OBSERVATION OF JOSEPHSON GENERATION IN A Pb-I-Pb TUNNEL JUNCTION

A. A. Galkin and V. M. Svistunov
Donets Physico-technical Institute, Ukrainian Academy of Sciences
Submitted 24 March 1967
ZhETF Pis'ma 5, No. 11, 396-399 (1 June 1967)

According to Jospheson [1], the appearance of a finite voltage V across a tunnel junction should be accompanied by emission (or absorption) of photons of frequency $\omega = 2eV/\hbar$.

The authors of [2-4] have observed a steplike structure in the current-voltage characteristics of tunnel structures of the Sn-I-Sn and Pb-I-Pb type. Observation of a resonant maximum on the current-voltage characteristics of a Pb-I-Pb junction was reported in [5]. The appearance of the steps and the maximum could be explained [5-8] by relating them to excitation of resonant oscillations of electromagnetic waves in the region of the junction by the alternating superconducting current.

Direct experiments with samples of the Sn-I-Sn type [9-11] have shown that the appearance of steps is accompanied by microwave radiation.

We report in this letter observation of steps on the current-voltage characteristics and observation of generation in a tunnel junction of the Pb-I-Pb type.

Lead films approximately 1000 Å thick were sputtered in high vacuum ($\sim 10^{-6}$ Torr) on a glass substrate, forming a tunnel structure measuring 0.15 x 0.8 mm with specific tunnel resistivity of approximately 0.001 ohm-mm.

We used in the experiment a nonresonant connection of the tunnel junction to a waveguide, as described in [9, 12]. The film's 0.15 mm dimension was oriented along the wave propagation in the waveguide. A magnetic field produced by a small single-layer solenoid was directed in the same orientation. The sample and the solenoid were placed in a lead screen. The experiment was carried out at 4.2 and 3.4°K. The radiation was registered with a low-power meter for the 3-cm band (type P5-10(MISh-1)) connected directly to the waveguide.

Steps at $V_1 = 18.4$ μV and $V_2 = 36.8$ μV were observed at T = 4.2°K in a field of 8 Oe (Fig. 1). The voltage V_1 corresponded in this case to the lower edge of the receiver pass band, making it quite difficult to register the radiation at this step. Nonetheless, we were

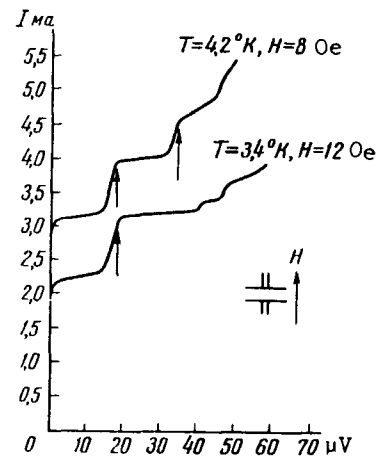

Fig. 1. Initial sections of current-voltage characteristics of Pb-I-Pb tunnel junction in different temperature and magnetic fields. The arrows indicate the voltages at which microwave generation sets in. Insert - configuration of junction and orientation of magnetic field. Junction size 0.15 x 0.8 mm.

successful in observing microwave power at the first step, and an even larger power at the second step (Fig. 2a). A slight change in the magnetic field caused the power to be observed only at V_2. This is evidently connected with the fact that in this case the equality of phase velocities [1-3] takes place for V_2, as a result of which the interaction of the electromagnetic wave with the alternating Josephson current is maximal, and the generation power is therefore also maximal. The resonant frequency to which the receiver was tuned was 8905 MHz. No generation was observed at other frequencies.

