TRANSPORT PROPERTIES OF NANOBRIDGES CREATED ON MOLYBDENUM CARBIDE SUPERCONDUTING THIN FILMS

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1. Introduction

Nowadays, highly disordered superconductors are being extensively investigated. Their large sheet resistance implies a large kinetic inductance [1], which can be used for precise detection [2] or quantum information processing [3,4]. Many interesting phenomena occur if the dimensions of the superconducting structures are smaller than the Ginzburg-Landau (GL) coherence length ξ and the London penetration depth λ. For example,the temperature dependence of the resistance (RT) of a nanowire decreases exponentially below the critical temperature T_c and saturates at a residual value. A temperature dependent resistance below $T_c$is associated with thermally activated phase slip (TAPS),whereas its saturation at $T<<T_c$ is ascribed to quantum phase slip (QPS) processes [5,6]. In TAPS process the superconductivity is suppresed stochastically at a random point along the wire due to the thermodynamic fluctuation, which leads to sudden change of the phase of the GL order parameter ψby2π. The superconductivity is temporarily suppressed in the volume $A\xi$ of the nanowire which costs the superconducting condensation energy $\Delta F=0.15H_c^2$(H_c is the critical magnetic field and A is the cross-section area of the wire). The energy should be provided by thermal fluctuations and therefore,the resistance decreases below T_c exponentially as $R_{TAPS}\propto e^{-\Delta F/kT}$, which implies a zero resistance at zero temperature. However, if the energy barrier is small,the barrier can be overcome by the quantum tunneling(QPS) process. The quantum tunneling is temperature independent and leads to a saturation of the resistance at finite residual value R_{QPS}.

The weak link in the nanowire can form phase slip centers (PSCs) [8], which were related to the local defects or imperfections in the nanobridge with smaller local critical current. If this current is exceeded by the excitation current, the superconductivity is locally suppressed, which implies a voltage drop in the wire. The presence of PSCs can be observed by measuring the discrete voltage steps in the current-voltage characteristics (I-V). This effect was observed in nanowires and whiskers made from pure superconductors (In, Sn, Ni) [8,9,10]. If the defects are not sufficiently strong the I-V characteristic exhibits hysteresis behavior [9].

In this paper, we present interesting results in RT and IV characteristics measured in nanobridges created on highly disordered superconductor MoC, which can be explained by above mentioned phenomena.

2. Sample preparation and measurement

The investigated nanobridges were prepared on 10nm MoC thin films deposited on sapphire substrate using d. c. magnetron sputtering from Mo target (*99.99%*, *50mm* in diameter) in Ar glow discharge andacetylene reactive gas as carbon source. All substrates were ultrasonically cleaned in acetone and isopropyl alcohol. The vacuum chamber was evacuated initially to a residual gas pressure of $4 \ x \ 10^{-5} Pa$. Subsequently, the substrates were heated to*500°C* for *60min* to remove water vapor from the surface. The Ar+ acetylene reactive atmosphere was maintained on *Ar/acetylene* ratio *~1:10*[11] by means of mass flow controllers during deposition. Substrates were biased negatively $U_s = -400V$. Working temperature of deposition was 200°C.

The 4 point probe measurement structures (Fig.1a) with defined geometry 10umx100um and one nanobridge at the center were patterned by electron lithography.

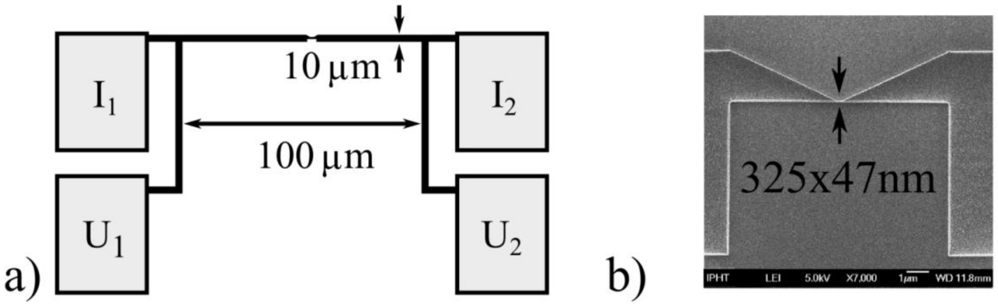

Fig. 1: *a) Scheme of the four probe measurement connected to a sample, b) SEM image of MoC nanobridge*

The measurement of the DC transport properties of the nanobridges werecarried out in an Oxford HelioxAC-V ^{3}He refrigerator at temperatures ranging down to 340 mK. The sample was wire-bonded to a printed circuit board sample holder with 50μm aluminum wires. The transmission properties were measured by four-probe technique with Keithley 6221 current source and Picolog ADC-24 24-bit precision data logger.

3. Results and discussion

At first the temperature dependence of the nanobridge resistance was measured (Fig. 2a) with 100 nA current, corresponding to current density of ~ 2×10^4 A/cm^2. The resistance of the nanobridge was found to slightly rise from room temperature value (R_{300K}=5570Ω), saturating at 11 K (R_{11K}=5840Ω) and at T_c=6K(see fig. 2).The sharp resistance drop corresponds to superconducting phase transition. However, the resistance of the nanobridge does not decrease to zero, as it is expected for bulk superconductor, but exponentially decays and at ~4 K reaches its minimum (R_{4K}=160Ω) and at lower temperatures slightly rises again. The exponential decay of the resistance could be explained either by thermally activated phase-slipor phase slip centers in the nanobridge [5,6], while the residual resistance of the nanobridge at temperatures well below T_c can be explained by quantum phase-slips (QPS), according to Giordano[13]. However, neither theory of these theories explains the resistance minimum at 4 K. Similar behavior was measured for 20nm Sn whiskers [7] and for granular In wire of 41 nm in diameter [12], but the origin of this phenomena is unexplained yet.

