Weak superconducting ceramic link with $T_c \approx 90$ K in a microwave field

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A weak ceramic link with $T_c \approx 90$ K, which has the characteristics of a single Josephson junction in a 25–40-GHz microwave field, has been synthesized. At 77 K the weak link was found to respond to a microwave field up to 3.5×10^{12} Hz.

After the discovery of the Josephson effect "weak" superconductivity became one of the focal points of interest in superconductivity research because of the interest in the study of macroscopic quantum systems and because of the possibility of creating new devices. The main task in this problem is the establishment of a reliable Josephson junction.

The synthesis of high-temperature superconductors, primarily the Y-Ba-Cu-O composite with a stable critical temperature above 77 K—the boiling point of nitrogen— has raised the question of mastering the method of fabricating the Josephson junctions made from this material. The use of ceramic samples obtained by sintering them from the initial composition was found to be the most promising, since this method made it possible to establish a controllable superconducting coupling along the sample. Using ceramic bridges $\sim 10^{-2}$ cm^3, we were able to obtain stable links having the characteristics of an isolated Josephson junction in the interference circuit.[1]

It has been established previously that the characteristics of a ceramic are described well by a model of a superconducting glass consisting of many superconducting granules of the stock material, which are linked by Josephson junctions. A bombardment of various ceramic contacts with microwave radiation was known to cause an abrupt change in current typical of the Josephson junction, but the views were contradictory as to what parts of the contacts in the ceramic are responsible for the abrupt current change.[2–7]

To solve this problem, we studied bridges $\sim 10^{-2}$ cm^3 in dimension which were isolated from the interferometers with a persistent stability of the characteristics.[1] The *I-V* characteristics were measured by the four-contact method.

The critical current I_c of the six test samples was $5–50 \times 10^{-5}$ A at 77 K and increased to $3–300 \times 10^{-3}$ A at 4.2 K. The critical current was found to be a periodic function of the external field (Fig. 1a), allowing us to estimate the cross section of the superconducting quantizing loops: $\sim 10^{-6}$ cm^2, which is approximately equal to the cross section of the granules of the stock material.

Bombardment of the link with microwave radiation, $\omega = 25–40$ GHz, caused the current to change abruptly, over the entire range of measurement temperatures from

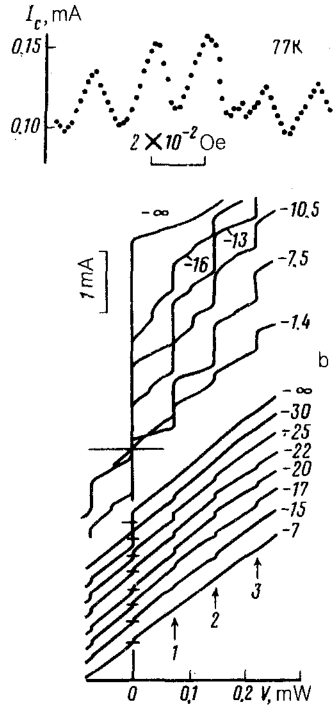

FIG. 1. (a) Critical current of the ceramic bridge versus the external magnetic field; (b) I-V characteristic of a weak ceramic link in a microwave field, $\omega = 35.5$ GHz. Labels on the curves—Attenuation of the microwave signal in dB. Top part—The trace recorded at 4.2 K; the bottom part—the curves obtained at 77 K. The origin of the curves (at $T \approx 77$ K), denoted by bars, has been shifted.

4.2 K to 77 K, on the I-V curves the voltages $V_n = n(h\omega/2e)$, where n is an integer (Fig. 1b). The value of V_n varies in direct proportion to ω. The calculated and experimentally determined values of V_n agree within the measurement accuracy, 3×10^{-4}. The value obtained by us confirms the assertion that pairs are responsible for the charge transfer in high-T_c superconductors.

Aside from the basic current steps at $V = V_n$, the I-V curves exhibit structural features at $V = V_{n/2}$ which are frequently observed in various types of Josephson junctions made of ordinary superconductors.[8]

The amplitude of the current steps depends essentially on the amplitude of the microwave field, whose curve differs markedly from the Bessel curve, because all the measurements were carried out under conditions in which the current was specified.[8] A comparison with the results of an analog calculation[9] for this case, represented by a solid curve in Fig. 2, shows a satisfactory agreement. For the test sample the dimensionless frequency is $\Omega = (h\omega/2eRI_c) \approx 2\times10^{-2}$. The experimental data were fitted to the calculation on the basis of a linear extrapolation of I_c from the amplitude A of the microwave field and on the basis of the fourth zero. A slight difference between the calculated and experimental curves, which occurs only at A < 0.4, could be due to the approximations used in the calculations.[9]

If up to twenty current steps could clearly be seen at 4.2 K, then at 77 K only 3–5 current steps were seen. Because of thermal fluctuations,[8] the current steps become diffuse when $\hbar I_c/2e \lesssim 5\ kT$, changing the slope of the I-V curve. These breaks in the

