Unusual quantum magnetoresistance oscillations in the superconducting microstructure with a small loop

Vladimir I. Kuznetsov [a,1], Sergey. V. Dubonos [a], Aleksey. V. Nikulov [a], Viacheslav. A. Tulin [a]

[a] *Institute of Microelectronics Technology and High Purity Materials, Russian Academy of Sciences, 142432 Chernogolovka, Moscow Region, Russia*

Abstract

In order to verify a possibility of a dc voltage predicted on segments of an inhomogeneous superconducting loop the quantum voltage oscillations are investigated on symmetrical and asymmetric Al loops. The amplitude of the voltage oscillations ΔV measured on segments of symmetrical loop increases with the measuring current I_m and $\Delta V = 0$ at $I_m = 0$. Whereas the ΔV measured on segments of asymmetric loop has a maximum value at $I_m = 0$.

Key words: mesoscopic phase-coherent transport; quantum oscillations

The present work is devoted to the experimental verification of a theoretical result [1] according to which a dc voltage can be observed on segments of a inhomogeneous superconducting loop at $T \approx T_c$ without any external current. The value and sign of this dc voltage depend in a periodic way on a magnetic flux Φ within the loop $\overline{V_{os}}(\Phi/\Phi_0)$.

We used the mesoscopic Al structures, one of them is shown on Fig.1. These microstructures are prepared using an electron lithograph developed on the basis of a JEOL-840A electron scanning microscop. An electron beam of the lithograph was controlled by a PC, equipped with a software package for proximity effect correction "PROXY". The exposition was made at 25 kV and 30 pA. The resist was developed in MIBK: IPA = 1: 5, followed by the thermal deposition of a high-purity Al film 60 nm and lift-off in acetone. The substrates are Si wafers. The measurements are performed in a standard helium-4 cryostat allowing us to vary the temperature down to 1.2 K. The applied magnetic field, which is produced by a superconducting coil, never exceeded 35 Oe. The voltage variations down to 0.05 μV could be detected. We have investigated the dependencies of the dc voltage V on the magnetic flux $\Phi \approx BS$ of some round loops with a diameter 2r = 1, 2 and 4 μm and a linewidth w = 0.2 and 0.4 μm at the dc measuring current I_m and different temperature closed to T_c. Here B is the magnetic induction produced by the coil; $S = \pi r^2$ is the area of the loop. The sheet resistance of the loops was equal approximately 0.5 $\Omega/\diamond$ at 4.2 K, the resistance ratio $R(300K)/R(4.2K) \approx 2$ and the midpoint of the superconducting resistive transition $T_c \approx 1.24\ K$. All loops exhibited the anomalous features of the resistive dependencies on temperature and magnetic field. We assume that these features can be connected with big value of the Al superconducting coherence length which can exceed a structure size near T_c.

According to [1] the dc voltage can observed in a inhomogeneous loop. In order to investigate the influence of the heterogeneity of loop segments we made both symmetrical and asymmetric loops in each investigated structure (see Fig.1). Because of the additional potential contacts the higher and lower segments of the lower loop (on Fig.1) can have a different resistance at

[1] Corresponding author. Present address: Institute of Microelectronics Technology and High Purity Materials, Russian Academy of Sciences, 142432 Chernogolovka, Moscow Region, Russia, e-mail: kvi@ipmt-hpm.ac.ru

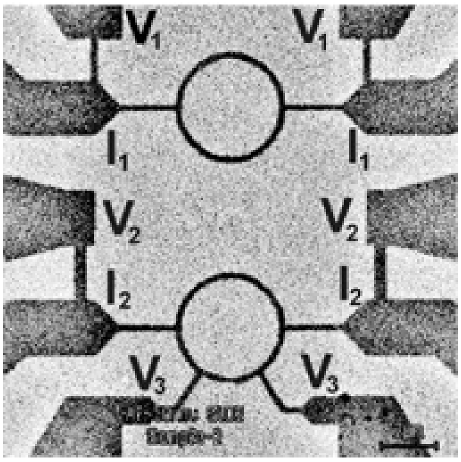

Fig. 1. An electron micrograph one of the aluminum loop samples. I_1 and V_1 are the current and potential contacts of the symmetrical loop. I_2 and V_2 are the current and potential contacts of the asymmetric loop. V_3 are the additional potential contacts of the asymmetric loop.

