GENERATION AND DETECTION OF MICROWAVE RADIATION BY A SUPERCONDUCTING POINT CONTACT OF TIN ELECTRODES

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The nonlinearity of metallic point contacts at helium temperature was reported in [1,2]. However, the fact that the electrodes forming the contact were made of different materials (Ag and Bi in [1], Pt and Sn in [2]) made it impossible to identify with certainty the physical state and the chemical composition of the contact.

We report here an investigation of point contacts of electrodes made of very pure tin ($\rho_{300^\circ K}/\rho_{4.2^\circ K} \sim 10^5$). The contacts were produced in liquid helium by tin wires of 1 - 2 mm diameter, mechanically pointed on the end, touching the flat surface of a bulky tin sample. At the instant of contact, an electrically insulating oxide layer on the surface of the tin was broken down by a voltage of approximately 150 - 200 V through a resistance of 1 Meg. The resistance of the resultant contact was 0.1 - 0.01 ohm. The point contact was inside a coaxial resonator (Fig. 1) tuned to f_r = 9.2 GHz, so that the electrodes of the contact were wire 1 and the bottom 2 of the resonator (the resonator length was equal to microwave radiation wavelength).

Two phenomena were investigated: 1) the influence of external microwave radiation on the current-voltage characteristics of the contacts, and 2) microwave radiation from the volume of the contact when dc is made to flow through it. In the former case a klystron oscillator was connected to the input of one of the coaxial lines 4 coupled to the resonator, and in the latter a superheterodyne receiver for the 3 cm band (P-5-10) was used.

At a contact temperature $T < T_{cb}$ (the critical temperature of bulk tin was T_{cb} = 3.73°K), the results obtained agreed with those published in [3,4]. The behavior of the superconducting point contact is similar to the behavior of Jospheson tunnel junctions at $V \neq 0$. Exposure of such contacts to microwaves of frequency f leads to the appearance of steps on their current-voltage

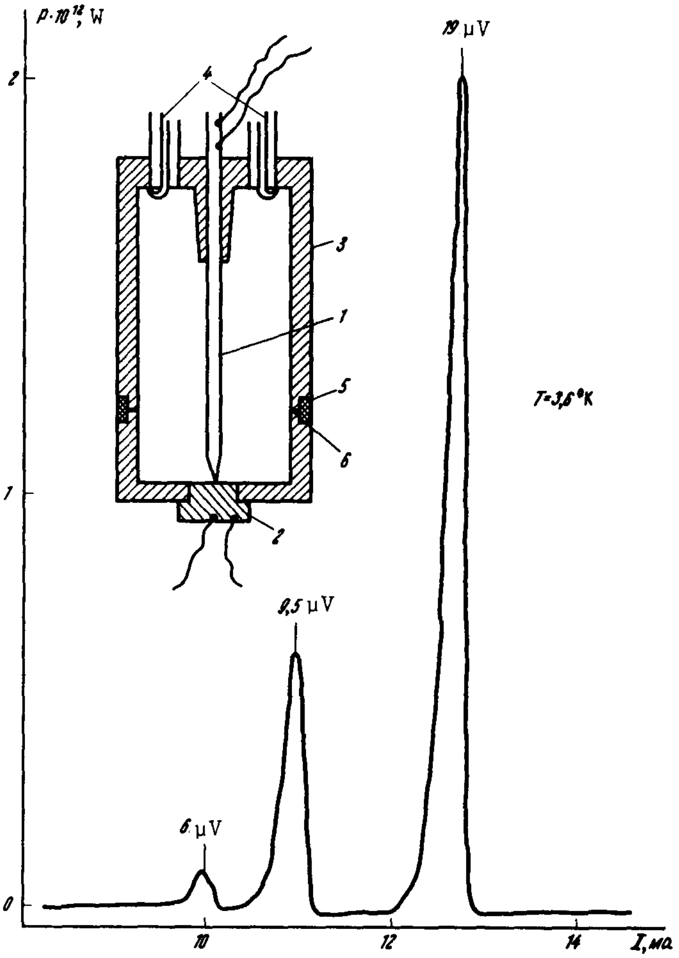

Fig. 1. Resonator arrangement: 1 - central tin wire, 2 - tin bottom of resonator, 3 - copper housing, 4 - coaxial lines, 5, 6 - insulating liners. Curve - record of radiation from Sn + Sn point contact.

characteristics at voltages

$$V = \frac{m}{n} \frac{h}{2e} f, \tag{1}$$

where e is the electron charge, h Planck's constant, and m and n integers.

