Relaxation phenomena at UHF in superconducting niobium films

M. E. Gershenzon and V. N. Gubankov
Institute of Radio Engineering and Electronics, USSR Academy of Sciences

(Submitted 3 January 1979)

Pis'ma Zh. Eksp. Teor. Fiz. **29**, No. 3, 189–192 (5 February 1979)

The processes of destruction of superconductivity in niobium films by UHF signals were investigated under the conditions of homogeneous Ginzburg-Landau phase transition and the relaxation time of the energy gap in niobium was calculated.

PACS numbers: 74.30.Gn, 74.70.Lp, 73.60.Ka

A number of theoretical works in recent years[1,3] have shown that the processes of relaxation of the energy gap magnitude Δ to its equilibrium value are dependent, for most superconductors, on the inelastic electron-phonon interaction with associated characteristic time $\tau_{e\text{-}ph}$. In the immediate vicinity of the critical temperature T_c ($T/T_c \gtrsim 0.98$) the relaxation time of the energy gap τ_Δ increases due to collective excitation as $T/\Delta\tau_{e\text{-}ph}$ when $T \to T_c$.[1,2] The basic experimental results[4] on In, Sn and Al pertain to this temperature region. At $T/T_c \lesssim 0.98$, τ_Δ should be determined by the relaxation

 0021-3640/79/030169-04$00.60

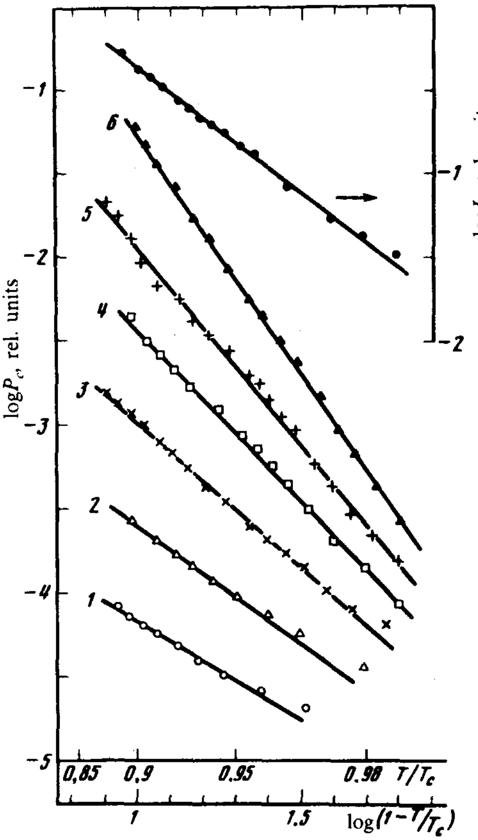

FIG. 1. Functions $P_c(T)$ and $I_c(T)$. UHF radiation frequencies in GHz: 1–23.3; 2–8.5; 3–7.5; 4–4.0; 5–2.56; 6–1.2.

times of quasi-particles which are practically independent of temperature in the interval $T/T_c \approx 0.8$–0.97, and are close to the value $\tau_{e\text{-}ph}$.[3]

In our work we report on the use of a new experimental method for the first determination of τ_Δ in niobium at $T/T_c = 0.87$–0.97, and we confirm the theoretical predictions concerning the weak temperature dependence of τ_Δ in this temperature range as well as smallness of $\tau_{e\text{-}ph}$ in Nb.[3]

The relaxation time τ_Δ was determined in the course of UHF current flow in a superconductor in which the homogeneous Ginzburg-Landau (G-L) phase transition occurs at currents with magnitudes near the critical current $I_c^{\rm GL}$. Current flow in a superconductor should slightly increase the value of τ_Δ such that for $I \approx I_c^{\rm GL}$, $\tau_\Delta(I_c^{\rm GL}) \approx 1.2\tau_\Delta$ $(I=0)$.[1] We measured the function $P_c(T)$ over the temperature range in question, where P_c is the critical UHF power that destroys superconductivity in a specimen with density of superconducting condensate homogeneous with respect to cross-section, and may be expressed as $P_c \sim (I - T/T_c)^k$, where $k = k(\omega)$. Determination of the frequency-dependent exponent k over a range of frequencies that includes the limiting cases $\omega\tau_\Delta \ll 1$ and $\omega\tau_\Delta \gg 1$ yields a value of τ_Δ.

