Combined electrical breakdown of a dielectric nanolayer between thin film electrodes

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Electrical breakdown of a dielectric nanolayer between film electrodes under the combined action of direct current and capacitor discharge current makes it possible to form Josephson bridges with a reproducible resistance exceeding 1 Ω. A new feature of the formation of a bridge during electrical breakdown, which is preceded by a series of preliminary breakdowns (auto breakdowns) of a dielectric nanolayer, has been discovered. The mechanism of the process and the role of the thickness of the cathode film in the formation of the bridge are discussed.

1. Motivation

- the need for a simple technology for manufacturing a Josephson film contact [1],
- impact determination of the method of electrical breakdown of a dielectric nanolayer between two film electrodes on the resistance of the resulting Josephson contact in the form of a metal nanobridge.

2. Method for solving these problems

- The formation of a metal nanobridge was carried out as a result of electrical breakdown of a nanolayer of niobium oxide on the surface of a niobium film at a temperature of 300K. The oxide thickness was 30 nm. The combined effect on the resistance of nanobridges of a slow increase in voltage and capacitor discharge was studied [2]. The variable parameters of the discharge circuit were the value of the limiting and discharge resistances and the value of the capacitor capacitance.

3. Scheme of the experimental sample

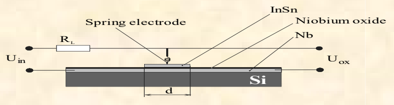

Fig.1. Schematic representation of the cross section of the experimental sample of the structure, consisting of the upper electrode in the form of a film disk with a diameter d from an indium-tin alloy, a layer of niobium oxide, and a lower electrode in the form of a niobium film on a silicon substrate.

4. Electrical diagram of oxide breakdown

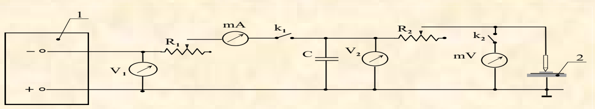

Fig. 2. Electrical circuit of the device for combined breakdown of niobium oxide.1 – constant voltage source, 2 – structure of InSn and Nb thin films separated by a niobium oxide, C – capacitor; K1, K2 – keys; R1, R2 – variable resistors; mA – milliammeter; V1, V2, mV - voltmeters and millivoltmeters

5. Results and their discussion

- Two features of the combined breakdown method have been established. The first of them is the dependence of the resistance of nanobridges (R_b) on the value of the discharge resistance in the electrical breakdown circuit. It has been shown that the resistance of nanobridges is a nonlinear function of the discharge resistance and makes it possible to obtain bridges with a reproducible resistance value of up to 8.5 Ohms. In this case, the calculated value of the critical bridge current at T=0K can be about 100 μA.
- The second feature is the dependence of the homogeneity of the cathode film on the magnitude of the discharge current of oxide breakdown. It has been established that at a breakdown current amplitude of 1A or more, the cathode film becomes visually inhomogeneous (**Fig. 4**). In this case, the breakdown process, instead of a one-time one, becomes periodically repeated up to 10 times within two seconds. Analysis of the phenomenon showed that this phenomenon of auto-breakdown is caused by the melting and destruction of the cathode film under the action of a high-density current at the breakdown point, followed by breakdown in the adjacent oxide section under the cathode spot. The period of the breakdown process is determined by the time constant for recharging the capacitor through the limiting resistance (about 0.2 s). The series of breakdowns ends after the formation of a bridge with a sufficiently low resistance, which bypasses further charging of the capacitor.

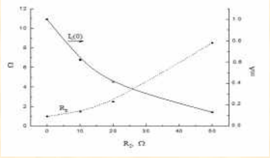

Fig.3. Dependencies of the value of the bridge resistance R_b and the calculated value of the critical current of the bridges on the value of the discharge resistance R_2 in the capacitor circuit.

Fig. 4. Appearance of a non-uniform cathode film (a bright spot with a diameter of about 0.5 mm) on niobium oxide after its combined breakdown in a circuit with a 180 μF capacitor and a limiting resistance of 1 kOhm with a discharge resistance of 10 Ohms.

Fig. 5. Appearance of a homogeneous cathode film (a bright spot with a diameter of about 0.5 mm) on niobium oxide after its combined breakdown in a circuit with a 180 μF capacitor with a discharge resistance of 20 Ohms and a limiting resistance of 1 kOhm.

The phenomenon of auto-breakdowns can be eliminated by increasing the discharge resistance. The cathode film remains homogeneous at a discharge resistance of 20 Ohms, which corresponds to a discharge current amplitude from the capacitor of 0.5A (**Fig. 5**).

References:

[1] S. I. Bondarenko, A. V. Krevsun, V. P. Koverya, A. G. Sivakov, R. S. Galushkov, *Low Temp. Phys.* 48, 741 (2022).https://doi.org/10.1063/10.0013310

[2] A. V. Krevsun, S. I. Bondarenko, V. P. Koverya, Low Temp. Phys. 49, 83 (2023).https://doi.org/10.1063/10.0016479