Quantum interference on Nb_3Sn film contacts at hydrogen temperatures

A. I. Golovashkin, I. S. Levchenko, A. N. Lykov, and
L. I. Makhashvili

P. N. Lebedev Physics Institute, USSR Academy of Sciences

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The properties of superconducting Nb_3Sn bridge contacts prepared by scraping sputtered films, were investigated experimentally. It is shown that the current-voltage characteristics of the contacts satisfy the parabolic law $V = C(I^2 - I_c^2)$, where I_c is the critical current. It is observed that $C \sim 1/I_c$. The velocity of the Abrikosov vortices in the contact is estimated. Nb_3Sn quantum interferometers operating at "hydrogen" temperatures were constructed. The temperature dependence of the properties of the interferometers was investigated.

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Superconducting bridge contacts, having properties of Josephson junctions, as well as superconducting circuits with such contacts connected in parallel, have been recently the subject of diligent research.[1–7] The bridge contacts of superconducting alloys with A15 lattice[8,9] have attracted attention because of the exceptionally high critical parameters of these alloys. In this paper we

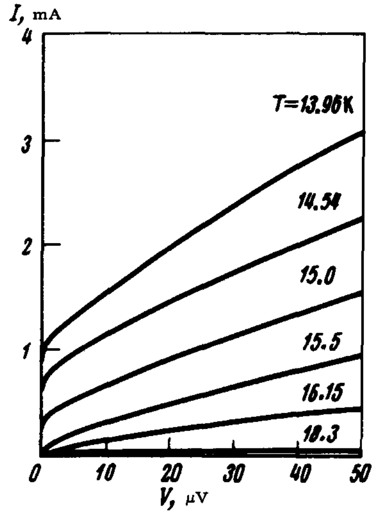

FIG. 1. Current-voltage characteristics of bridge contact of Nb_3Sn at different temperatures (T_c=17.6 °K). The measurement temperature is indicated next to each curve.

report a study of the properties of superconducting bridge contacts made of Nb_3Sn films, as well as circuits consisting of parallel bridges.

The superconducting Nb_3Sn films were prepared by simultaneously evaporating Nb and Sn from different evaporators in a vacuum 3×10^{-6}—8×10^{-6} mm Hg. The alloy was deposited on polished ruby substrates heated to 700—900 °C. Prior to the evaporation of the alloy components, a niobium layer was coated on the hot substrate, with a thickness 1000 Å. This niobium sublayer contributed to the formation of the alloy lattice, and served as a shunt in the electrical measurements. The rate of sputtering of the films was 20—30 A/sec. Immediately after the deposition, the films were annealed in a vacuum of 2×10^{-6} mm Hg at a temperature 900—1000 °C for 5—10 minutes and at a temperature 700—750 °C for several hours. The thickness of the employed films was in the range 5000—7000 Å. The temperature of the transition into the superconducting state was 17.6—18.1 °K and the width of the transition was ~0.2 °K.

The Nb_3Sn bridges were prepared by the scraping method.[4,7,9] The method consists essentially of cutting beforehand on the substrate one or several parallel grooves of the required dimension with a diamond cutter. After deposition, the film is cut again transversely to the grooves, so that only narrow conducting bridges remain to join the two parts of the film. We have prepared bridges 1—5 μ thick and 1—2 μ long, as well as superconducting quantum interferometers (SQI) of area 10—200 μ^2.

We investigated the current-voltage characteristics (CVC) and the voltage-field characteristics (VFC) of the contacts. The measurements were performed at temperatures 13.96—20.3 °K in liquid hydrogen. The magnetic field was produced with an external solenoid or a small coil placed in the cryostat near the sample. The temperature was determined from the vapor pressure of the hydrogen and with an Allen—Bradley thermometer in thermal contact with the copper holder of the samples.

Figure 1 shows a typical CVC of one of the samples at different tempera-

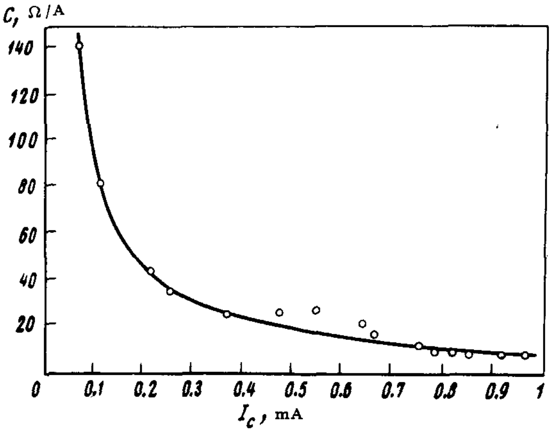

FIG. 2. Dependence of C on the critical current I_c for one of the contacts. The solid curve corresponds to the relation $C=r/I_c$, where $r=8\times10^{-3}$ ohms.

tures. The maximum temperature at which a finite current was observed on the CVC at a zero voltage was ~17 °K.