When the superconducting point contact is at a step (1) of the characteristic, it acts as a sensitive detector of radiation at the corresponding frequency. The device with Sn + Sn contact described in [2] yielded, at T = 2.95°K, a video detection sensitivity of $\sim 10^{-12}$ W at a frequency f = 40 GHz. It was shown in [5] that a point contact of two superconductors can serve as a sensitive detector in the submillimeter band, too.

When direct current flows through the contact, such as to satisfy the condition

$$V = \frac{h}{2e} \cdot \frac{f_r}{n}, \tag{2}$$

microwave radiation is observed. Figure 1 shows a plot of the output signal of a receiver tuned to the fundamental resonator frequency f_r; in some cases up to 10 such peaks were observed - up to n = 10 - with decreasing amplitudes. This is evidence that the radiation from the contact has a high harmonic content. The maximum radiation power in our experiments reached $\sim 10^{-11}$ W with a current I ≈ 20 mA through the contact.

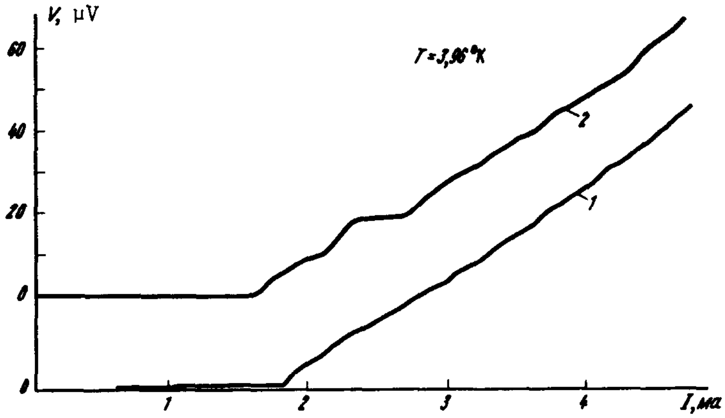

Fig. 2. Current-voltage characteristics of Sn + Sn point contact without (1) and with (2) microwave power ($\sim 10^{-7}$ W) incident on it.

We now turn to the investigation of the nonlinearity of the point-contact resistance, which was observed in [2] at $T > T_{cb}$. Curve 1 of Fig. 2 shows a typical V(I) plot for such a contact at T = 3.96°K. This plot has the same form as the curve representing the superconductivity destruction by current with R = 0 at I < 1.8 mA. The absence of such a clearly pronounced section with zero resistance from the characteristics of the contacts investigated in [1,2] is apparently due to the presence in these contacts of metals that exhibit no superconductivity (Ag and Bi in [1], Pt in [2]). Curve 2 of Fig. 2 was obtained with microwave power ($\sim 10^{7}$ W incident on the contact. The steps at voltages ∿20 and ∿10 W, satisfying Eq. (1) at f = 9.2 GHz and m/n = 1 and 1/2 are clearly seen.

Figure 3 shows a plot of the radiation of the same contact as in Figs 1. and 2, but at 3.96°K. The peak at V = 19 μV corresponds to a radiated power $\sim 10^{-13}$ W. As to the radiation observed at 30 μV and probably also at 42 μV, the following can be noted: The voltage measured in this region is apparently no longer equal to the voltage on the radiating section of the superconducting contact, and is equal to the sum of the latter with the voltage drop on the metal in the normal state. This explanation is corroborated by the fact that at $T < T_{cb}$, when the entire measured voltage drop is determined by the "resonant" state of the point contact, the radiation is observed only at the correct values of V (Fig. 1).

