Investigation of superconducting transition in the molybdenum-copper thin film structure showing the proximity phenomenon with the purpose of constructing TES bolometer

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Abstract. We are developing highly sensitive direct detectors based on Mo/Cu superconducting transition edge sensor (TES) for submillimeter radio astronomy and spectroscopy. Toward this end Mo/Cu bi-layers with different layers thickness values showing the superconducting transition in the temperature range ≈0.075 – 1.0 K have been experimentally tested. We have shown that the temperature of the superconducting transition edge can be adjusted because of proximity phenomenon by varying the thickness of Mo and Cu layers. We present details of measurements and fabrication of these devices.

For the purpose of equipping of radio telescopes for ground based, airborne and space based radio astronomical observation we are developing highly sensitive receivers based on direct detectors of sub-millimeter range [1, 2]. Use of transition edge sensor bolometer with ultra low (≈0.3-0.1 K) temperature of operation is one of the most promising way to achieve appropriate sensitivity and low time constant [3]. The transition edge sensor inserted into the center of planar antenna works as an absorber of incoming radiation and simultaneously as a signal detector. For signal read-out and amplification the SQUID's based circuits are used. The temperature of operation is set near the superconductor-normal metal transition edge temperature. A sensor is voltage biased to provide the electro-thermal feedback mode of operation with very low time constant [3].

Since it is very important to have temperature of superconducting transition edge in the range of stable operation of used refrigerator it has been proposed to use the superconductor-normal metal bi-layers [3] showing the proximity phenomenon [4]. Changing the thickness of superconductor and normal metal layers the temperature of superconducting transition edge of the bi-layer structure can be adjusted to the desired value. According to estimations [2, 3, 5] using this strategy the best ultimate sensitivity and fast response can be achieved simultaneously.

Toward this end Mo/Cu the bi-layers with different layers thickness values showing the superconducting transition in the temperature range ≈0.075 – 1.0 K have been experimentally tested. The sample fabrication procedure was as follows. Two layers of Mo and Cu were deposited successively on the polished silicon wafer of 24 × 15 mm^2 size and 430 μm thick, kept at ambient temperature, using the dc magnetron sputtering in

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argon atmosphere. The background pressure in a vacuum chamber prior to deposition was about 3×10^{-7} mbar. The argon working pressure was 6×10^{-3} mbar and 9×10^{-3} mbar during Mo and Cu deposition correspondingly. The deposition rate was 1.7 nm/sec for Mo and 0.9 nm/sec for Cu. The calibration has been done independently using specially deposited films measured by alpha step profilometer. Finally samples were cut into pieces of 24 × 1.5 mm^2 size to provide measurements.

Samples with the following Mo/Cu thickness values (nm) have been fabricated:

(1) 8/0, 8/30, 8/50, 8/100;
(2) 12/0, 12/30, 12/50, 12/100;
(3) 15/50, 25/50, 35/50, 50/50;
(4) 10/40, 15/35, 20/30, 30/20.

Dependencies of resistance versus temperature $R(T)$ have been measured in ^{3}He/^{4}He dilution refrigerator using four-probe method. The transition edge temperature of samples with Mo thickness 12 – 15 nm turned out to be the most sensitive to Cu thickness. Such samples have shown the transition edge temperature in the range ≈0.075 – 0.4 K, which is required for bolometer operation. Samples with thinner Mo layer haven't demonstrated the superconducting transition at all. $R(T)$ dependencies for Mo/Cu thickness values 15/35 and 12/100 (nm/nm) are shown on Fig.1 together with $R(T)$ dependence for pure Mo film of 12 nm thickness.

The effect of proximity is clearly seen from the Fig.1. The transition edge temperature decreases with thickening of the Cu layer, simultaneously the resistance of bi-layer structure getting smaller. The pure Mo film has shown transition temperature of ≈0.93 K,which is expected value for Mo.

The parameter $\alpha = T/R \cdot dR/dT$, which characterizes the abruptness of superconducting transition, has been estimated in the vicinity of the superconducting transition edge temperature (T_c) for three measured samples. It was found to be $\alpha \approx 1070$ for $T_c \approx$ 0.93 K, $\alpha \approx 150$ for $T_c \approx$ 0.4 K and $\alpha \approx 510$ for $T_c \approx$ 0.08 K. This parameter determines the speed response: the larger α the smaller response time of bolometer [3]. The value of α found in our measurements for $T_c \approx 0.08$ K and 0.4 K is about two times smaller in comparison with this value reported in [3] for similar bi-layer structure. Probably it can be explained by nonuniformity of our sputtered thin films.

Obtained results will provide the basis for subsequent developments of bolometer microcircuits with transition edge sensor of micrometer and sub-micrometer size.

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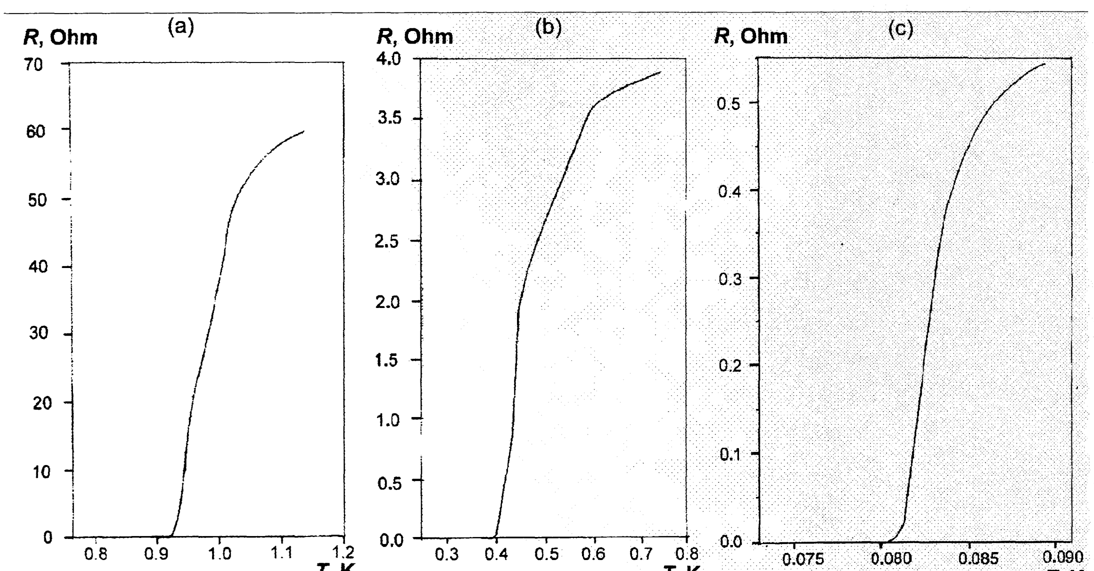

Fig.1 Dependencies $R(T)$ for three Mo/Cu samples of 24x1.5 mm^2 size with the following Mo and Cu thickness values (nm/nm): (a) 12/0, (b) 15/35 and (c) 12/100.