976) [Sov. Phys. JETP **43**, 545 (1976)].
[2]L.P. Gor'kov and G.M. Éliashberg, Zh. Eksp. Teor. Fiz. **54**, 612 (1968) [Sov. Phys. JETP **27**, 328 (1968)].
[3]B.I. Ivlev, S.G. Lisitsyn, and G.M. Éliashberg, J. Low Temp. Phys. **10**, 449 (1973).