We used narrow (width 1 μm) niobium films as specimens whose fabrication and

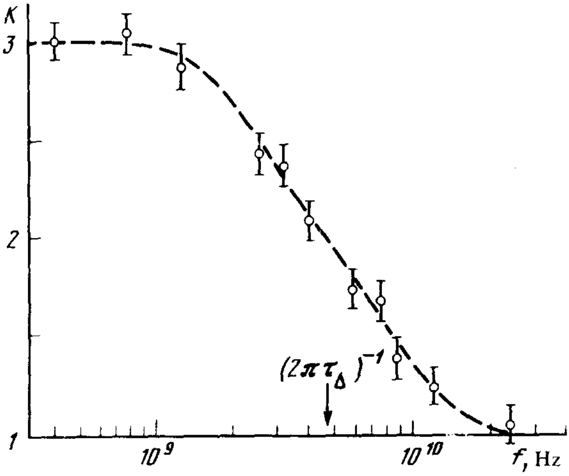

FIG. 2. Frequency dependence of k.

parameters are described elsewhere.[5] The selection of such narrow films was dictated by the requirements of condensate density stability over the cross-section and the absence of other relaxation mechanisms (for example, associated with the motion of vortexes). The parameters of a typical specimen are: width 1 μm, length 348 μm, thickness 520 Å, critical temperature 6.68 K, coherence length $\xi(0) = 86$ Å, effective depth of magnetic field penetration $\delta_\perp(0) = 0.52$ μm. The G-L phase transition currents were achieved in specimens not unlike these over a wide range of temperatures.[5] Sputtered on a sital substrate, the film was spliced into a narrow conductor that forms an asymmetric strip line which was connected by a coaxial-junction with a cable from a cryostat. This setup could be used for measurements over a broad range of frequencies. Temperature measurements were carried out by means of a germanium thermometer that was in good thermal contact with the specimen, and the bridge scheme was capable of temperature stability to within 0.01 K.

In this experiment we recorded the critical power P_c that corresponds to the onset of specimen transition to the normal state. Film resistance was measured by passing a small measuring current (~ 1 μA) through it. Figure 1 shows the functions $P_c(T)$ for different signal frequencies. At low frequencies ($f \lesssim 1$ GHz), the observed temperature dependence was $P_c(T) \sim I_c^2(T) \sim (I - T/T_c)^3$ which corresponds to the low-frequency limit. At higher frequencies ($f \gtrsim 25$ GHz), $P_c \sim (T - T/T_c)$ which was theoretically predicted for the case $\omega\tau_\Delta \gg 1$,[6] and experimentally observed in lead films.[7] In the intermediate frequency range, k varies smoothly $[P_c \sim (I - T/T_c)^k]$ as it is associated with transition from the case $\omega\tau_\Delta \ll 1$ to $\omega\tau_\Delta \gg 1$. The fact that in a broad range of frequencies $\log P_c \sim k \log(1 - T/T_c)$ at $T/T_c = 0.87$–0.97 confirms that τ_Δ exhibits a weak temperature dependence over this range, a result that is in agreement with theoretical predictions.[3] Figure 2 shows the dependence of k on the frequency. The midpoint of the transition shown as a dotted line corresponds to $\tau_\Delta = (3.3 \pm 0.2) \times 10^{-11}$ sec.

The value of τ_Δ measured in this manner may be used to determine the characteristic time of inelastic scattering of electrons by phonons $\tau_{e\text{-}ph}$ in niobium. At $T/T_c \approx 0.8$–0.98, the relationship $\tau_\Delta \approx \tau_{e\text{-}ph}$ should be satisfied.[2,3] The experimental values of τ_Δ are in a good agreement with the theoretical estimates of $\tau_{e\text{-}ph} = 3.6 \times 10^{-11}$ sec.[3]

Thus, these results confirm the correctness of theoretical assumptions concerning the weak temperature dependence of τ_Δ in the temperature range (0.87–0.97) T/T_c, and the fact that the relaxation times in niobium are an order of magnitude lower than in Sn and In. The latter is of interest from the standpoint of practical application of the G-L nonlinearity to the mixing and parametric amplification of UHF signals.[8]

In conclusion the authors thank A.F. Volkov, A.V. Zaĭtsev, and K.K. Likharev for useful discussions of results.

[1]A. Schmid, Phys. Rev. **186**, 420 (1969).
[2]A. Schmid and G. Schon, J. Low Temp. Phys. **20**, 207 (1975).
[3]S.B. Kaplan, C.C. Chi, D.N. Langenberg, J.J. Chang, S. Jafarey, and D.J. Scalapino, Phys. Rev. **B14**, 4854 (1976).
[4]J.R. Leibowitz, and M.S. Wilt, Phys. Rev. Lett. **38**, 1167 (1977); I. Schuller and K.E. Gray, ibid. **36**, 429 (1976); R.A. Peters and H. Meissner, ibid. **30**, 965 (1973).
[5]M.E. Gershenzon and V.N. Gubankov, Fiz. Tverd. Tela **21**, No. 3 (1979) [Sov. Phys. Solid State **21**, No. 3 (1979)].
[6]I.O. Kulik, Zh. Eksp. Teor. Fiz. **57**, 600 (1969).
[7]V.M. Dmitriev and G.E. Churilov, Fiz. Niz. Temp. **2**, 1215 (1976) [Sov. J. Low Temp. Phys. **2**, 596 (1976)].
[8]M.E. Gershenzon and V.N. Gubankov, Radiotekh, i elektr. **24**, 653 (1979).