SOVIET PHYSICS JETP VOLUME 36, NUMBER 3 MARCH, 1973

EFFECT OF AN ELECTROMAGNETIC FIELD ON POINT JOSEPHSON JUNCTIONS UNDER STRONG FLUCTUATION CONDITIONS

I. M. DMITRENKO, V. I. KARAMUSHKO and L. K. SNIGIREVA

Physico-technical Institute of Low Temperatures, Ukrainian Academy of Sciences

Submitted February 24, 1972

Zh. Eksp. Teor. Fiz. **63**, 981–984 (September, 1972)

The interaction between a point Josephson junction and a uhf field is studied experimentally for such junction resistances and temperatures that the fluctuations not only suppress the current at zero junction voltage but also the current steps on the volt-ampere characteristic induced by external radiation. Under these conditions, the current in excess of the "normal" current and the nonlinearity of the volt-ampere characteristic vary periodically with increase of uhf power. The dependence of the amplitude and period of the oscillations on the temperature and frequency of radiation corresponds qualitatively to the theoretical calculations.

IT has already been pointed out in the literature[1,2] that fluctuations which completely disrupt the current in Josephson junctions at zero voltage, leave unsuppressed the phenomena of the nonstationary Josephson effect in the form of current steps, which are either natural or induced by the external radiation, on the volt-ampere characteristics (VAC). With metallic point Josephson junctions, one can always choose the resistance and the junction temperature so that the binding energy of the superconductors is found to be so small that, on the one hand, fluctuation effects appear and, on the other, the dependence of the height of the current step on the amplitude of the uhf field is described by functions that are close to Bessel functions[3] (the anharmonicity of the alternating Josephson current is small[4,5]). The present paper reports the results of an experimental investigation of the effect of the uhf field on point (clamped) Josephson junctions under conditions of such a strong effect of the fluctuations that the phenomenon and the current steps in the VAC are suppressed.

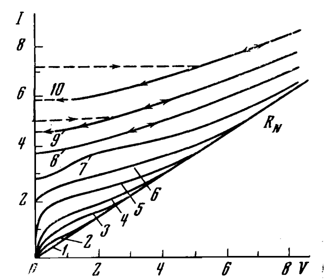

FIG. 1

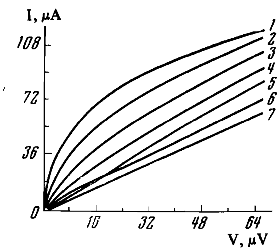

FIG. 2

FIG. 1. Modified VAC of a superconducting point junction, obtained upon lowering the temperature below critical in the absence of radiation (increasing number of the curve corresponds to decrease in the temperature). The current and the voltage are in arbitrary units).

FIG. 2. VAC of a superconducting point junction of the pair tantalum-tantalum for a temperature of 4.1°K for different levels of uhf power (in decibles): 1–53.2, 2–42, 3–38, 4–34, 5–25, 6–22, 7–10; $R_N = 0.9$ ohm.

1. EXPERIMENTAL RESULTS

Sufficiently resistive (0.1 ohm or more) point junctions at temperatures below the critical have nonlinear VAC, while the current in excess of the "normal" (which obviously determines the VAC) increases with decrease in the temperature (Fig. 1). For highly resistive junctions, at temperatures close to T_c, switching on of the uhf power does not lead to the phenomenon of a current step and only changes the value of the excess current and the nonlinearity of the VAC (Fig. 2).

The setup of the experiment was as follows. A clamped point junction, made by means of a special mechanism, was placed in a standard waveguide of the 3-cm band at a distance of a quarter wavelength from a short-circuiting piston. The VAC were recorded on a two-coordinate potentiometer at different temperatures and levels of uhf power applied to the junction. Junctions of tin-tin and tantalum-tantalum pairs were studied. The normal resistance of the junctions could be varied from several to 10^{-3} ohm.

For the junctions with highest resistance, the excess current decreases monotonically with increase in the uhf power for all voltages on the junction with the exception of the initial part near $V = 0$, where a periodic change in the initial slope of the VAC with increase in uhf power is observed. It should be noted that one can prepare junctions which, in the region of monotonic increase in the voltage under the influence of the uhf power, exhibit (for fixed values of the transport current) very high volt-watt sensitivity, reaching 10^2 V/W for a signal level of 10^{-7} W.[1)]

With increase in the binding energy of the junction, the region of periodic change in the excess current with the uhf power extends over a broad region of the VAC, exceeding $V_1 = \hbar\Omega/2e$ by severalfold (Ω is the frequency of the external irradiation). If the transport current is fixed, the oscillations of V(P) take the form shown in Fig. 3.

With decrease in the temperature, the oscillations increase in amplitude (with the period remaining practically unchanged) and shift in the direction of higher uhf powers. The period of oscillation as a function of the amplitude of the uhf radiation ($\sqrt{P}$) is a constant

1)This result was obtained in measurements made by Yu. G. Bevza.

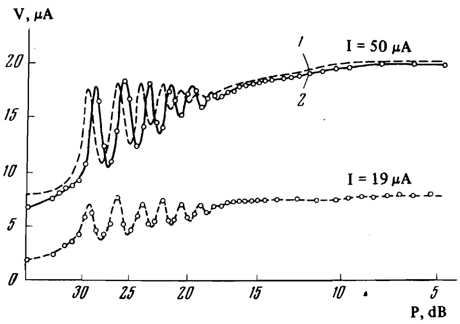

FIG. 3. Oscillations of the voltage on the junction for increase in uhf power and for fixed values of the transport current. With decrease in tempeature, the curves shift in the direction of higher powers (curve 1—3.98°K, curve 2—3.96°K).

