Phase separation of a homogeneous superconductor in a uhf radiation field

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It was observed experimentally that at a certain critical uhf radiation power a superconductor undergoes a transition at a temperature below T_c from a homogeneous nonequilibrium state to an inhomogeneous nonequilibrium resistive state, which is characterized by the formation and development of a regular N–S structure with increasing power.

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The phase separation of current in a homogeneous superconductor at a current greater than the critical[1] has been established and different aspects of this separation have been studied. Ivlev[2] examined theoretically the possibility of a transition of a homogeneous superconductor to a spatially inhomogeneous state in a uhf radiation field. In this paper we investigate experimentally such a possibility.

We investigated thin (~1000 Å), narrow (~1–2 μm) and long (~100 μm) tin samples similar to those which were described in Ref. 3. Figure 1 shows the current-voltage characteristics (IVC) of one of the samples, which are typical of our samples, for different uhf radiation power. First of all it can be seen that in the absence of radiation (−55 db) there is a good current separation whose length of the normal regions[4] is $L_n \approx 2\delta_E \approx 18\ \mu$m (the length of the sample is $L = 62\ \mu$m, $R_{4.2} = 4.2\ \Omega$). The critical current increases as a result of increasing the radiation power and the sample becomes more homogeneous with respect to the superconducting order parameter. At a power of 22 db the stimulation of superconductivity reaches a maximum and then decreases with further increase of the radiation power. The critical current then

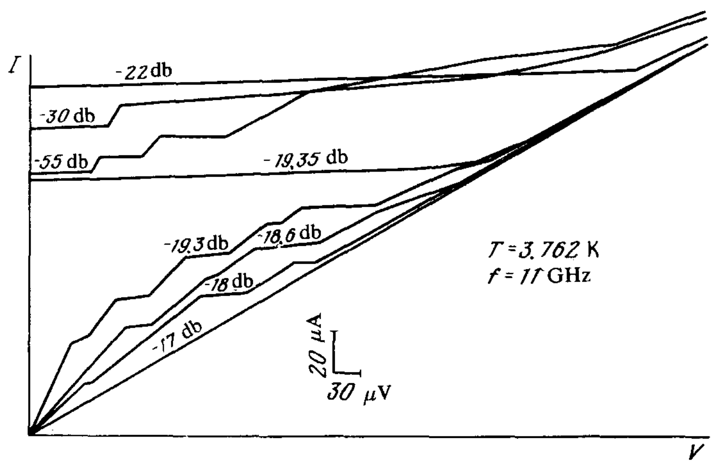

FIG. 1.

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vanishes abruptly in a very narrow power range (0.05 db at the 19.3 db level). The key point is that this is not a thermal collapse to the normal state. As seen in Fig. 1, the resistance of the sample in this new state, which is lower than that in the normal state, is $R_{g1} \approx 0.9\ \Omega$.

As the direct current increases in the sample, it develops a structure characteristic of the phase separation (there are five regions with a dynamic resistance which is approximately a multiple of $0.9\ \Omega$). At 18.6-db radiation power the sample abruptly changes its state in such a way that its resistance doubles to $1.8\ \Omega$ in the absence of a direct current. As the current increases, the spatial structure develops due to a multiple increase of the resistance of the sample by $0.9\ \Omega$. At $P = -18$ db the resistance of the sample at zero direct current is equal to $0.27\ \Omega$, i.e., it is triple that of the initially formed spatial structure of the sample. Subsequently, the sample goes normal at $P = -17$ db.

Thus, the superconductor goes normal in the uhf radiation field at a certain power P_2, whereas the resistance increases in it abruptly at a certain power P_1. This power is slightly larger than that at which the maximum stimulation of superconductivity occurs in the sample. At $P_1 \leqslant P \leqslant P_2$ the sample is in the resistive state, which is characterized by the formation and development of spatially inhomogeneous structure as a result of increasing P or I. The estimates of L_n in this case give the value $\approx 13\ \mu$m, which is noticeably smaller than that in the case of a current separation at $P = 0$. This difference may be attributable to the dynamics of development of the structure at $\omega \neq 0$, and in this case the time averaging of δ_E can be smaller. The determination of the connection between δ_E and the frequency of the current which excited the structure requires a special investigation.

In Ref. 2 the relative radiation power, at which the transition of the homogeneous superconductor to the spatially inhomogeneous state occurs, has the form

$$\frac{a_c}{\gamma} = \frac{14\zeta(3)}{\pi^2 f_0} \frac{\Delta^2}{\hbar \omega kT}, \tag{1}$$

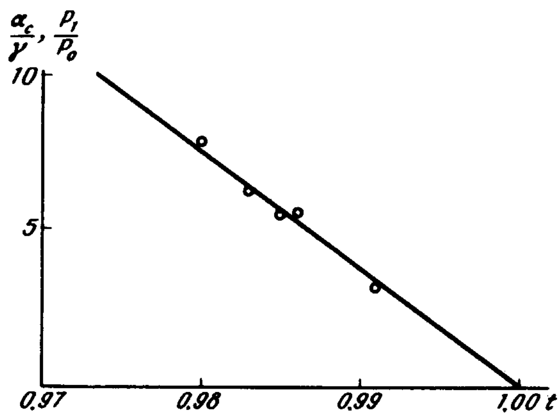

FIG. 2.

where $f_0 \sim 1$ and γ is the inverse time of the energy relaxation. At temperatures remote from T_c the temperature dependence $\Delta(T)$ is close to that of the equilibrium gap.[3] Thus the solid line in Fig. 2 represents the temperature dependence of α_c/γ. Figure 2 also shows the experimental values of P_1 plotted in relative units. The slope angles of these dependences are superimposed, because we measured the relative power level.

Since the experimental data are in good agreement with the theoretical predictions of Ivlev,[2] we can say that a systematic spatial structure, which is produced as a result of uhf radiation, has been identified experimentally in a homogeneous superconductor. In this connection, we should mention the results obtained by Latyshev and Nad',[5] who observed a steplike structure in the superconducting transition of a tin film induced by microwave radiation. An analysis of the temperature dependence of the power of the first step in the transition (see Fig. 1 in Ref. 5) at temperatures remote from T_c also gives a linear temperature dependence of the power.

It should be noted that, in the absence of stimulation of superconductivity, the transition to the resistive state occurs at $P_c \sim E_c^2 \sim \omega^2\, [E_c = \hbar\omega/(\sqrt{2})e\xi(T)]$,[6,7] and in the case of Eq. (1) $\alpha_c \sim \omega^{-1}$. Moreover, if the nonequilibrium value of Δ in Eq. (1) is taken into account (at least near T_c), we can expect the temperature dependence for P_c to be different from that for α_c in a sufficiently wide temperature range.

Thus, the transition of a homogeneous quasi one-dimensional superconductor to a spatially inhomogeneous resistive state, which is characterized by *N-S* separation, has characteristic frequency and temperature singularities which depend on whether the transition proceeds from a homogeneous equilibrium or nonequilibrium state under the action of external currents of different frequencies. These singularities require further investigation.

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