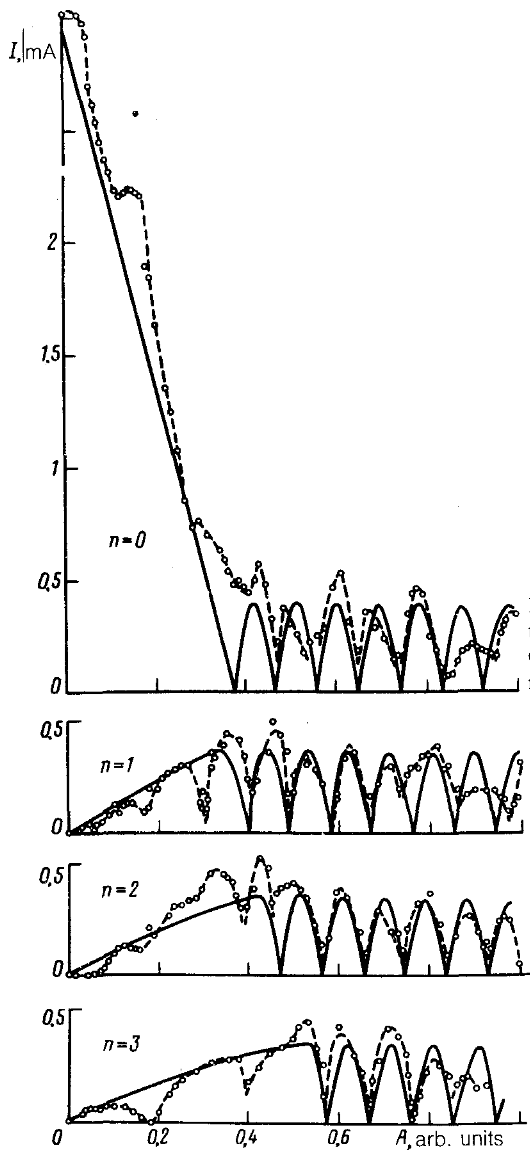

FIG. 2. The amplitude of the current steps versus the amplitude of the microwave field. Solid line—Calculation taken from Ref. 9; dashed line connects the experimental points.

curve are clearly seen on the dV/dI-V curves in Fig. 3. Using the modulation method, we could detect the induced microwave features on the dV/dI-V curves up to the hundredth step at an irradiation frequency of 35.5 GHz. Since very basic hardware was used to detect the signal and since there was no additional matching of the weak link to the waveguide channel, the frequency 3.5×10^{12} Hz which we obtained is in fact the lower bound of the frequency range in which this weak link could be used as a mixer or a radiation detector.

Our results show that the characteristics of the ceramic link which we are study-

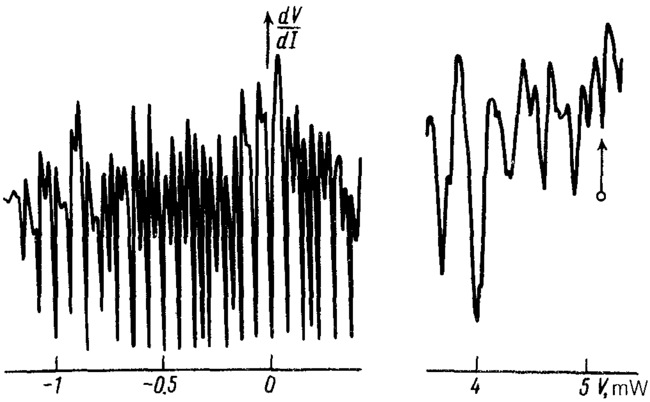

FIG. 3. Dependence of dV/dI on the voltage across the ceramic bridge when it is bombarded by microwave radiation at the frequency $\omega = 35.5$ GHz. On the left—A trace recorded at $T = 4.2$ K; on the right—a part of the trace recorded at 77 K (the position of the structural feature with $n = 70$ is indicated by the arrow).

ing do not differ substantially, in a microwave field or in an interference circuit, from the characteristics of an isolated Josephson junction such as the Dime bridge. At the same time, hundreds of superconducting granules of the stock material are found along the cross section of the ceramic link, but, as follows from the discussion above, only single granules among them are effective. Making use of the data on the critical current density of $YBa_2Cu_3O_7$ at 4.2 K, 10^7 A/cm^2 (Ref. 10), we find that a superconducting filament with an effective cross section of only 3×10^{-8}–3×10^{-10} cm^2, i.e., smaller than the granule size, can provide the required critical current for the weak link. We believe that a weak ceramic link can be created by chemically synthesizing a superconducting filament with a low-density lattice in a solid-phase reaction. Additional experimental studies of the thermal treatment of various samples have confirmed this assumption.

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