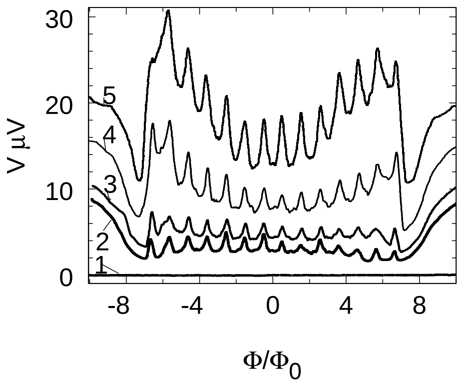

Fig. 2. The voltage oscillations measured on the V_1 contacts of the symmetrical loop with 2r = 4 μm and w = 0.2 μm at different I_m values between the I_1 contacts: 1 - I_m = 0.000 μA; 2 - I_m = 1.83 μA; 3 - I_m = 2.10 μA; 4 - I_m = 2.66 μA; 5 - I_m = 3.01 μA. $T = 1.231K$ is corresponded to the bottom of the resistive transition

$T \simeq T_c$ when the magnetic flux Φ contained within a loop is not divisible by the flux quantum $\Phi_0 = \pi\hbar c/e$, i.e. $\Phi \neq n\Phi_0$, whereas the one of the higher loop should have the same resistance if any accidental heterogeneity is absent.

The voltage oscillations measured on the V_1 contacts Fig.2 and on the V_2 contacts Fig.3 confirm qualitative difference between the symmetrical and asymmetric loops. In the first case the amplitude ΔV of the voltage oscillations increases with the measuring current I_m and the oscillations are not observed at $I_m = 0$. Whereas in the second case the greatest oscillations are observed at $I_m = 0$ and the ΔV value does not increase with the I_m, Fig.3. Not only the voltage value but also the sign of the voltage are changed with the

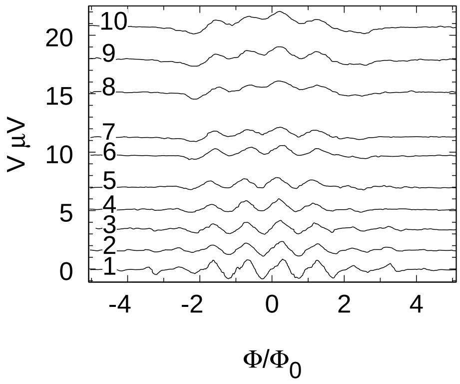

Fig. 3. The voltage oscillation measured on the V_2 contacts of the asymmetric loop with 2r = 4 μm and w = 0.4 μm at different value of the measuring current between the I_2 contacts: 1 - I_m = 0.000 μA; 2 - I_m = 0.29 μA; 3 - I_m = 0.65 μA; 4 - I_m = 0.93 μA; 5 - I_m = 1.29 μA; 6 - I_m = 1.79 μA; 7 - I_m = 2.06 μA; 8 - I_m = 2.82 μA; 9 - I_m = 3.34 μA; 10 - I_m = 3.85 μA. $T = 1.231K$ is corresponded to the bottom of the resistive transition

magnetic field at $I_m = 0$, Fig.3.

The anomalous behaviour, the downfall observed before the disappearance of the oscillation Fig.2, have been observed. In contrast to the classical LP [2] experiment no resistance but voltage oscillations are observed on the asymmetric loop: $V \approx V_{os}(\Phi/\Phi_0) + R_{nos}I_m$ Fig.3. The resistance R_{nos} depends faintly on I_m and on the magnetic field at low I_m Fig.3. At a high I_m value the negative magnetoresistance R_{nos} is observed Fig.3.

We can not state that the voltage oscillations observed in our work at $I_m = 0$ are induced in the equilibrium state although the power $W = \overline{V_{os}I_{sc}} \approx 2\ 10^{-13} Wt$ does not exceed the limit value $k_B T/\hbar \approx 10^{-12}$ [3] which can be induced by the thermal fluctuations. This switching can be induced by both the thermal fluctuations and an external electric noise.

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