# NONEQUILIBRIUM PHENOMENA IN SUPERCONDUCTING Al BRIDGES UNDER THE MICROWAVE RADIATION

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NONEQUILIBRIUM PHENOMENA IN SUPERCONDUCTING Aℓ BRIDGES UNDER THE MICROWAVE RADIATION

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Résumé.- On a fait une étude expérimentale du déplacement de la transition supraconductrice des ponts en pellicule d'aluminium sous l'effet de radiations UHF. On a trouvé que la température critique du pont peut être plus haute que celles des berges. Dans ce cas, à la frontière du pont et de la berge, apparaît une résistance additionnelle qui dépend de la température et qui peut être expliquée par une distribution hors d'équilibre des quasiparticules avec des branches non compensées.

Abstract.- The shift of the resistive transition of the Aℓ bridges under microwave radiation is investigated experimentally. It is found that $T_c$ of a bridge can exceed $T_c$ of banks. Under this condition the temperature dependent extra resistance due to a nonequilibrium quasiparticle distribution with branch imbalance appears at the interface between bridge and bank.

It is well known that the critical temperature of superconducting microbridges can be enhanced by microwave radiation. So far, however, the enhanced $T_c$ never exceeded $T_c$ of wide electrodes (banks) /1-3/. In short bridges this phenomenon may be associated with the dependence of the bridges' parameters on banks' properties, while in long bridges it may be prevented by the instability of nonequilibrium state induced by microwave radiation and heating effects /4-6/.

To reduce these impending factors we investigated the enhancement of $T_c$ by microwave radiation in narrow long Aℓ bridges. These bridges possess a long energy relaxation time and provide good heat transfer. The latter occurs because firstly aluminium films at $T \sim T_c$ are in superfluid helium and secondly because the heat transfer from the Aℓ film into the quartz substrate is high.

Long narrow Aℓ bridges (of length ~ 100 μ, width ~ 1 μ and thickness ~ 1000 Å) were evaporated at $10^{-6}$ torr into crystalline quartz substrates at 50°C. We used a.c. current of 0.1 μA at 1 kHz for measuring the resistance of a bridge. The frequency of incident radiation was 8.8 GHz. The temperature was measured with thermometer cut out from "Allen Bradley" resistor and calibrated in each temperature cycle. The absolute value of temperature was measured with an accuracy of ≈ 7 mK and the relative value ≈ 0.5 mK.

Figure 1 shows a set of resistive transitions R(T) at various levels of microwave power W. A slight change of the R(T) curve at $T_c^b$ = 1.267 K corresponds

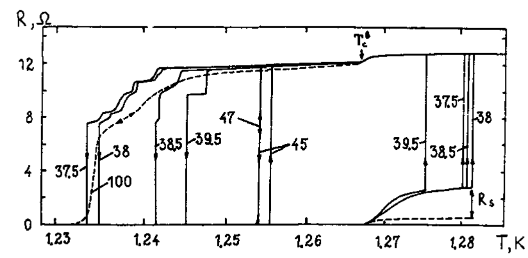


Fig. 1 : Resistive transitions of aluminium bridge at various levels of microwave power (in decibells). Dimensions of the bridge : 0.85 × 1 × 51 $\mu^3$.

to the transition of the banks to the superconducting state. The resistive transition of the bridge itslef in the absence of radiation (attenuation 100 dB) was rather wide and was observed at the temperatures lower than $T_c^b$. Under radiation of small powers (attenuation more than 40 dB) the resistive transition gradually shifts to the higher temperatures and becomes narrower up to the discontinuous jump (the curve at 47 dB). With further increase of W the enhancement of the transition from normal (N) to superconducting (S) state ceased (curve at 45 dB). Simultaneously resistive transition becomes hysteretic, i.e. transition S → N occurs at higher temperatures than N → S /4,7/. This hysteretic behaviour indicates the possible existence of a "superheated" superconducting state in a high frequency field. Approximately at these power levels (45 dB) N → S transition begins to move back to lower temperatures, whereas $T_c$ of $S \to N$ transition continues to increase, i.e. hysteresis extends. At these powers (39.5-37.5 dB) the step-like structure appears at $N \to S$ transitions, similar to the structure obtained in Sn bridges /4/, but $S \to N$ transitions are still discontinuous. The maximum enhancement of $T_c$ of $S \to N$ transition was reached at 38 dB and was equal to 48 mK (~4% of $T_c$), then $T_c$ of $S \to N$ transition also begins to decrease (37.5 dB).