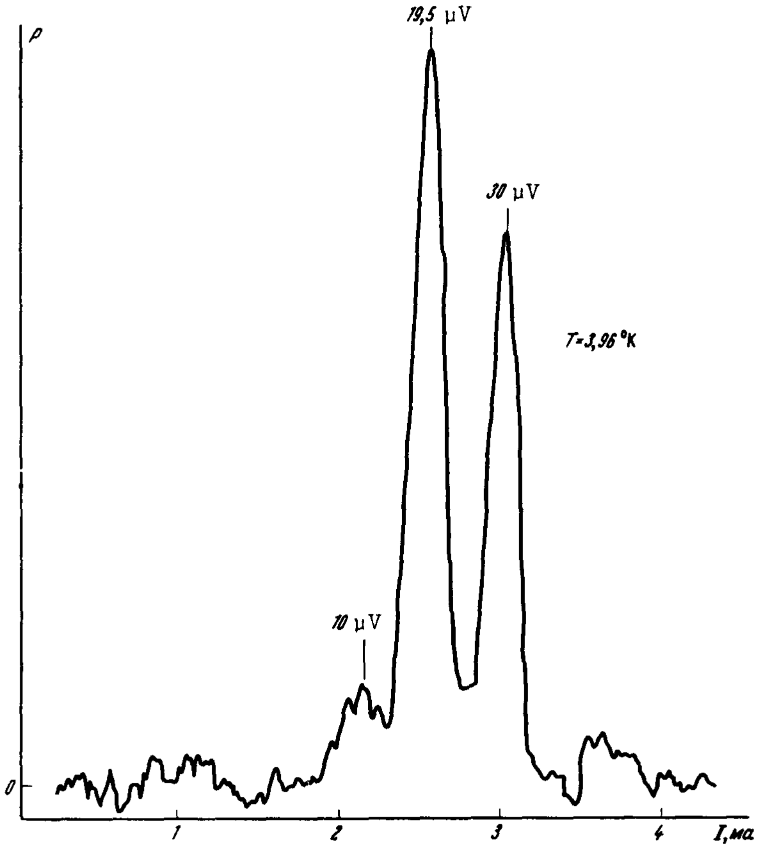

Fig. 3. Plot of radiation from Sn + Sn contact. The power radiated at V = 19.5 V amounts to $\sim 10^{-13}$ W.

The foregoing results of the investigation of point contacts at $T > T_{cb}$ show that such contacts are superconducting. The measurements have shown that their critical temperature is $T_v \approx 4.17°K$ and $dH_c/dT \approx 700$ Oe/°K at $T \approx T_c$.

The nonlinearity in the Pt + Sn contacts [2] can apparently likewise be attributed to their superconductivity, since control experiments have shown that these contacts radiate microwaves at

$$V = \frac{h}{2e} \frac{f_r}{2}$$

(no radiation was observed at $V = (h/2e)f_r$, since the current required to produce such a voltage drop transforms the contact to the normal state).

The occurrence of superconductivity in a point contact at $T > T_{cb}$ can probably be attributed to the strong deformation of the metal in the region of the contact, since the electric contact is produced by applying a destructive pressure on the metal and by breaking down the oxide with an electric discharge. As is well known, T_c may greatly exceed T_{cb}, for example, in the case of films condensed at low temperatures [6] or superconductors subjected to plastic deformation at low temperatures.

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[1] L. Esaki and P. J. Stiles, Phys. Rev. Lett. 15, 152 (1965).
[2] M. S. Khaikin and I. Ya. Krasnopolin, ZhETF Pis. Red. 4, 290 (1966), JETP Lett. 4, 196 (1966).
[3] A. H. Dayem and C. C. Grimes, Appl. Phys. Lett. 9, 47 (1966).
[4] J. E. Zimmerman, J. A. Cowen, and A. H. Silver, Appl. Phys. Lett. 9, 353 (1966).
[5] C. C. Grimes, P. L. Richards, and S. Shapiro, Phys. Rev. Lett. 17, 431 (1966).
[6] A. I. Shal'nikov, Zh. Eksp. Teor. Fiz. 10, 630 (1940); N. V. Zavaritskii and A. R. Yaroshenko, Paper at 10th Intern. Conf. on Low-temperature Physics, Moscow, 1966.
[7] V. I. Khotkevich and V. R. Golik, Zh. Eksp. Teor. Fiz. 20, 427 (1950).

GALVANOMAGNETIC PROPERTIES OF NIOBIUM SINGLE CRYSTALS

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The Fermi surfaces of a number of transition metals, including niobium, have not been thoroughly investigated as yet. The main reason is the difficulty is obtaining pure and sufficiently perfect single crystals of these metals. We measured the galvanomagnetic properties of niobium samples with resistance ratios $\alpha = \rho_{300^\circ K}/\rho_{4.2^\circ K}$ from 400 to 1000. The initial material were niobium single crystals obtained by zone melting in an electron-beam furnace. The single crystals were roasted after melting at 2200°C in an oxygen atmosphere and a pressure 10^{-4} mm Hg. They were then annealed for eight hours at 2200°C in a vacuum of $10^{-9} - 10^{-10}$ mm Hg. A mass-spectral analysis of the single crystals prepared in this manner revealed the presence of the impurities listed in the table. The samples were prepared by electric-spark cutting from the x-ray oriented single crystals. The samples usually measured 0.3 x 0.3 x 5 mm. They were etched in a mixture of hydrofluoric and nitric acid, after which current and potential leads, terminating in small drops of nickel, were attached to them.

Mass-spectral analysis of niobium

	Ta	Zr	W	Mo	Hf	Ti	Fe	Ni	Cu
C(10^{-4} at.%)	330	80	3	9	3	1	0,1	0,1	0.2

To prevent possible contamination during the welding of the potential leads, the samples were cut in such a way that small potential projections were provided at a distance of 1 mm from each end of the sample. The potential leads were then welded to these projections. The samples prepared in this manner were mounted either on a rotating holder located between the poles of permendur concentrators placed in a superconducting solenoid [1], or in the holder of a pulse