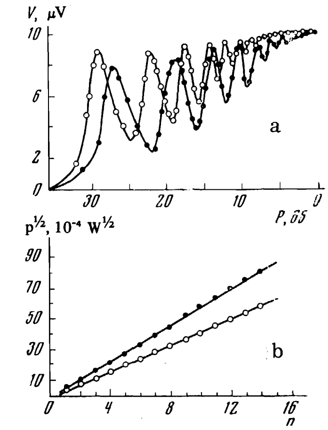

FIG. 4. a—Oscillations of the voltage on the junction with increase in uhf power for two frequencies: ○—10 MHz, ●—7.5 MHz (T = 3.7°K, R_N = 0.4 ohm, I = 25 μA, 0 dB corresponds to 166 μW); b—change in the period of oscillations with change in frequency; n—order number of the extrema of the oscillating curve V(P).

quantity and increases with increase in the frequency of the uhf field (Fig. 4).

With decrease in the resistance of the junction or with decrease in temperature, steeper current steps appear in the VAC upon irradiation. The oscillating portions of the VAC contract and remain only in the vicinity of the current steps. The null current and the height of the current steps also oscillate with increase in uhf power.[3] The oscillations of the portions of the VAC belonging to the steps are similar to Fig. 4 but take place in opposite phase. This situation refers however to the case in which the binding energy is larger or much larger than the fluctuation energy.

2. DISCUSSION OF RESULTS

A. Volt-ampere characteristics. Existing theories[6] do not completely describe the experimentally observed VAC of point Josephson junctions (Fig. 1), their dependence on the temperature and the resistance of the junction. The fluctuations determine the form of the VAC in essential fashion. Furthermore, the normal resistance of the junction to single-particle current, which enters into the equation of the total current, depends both on the temperature and on the current. Finally, the current in excess of "normal" (which determines the nonlinearity of the VAC) is the dc component of the alternating Josephson current and, consequently, is closely connected with the dependence of the phase on the time, i.e., with the spectral properties of the junctions. For a complete description of the VAC, account of the three factors just mentioned is necessary. Voltage jumps and hysteresis in the VAC appear earlier with decrease in temperature the lower the resistance of the junction, i.e., they are determined in the final analysis by the value of the critical current (binding energy). These jumps can probably be described as thermal processes which lead to the appearance of a declining portion on the VAC and, in circuits with given current, to the appearance of hysteresis.

B. Oscillations of the excess current. A numerical calculation of the form of the VAC of a Josephson junction with account of the fluctuating term in the equation of the total current and under the effect on the junction of the uhf field has been undertaken by I. O. Kulik and co-workers.[7] The results obtained by them contain solutions corresponding to oscillations of the initial slope of the VAC [$\rho = (d\overline{V}/dI)_{\overline{V}=0}$, the dynamic resistance]—as functions of the amplitude of the variable field v. The period of oscillations Δv is approximately equal to $\Delta v \approx \pi\hbar\Omega/2e$ and does not depend on the temperature as in the theory of Shapiro,[3] who considered the dependence of the null current and the height of the current step on the uhf power without account of fluctuations. With account of fluctuations, the exact form of the oscillations obtained by numerical calculation differs essentially from a Bessel function (Fig. 4 in[7]) and is close to the experimental curve (Fig. 3). The calculation was carried out under the assumption that the amplitude of the high-frequency current is given but not the voltage as in our experiments. In this connection, we can claim only qualitative agreement of the experiments with the work of[7]. The period of the oscillations is proportional to the frequency of the incident radiation Ω, is almost unchanged for $T \lesssim T_c$, and decreases somewhat for very low temperatures. The dependence of the amplitude of the oscillations on the temperature and the form of the curves also correspond qualitatively with the theory.

In conclusion, we express our gratitude to I. O. Kulik for discussion of the results and for making the contents of[7] known to us before its publication.

1 L. L. Vant-Hull and J. E. Mercereau, Phys. Rev. Lett. 17, 629 (1966).
2 I. M. Dmitrenko and Yu. G. Bevza, Fizika kond. sost. (Phys. of the Condensed State, Kharkov) 8, 86 (1970).
3 S. Shapiro, Phys. Rev. Lett. 11, 80 (1963); Rev. Mod. Phys. 36, 223 (1964).
4 I. M. Dmitrenko, Ukr. Fiz. Zh. 14, 439 (1969).
5 I. M. Dmitrenko, Doctoral Dissertation, Physicotechnical Institute of Low Temperatures, Ukrainian Academy of Sciences, Kharkov, 1970.
6 W. C. Stewart, Appl. Phys. Lett. 12, 277 (1968); D. E. McCumber, J. Appl. Phys. 39, 3113 (1968); L. G. Aslamazov and A. I. Larkin, ZhETF Pis. Red. 9, 150 (1969) [JETP Lett. 9, 87 (1969)]; P. A. Lee, J. Appl. Phys. 42, 325 (1971).
7 L. I. Kalashnik, A. M. Kislov, I. O. Kulik, E. M. Livshitz, K. V. Maslov and A. A. Motornaya, Zh. Tekhn. Fiz. 42, 1296 (1972) [Soviet Phys.-Tech. Phys. 17, 1029 (1973)].

Translated by R. T. Beyer
103