One of the most interesting results is the following. At ~38 dB the critical temperature of the bridge $S \to N$ transition $T_c$ essentially exceeds (by 13 mK) the $T_c^b$, which as was shown, is not affected by radiation /4/. It should be noted that at the power levels 40-37 dB and $T_c^b < T < T_c$ the measured resistance is not equal to the banks' resistance as it could be expected. It is higher and it increases with the increase of the temperature. As a result the value of resistance jump at $T = T_c$ (w) is less than the resistance of the bridge itself (without banks).

We also investigated the bridge with the narrow part thinner (1200 Å) than the banks (3000 Å). Consequently $T_c$ without radiation was essentially higher (by ~200 mK) than $T_c^b$, i.e. at $T > T_c^b$ this bridge was the N-S-N system. Under radiation $T_c^b$ didn't change as usual and resistive transition curves were transformed in a similar way as in bridges of the constant thickness.

Our results concerning the change of the resistive transition of Aℓ bridges are similar to ones on Sn bridges /4/, where the interpretation of these phenomena was also proposed. Under radiation the critical temperature of Aℓ bridge, however, can be reached higher than $T_c^b$ in contrast to Sn bridge. It means that banks do not really effect on enhancement of superdonductivity in a long narrow channel. Microwave radiation doesn't simply alligne $T_c$ with $T_c^b$, but changes the internal properties of the bridge, first of all the quasiparticle distribution function, which leads to the enhancement of $T_c$, $I_c$ and $\Delta$/8/.

Nonequilibrium state under radiation was caused by the change of distribution function only in energy. The populations of the $p > p_F$ and $p < p_F$ branches of the quasiparticle excitations are conserved. However, at $T \gtrsim T_c^b$ the banks are already in N state while bridge is still in S state (curve 38 dB). In this case a.c. current of low frequency used in experiment, flows across a NS interface. This leads to branch imbalance, penetration of electric field from the normal banks into superconducting bridge over the length $\ell_b$ and leads consequently to the appearance of temperature dependent extra resistance of SN interface /9,10/. The jump of electric field caused by the Andreev reflection of quasiparticle also gives contribution to this resistance. Finally, the extra resistance of the NS interface is equal to /11/ :

$$R_s = R_n^{\square} \frac{\ell_b}{d} \frac{1}{1 + 0.68\ (\Delta/T)(\tau\ T)^{1/4}}$$

where $\ell_b = (\frac{\ell v_F}{3} \tau_\varepsilon \frac{4T}{\pi\Delta})^{1/2}$ , $V_F$ is the Fermi velocity, $\ell$ is the mean free path, $\tau_\varepsilon$- the excitation relaxation time, d is the width of the bridge. For our Aℓ bridges ($V_F = 1.3 \times 10^8$ cm/s., $\tau_\varepsilon = 5 \times 10^{-9}$ s. /7/, $\ell = 200$ Å) considering $\Delta = \frac{\omega}{2}$ near the jump to the N state /6/, we obtained $R_s \approx 6.3$ Ohm. If we also consider that in the region where the narrow (~1 μ) bridge transforms into the wide banks (~ $10^3$ μ) current density drops abruptly and if we introduce the appropriate correction $\sim(2\xi/d)^{1/2}$ the value of extra resistance should be equal to 3.8 Ohm. The experimental value at $T = T_c = 1.282$ K is equal to 2.3 Ohm. Taking into account the inaccuracy of numerical values (especially for $\tau_\varepsilon$ and nonequilibrium $\Delta$) agreement can be considered as satisfactory.

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## References

/1/ Dayem, A.H., Wiegand, J.J., Phys.Rev. 155 (1967) 419

/2/ Dmitriev, V.M., Hristenko, E.V., Trubitsyn, A.V., Mende F.F., Ukr. Fiz. Zh. 15 (1970) 1611

/3/ Latyshev, Yu.I., Nad', F.Ya., Sov. Phys. JETP 44 (1976) 1136

/4/ Latyshev , Yu.I., Nad', F.Ya., Pis'ma Zh. Eksp. Teor.Fiz. 26 (1977) 488

/5/ Ivlev, B.I., Pis'ma Zh. Eksp. Teor. Fiz. 72 (1977) 1197

/6/ Schmid, A., Phys. Rev. Lett. 38 (1977) 922

/7/ Klapwijk, T.M., Mooij, J.F., Physica B.81 (1976) 132

/8/ Eliashberg, G.M., JETP Lett. 11 (1970) 114

/9/ Pippard, A.B., Shepherd, J.G., Tindall, D.A., Proc. R. Soc. A 324 (1971) 17

/10/ Tinkham, M., Phys. Rev. B 6 (1972) 1747

/11/ Artemenko, S.N., Volkov, A.F., Zaitsev, A.V., J. Low Temp. Phys. 30 (1978) 487