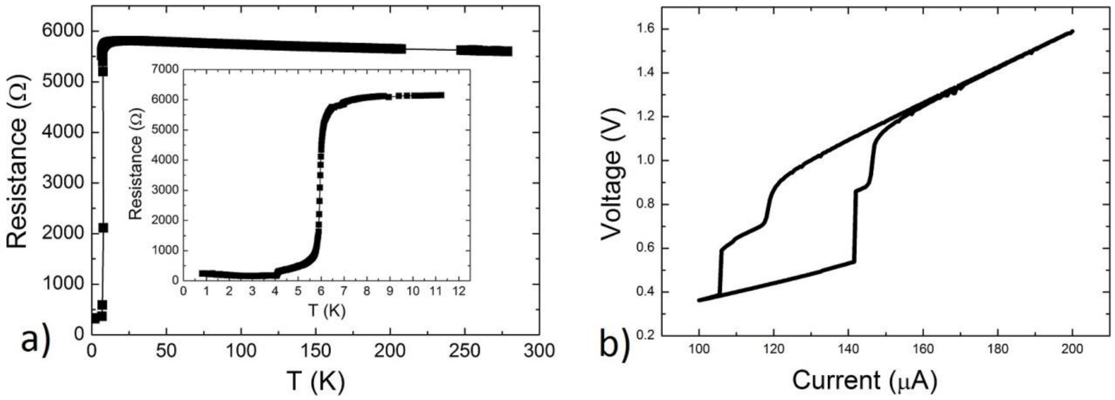

Fig. 2: *a) Temperature dependence of the nanowire resistance b) V-I characteristics at 3.5K with discrete voltage steps*

The I-V characteristics were measured at 3.5 K(Fig. 2 b). Discrete steps in voltage were observed corresponding to discrete values of resistance (Fig. 3a). Very similar steps were also measured in Sn whiskers [14] and associated with spatially localized “weak spots” or phase slip centers (PSCs) [15]. Moreover, the zoom of dependence close to zero current shows the saturation of resistance at the finite value of 180Ωat zero current (Fig 3b) in agreement with RT measurement.

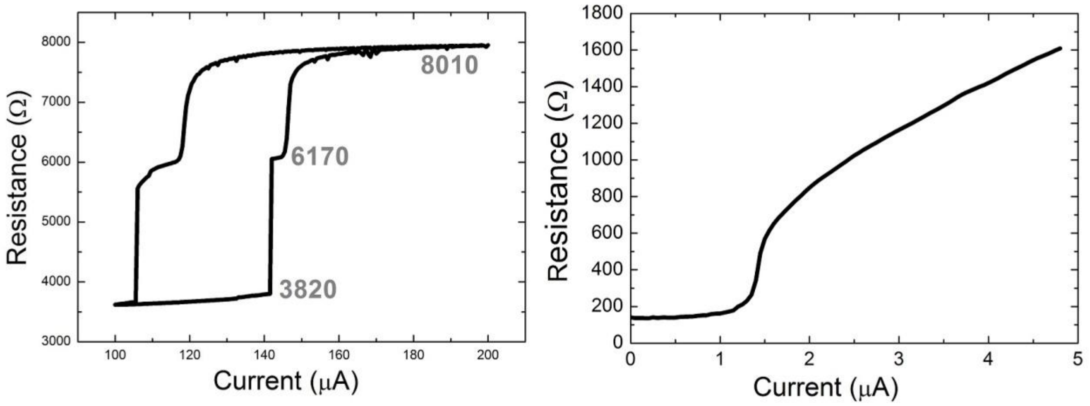

Fig. 3: *a) Discrete resistance steps recalculated from IV characteristics b) detailed zoom at saturated value at zero current*

Fig 2b) shows that the I-V characteristic exhibits hysteretic behavior which is theoretically predicted for PCS [16].

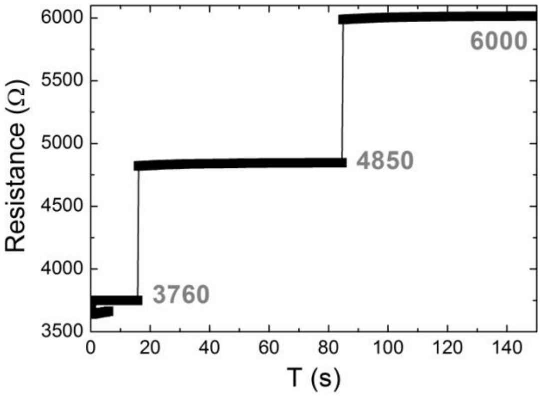

Fig. 4:*Discrete steps of the resistance in time caused probably by local heating of the sample*

Measuring the resistance of the nanobridge at 120 μA fixed current reveals instability of the resistance in time (Fig 4). The resistance of the nanobridge increases is two discrete steps up to 6000 Ω. Similar effects were observed, and argued to be the effect of local heating in the sample [8].

Conclusion

In summary, we have studied DC electrical transport properties of a 50 nm wide nanobridge patterned on 10nm MoC thin film. The nanobridge exhibits superconducting phase transition at 6 K, however, the resistance decreases exponentially with temperature and saturates at temperatures below 4 K, as possible consequence of the quantum fluctuations induced dissipation in low temperature regime. The I-V characteristics of the nanobridge exhibit discrete steps with hysteresis in the resistance. Similar effects caused by phase slip centers were observed in Sn and In nanowires.

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