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AC Josephson effect in Nb₃Sn thin-film bridges (*)

A. I. Golovashkin, A. N. Lykov, V. I. Novikov and B. G. Zhurkin

P. N. Lebedev Physical Institute of Academy of Sciences of USSR, Leninsky prospect, 53. Moscow, USSR

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Résumé. — On présente les résultats d'observations de l'effet Josephson non stationnaire dans des microponts à épaisseur variable de Nb₃Sn à la température de l'hydrogène liquide. Le courant critique et l'amplitude des premiers paliers induits sont étudiés en fonction de la puissance hyperfréquence. Les résultats obtenus correspondent à la théorie des tourbillons en mouvement dans les ponts supraconducteurs, ils mettent en évidence les avantages de l'utilisation d'alliages à haute température supraconductrice dans le domaine de la cryoélectronique.

Abstract. — The AC Josephson effect has been observed in Nb₃Sn variable thickness bridges, at liquid hydrogen temperatures. The microwave radiation power dependence of the critical current and the current steps height have been studied. The results are in agreement with a theory based on vortex motion in the superconducting thin-film bridges. We consider these results as indicating good prospects for the use of high temperature superconducting alloys in cryogenic electronics.

Interest in the properties of various superconducting structures which exhibit the Josephson effect is supported by the needs of cryogenic electronics and metrology [1]. Josephson junctions have some very specific desirable features and their applications are growing [2]. One of the most promising types of devices is the thin-film superconductor-constriction-superconductor junction, particularly those of the high-temperature superconductors.

The coherence length ξ in the most practical alloys with the A15 — type lattice is of the order of 30 Å [3], which makes it difficult to fabricate junctions with the constriction size less than ξ . Thus the Josephson properties of such thin-film bridges are associated with the periodic motion of the Josephson vortices inside the junction. It has been shown [4, 5] that quantum interference can be observed with Nb₃Sn junctions at liquid hydrogen temperatures. Previously on thin A15 film bridges some effects have been observed [4, 6] which were similar to the usual AC Josephson effect. But these effects were either observed in a low frequency microwave band [4], or the current steps on the I - V curves were irregular [6]. In the present work, we study the effect of the X-band microwave radiation upon Nb₃Sn junctions.

The superconducting Nb₃Sn films were fabricated by the simultaneous evaporation of Nb and Sn from the various sources in the vacuum chamber. The

metal vapours were condensed on a heated ruby substrate, the technology of which has been described in detail earlier [7]. The film thickness was in the range of 0.3-0.7 μm . Some features of the films have also been discussed earlier [5, 7]. For fabrication of the Josephson junctions we used the double-scratch method [5]. The junctions appear to be relatively wide variable thickness bridges (S-S'-S) : their width (1-5 μm) and length ($\sim 1 \mu\text{m}$) were both considerably larger than the coherence length of Nb₃Sn. The I - V curves of the junctions were measured in the temperature range 13-18.3 K using liquid hydrogen as a coolant. The temperature was measured with an Allen-Bradley carbon thermometer. For microwave measurements (frequency 9-10 GHz) the sample was mounted at the open edge of the wave-guide, the film plane being parallel to the narrow wall.

In the absence of microwave radiation the I - V curves had a parabolic shape [5], the critical current being equal to a few milliamperes. The temperature dependence of the critical current goes approximately as $(T_c - T)^{2.5}$. Typical I - V curves in the presence of microwave radiation are shown in figure 1 for a microwave power of about 50 mW. We can see the well-pronounced current step structure, typical for Josephson junctions; up to seven current steps could be easily observed. The positions of the steps on the V -axis satisfy the Josephson relationship $V_n = n\hbar\omega/2e$, where ω is the microwave frequency, $\hbar$ is Planck's constant, e is the electron charge and n is the step number. The current steps have been observed over a

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Fig. 1. — The I - V curves of a Nb_3Sn junction. The film thickness is $\sim 3\,000\text{ \AA}$.

wide temperature range (up to 16 K) and in a wide band of microwave powers. The presence of steps at the finite critical current in evidence for the coherent nature of the processes in the bridge. From our data, we can state that we observed such coherent phenomena in the Nb_3Sn thin-film bridges at the temperature of liquid hydrogen up to voltages 150-200 μV , which correspond to frequencies of 10^{11} Hz .

Subharmonic structure has been observed for the case of bridges with lower normal resistances [2], the current at voltages $V = n\hbar\omega/2me$ (where m is an integer) corresponds to that predicted by the theory for wide bridges [8, 9]. We note that the jump of the current at the voltage $V = \hbar\omega/4e$ could be as large as 60 % of height of the first current step at $V = \hbar\omega/2e$.

For some of the bridges, we studied the microwave power (P) dependence of the critical current I_c and of the current step heights. As the power increases, I_c decreases, depending approximately linearly as $\sqrt{P}$. We have not observed any oscillations in the microwave power dependence of the critical current and step heights. This is in agreement with the results of the theory [9, 10] of vortex motion in thin-film bridges of large size. Thus the observed AC Josephson effect can be identified with Abrikosov vortex motion. The inline character of this vortex motion is due to the large electromagnetic size of a vortex, which is comparable with the bridge constriction size. A model for analysis of the vortex interaction with an external field has been proposed in [10]. This model accounts for the current steps by synchronization of flux line motion with the applied field. The synchronization results from the possibility that the AC current phase changes in the moment of the flux appearance. It leads to a constant number of vortices which move

Fig. 2. — The I - V curves of a Nb_3Sn junction at different temperatures. The microwave power is $\sim 20\text{ mW}$ and the frequency is 9.58 GHz. The film thickness $\sim 7\,000\text{ \AA}$, (A) $T = 13.35\text{ K}$, (B) $T = 13.5\text{ K}$, (C) $T = 13.65\text{ K}$.

through the junction, and consequently to a constant voltage. The magnitude of the microwave induced step is twice the amplitude of the AC current. The nonlinear response of the flux line motion to the microwave excitation, due to pinning force at the microbridge edge, is an essential point of the theory [10]. This nonlinearity was taken into account by adding AC currents at frequencies 2ω , 3ω , ... to the AC current at frequency ω . This method account for current steps at voltages $\hbar\omega/e$, $3\hbar\omega/2e$, ... Thus numerically calculated I - V curves are in reasonable agreement with our experimental curves.

The results obtained here illustrate the possibility of high-temperature superconducting devices for cryogenic electronics and metrology with a temperature range of operation up to liquid hydrogen temperatures. The study of Josephson properties of other high-temperature superconductors is also of great interest.

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