The CVC of the Nb_3Sn bridge contacts obtained in the present study differ substantially from the hyperbolic dependence[1] $V=R_n\sqrt{I^2-I_c^2}$, where R_n is the resistance of the contact in the normal state. This dependence is valid for narrow bridges with constriction dimensions $a \ll \xi$ (ξ is the coherence length). In our case owing to the smallness of ξ in Nb_3Sn (~100 Å), the inverse relation $a \gg \xi$ is satisfied. In contacts of this type the Josephson properties are due to the periodic motion of the Abrikosov vortices.[2,3] The voltage on the contact is produced in this case as a result of the dissipative character of the vortex motion. The theory[2,3] predicts that the CVC of such junctions at large currents is quadratic $V \sim I^2$. The indicated dependence is explained by the fact that the voltage on the contact is proportional to the total number of vortices in the contact (i.e., to the current) and is inversely proportional to the time of motion of the vortex through the contact, which is inversely proportional to the current.

The experimentally observed CVC of our Nb_3Sn contacts at $I \gtrsim I_c$ are described by the formula

$$V = C(I^2 - I_c^2)\,. \tag{1}$$

Owing to the presence of a parallel normal shunt, the real CVC are described more accurately by the expression

$$I = V/R + \sqrt{V/C + I_c^2}, \tag{2}$$

where R is the shunt resistance. Usually, however, R is large and the difference between the real CVC and the relation (1) came into play only at currents $I \gg I_c$. The experimental CVC were reduced by least squares with a computer. For all four CVC families obtained for the different contacts, the rms deviation of the experimental curves from the theoretical form did not exceed 1% in a wide range of currents. The dependence of the parameter C on I_c was analyzed for all the investigated contacts. It turned out that $C=r/I_c$, where the constant r is a

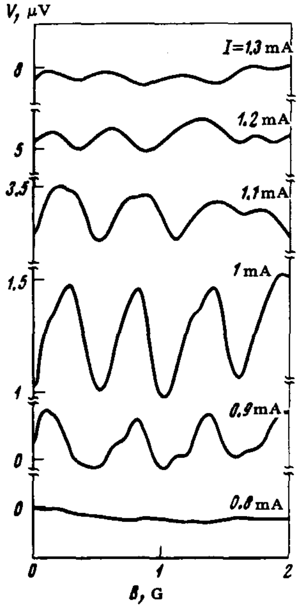

FIG. 3. Voltage-field characteristics of interferometer at 13.96 °K for different transport currents. (B is the magnetic induction and the current is marked on each curve.)

certain characteristic resistance. Figure 2 shows, for one of the samples, the dependence of C on the current I_c flowing through the contact at various temperatures.

Using the results of[2], we can estimate the different physical quantities connected with the motion of the vortices in our contacts. The time of motion of a pair of vortices through the contact is $t = (\pi^2/8)(\hbar/e)(a/\xi)^{1/2}/CI_c^2 \approx 10^{-9}$ sec at $I_c \approx 1$ mA. Here $2a$ is the width of the contact. The viscosity coefficient of the vortex motion is $\eta = (4/\pi)(\hbar/e)(I_c t/a^2) \approx 10^{-12}$ g/sec. Film bridges of Nb_3Sn were used to produce the SQI. Figure 3 shows the VFC of the interferometer for different transport currents at the hydrogen triple-point temperature 13.96 °K. (This temperature is convenient because of its stability). The lower curve ($I = 0.8$ mA) corresponds to a current smaller than the total critical current of the interferometer bridges. The next curve ($I = 0.9$ mA) pertains to the case $I \approx I_c$. The quantum interference of parallel Nb_3Sn bridges was observed by us up to a temperature ~16.5 °K. The amplitude of the oscillations decrease smoothly with increasing temperature. SQI made of Nb_3Sn are stable to electric load, their characteristics remain practically unchanged after many fillings, and can operate with solid hydrogen as the coolant.

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