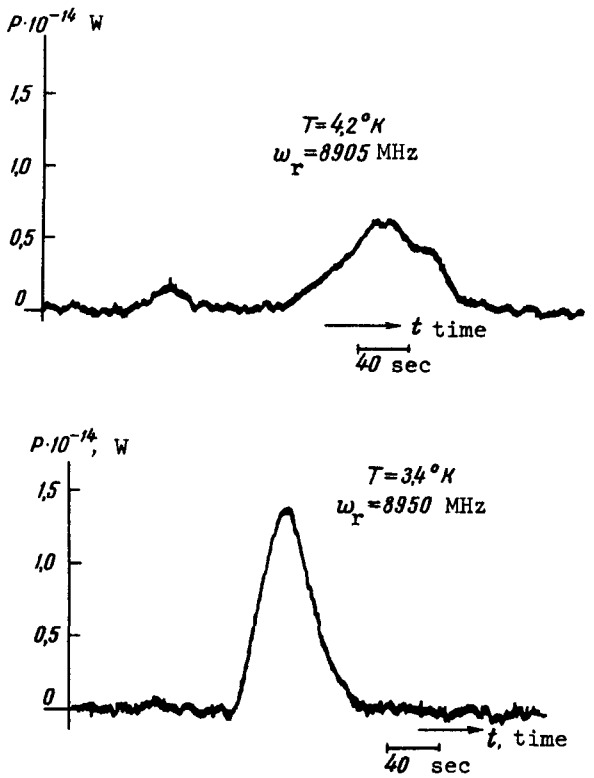

Fig. 2. Receiver output signal vs. time at slow chart speeds.* a) T = 4.2°K, H = 8 Oe, receiver resonant frequency ω_r = 8905 MHz; b) T = 3.4°K, H = 12 Oe, ω_r = 8950 MHz.

At T = 3.4°K and in a 12-Oe field, the edge of the first step on the V scale was somewhat higher: $18.4 < V_1 < 19.00$ μV (Fig. 1), and the finite slope of the step has made it possible to observe emission at the frequencies 8905, 8930, and 8950 MHz.

In this case, the receiver was tuned to a fixed frequency and the variation of the microwave power was traced as the junction current (and with it the voltage) was slowly increased or decreased. As already noted in [12], the radiation power increased with increasing frequency. Figure 2b shows the receiver output signal as a function of the time. The resonant tuning frequency was 8950 MHz and H = 12 Oe. This value of the magnetic field corresponded to the maximum power. No radiation was observed at other voltages.

Thus, direct observation of generation in a lead-dielectric-lead tunnel junction shows that the interaction between the alternating Josephson current and the electromagnetic field inside the junction is just as effective as for Sn-I-Sn junctions.

The authors thank Yu. M. Ivanchenko for useful discussions of the work.

[1] B. D. Josephson, Phys. Lett. 1, 251 (1962).
[2] M. D. Fiske, Revs. Modern Phys. 36, 221 (1964).
[3] I. K. Yanson, V. M. Svistunov, and I. M. Dmitrienko, JETP 47, 2091 (1964), Soviet Phys. JETP 20, 1404 (1965).
[4] T. I. Smith, Phys. Rev. Lett. 15, 460 (1965).
[5] R. E. Eck, D. J. Scalapino, and B. N. Taylor, Phys. Rev. Lett. 13, 15 (1964).
[6] D. D. Coon and M. D. Fiske, Phys. Rev. A138, 744 (1965).
[7] I. M. Dmitrienko, I. K. Yanson, and V. M. Svistunov, JETP Letters 2, 17 (1965), transl. p. 10.
[8] I. O. Kulik, ibid. 2, 134 (1965), transl. p. 84.
[9] I. K. Yanson, V. M. Svistunov, and I. M. Dmitrienko, JETP 48, 976 (1965), Soviet Phys. JETP 21, 650 (1965).
[10] I. Giaever, Phys. Rev. Lett. 14, 904 (1965).
[11] D. N. Langenberg, D. J. Scalapino, B. N. Taylor, and R. E. Eck, Phys. Rev. Lett. 15, 294 (1965).
[12] I. M. Dmitrienko and I. K. Yanson, JETP Letters 2, 242 (1965), transl. p. 154.

*The chart speeds used to obtain the current-voltage characteristics (Fig. 1) differ somewhat from one another, which naturally affects the P-t diagram.

ERRATA

Volume 5, No. 11

In the article by A. A. Galkin et al. (p. 324), the upper figure should be labeled "a" and the lower "b."

In the article by M. Ya. Azbel' et al. (p. 340, 10th line from top), replace "... in different regions:" by "...in different regions (see the figure):"