Digest of Tech. Papers The 12th Conf. on Solid State Devices, Tokyo

C-4-3

Nb weak links with three dimentional structure

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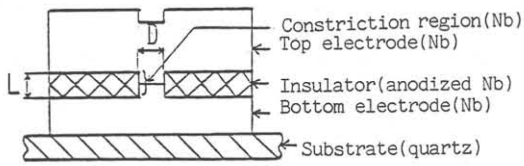
In recent years, three dimensional weak links attract attention because of their potential for high performance.[1,2] However, their features, to the authors' knowledge, have not yet been fully realized, owing to the severe requirement on constriction diameters. By employing anodization technique on Nb, we realized weak links with short and small diameter constriction between thick superconductor electrodes. The fabricated links were found to have wide temperature range for Josephson operation and large $I_C R_N$ product.

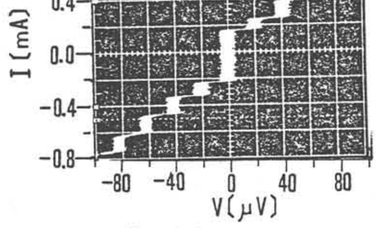
The configuration of the fabricated links is shown in Fig.1. All of the superconductor are Nb and top electrode is connected with bottom electrode through short constriction superconductor with small cross sectional dimension. We first deposited 400 nm-thick superconductor film onto a fused quartz substrate in a high vacuum of 1.3×10^{-6} Pa. The film was then patterned into 50 μm-wide bottom electrode by chemically etching. In next step, island pattern of resist was formed on the bottom electrode by photo or electron-beam lithography, and the electrode surface, except the part covered with the resist, was oxidized by anodization technique. The resulted insulator had high quality and scanning electron beam microscope observation showed that the layers with more than 20 nm thickness were free from pin holes. After removing the island shaped resist, the Nb surface was etched off by about 30 nm by using r.f. sputtering technique in order to remove possibly formed contaminated or oxidized layer. Without breaking the vacuum, 600 nm thick superconductor film was subsequently deposited and then patterned into 50 μm-wide top electrode.



D and L is constriction diameter and length, respectively.

Fig.1. The configuration of the weak links.

We made detailed experimental study on weak links with 0.3 to 2.0 μm constriction diameter and about 50 nm constriction length. The existence of Josephson super-current was checked by r.f. irradiation, that is, the links are judged to show Josephson effect when Shapiro steps are observed. Fig.2 shows typical I-V characteristics under 10 GH_Z r.f. irradiation.



D = 0.3 μm
$T/T_C = 0.7$

Fig.2. Typical I-V characteristics under 10 GH_Z r.f. irradiation.

Figure 3 shows the relation between the temperature range for Josephson operation and the constriction diameter D. For all weak links measured, the Josephson effect begins to be observed at about 8.2 K, which is 1 K lower than the critical temperature of electrode superconductor. For the links with 0.3 μm constriction diameter, Josephson effect was observed for temperature low as 3.6 K, which is the limit of our cooling capability. The smaller the constriction diameter, the wider is the temperature range for Josephson operation. Temperature dependence of $I_C R_N$ product, where I_C and R_N is the critical current and the normal resistance of the links, respectively, is shown in Fig.4. The dependences are linear for $T \lesssim 0.7\ T_C$ and exponential for $T \gtrsim 0.7\ T_C$, where T_C ($\simeq$ 8.2 K) is the critical temperature at which the supercurrent begins to be observed. The $I_C R_N$ product also tends to increase, as the constriction diameter is reduced. The $I_C R_N$ product and the critical current density for the link with 0.3 μm costriction diameter is estimated to be 2.6 mV and 1×10^{-6} A/cm^2 , respectively. Excess current ,which is thought to be peculiar to weak links,was observed. Excess current is about 0.4 I_C for $T \lesssim 0.7\ T_C$ and increases rapidly for $T \gtrsim 0.7\ T_C$. Judging from experimental results of temperature range for Josephson operation and $I_C R_N$ product temperature dependence, we think that the critical temperature of constriction superconductor is reduced because of Nb purity reduction and mechanical strain, and that the fabricated weak links have S - S′- S configuration.

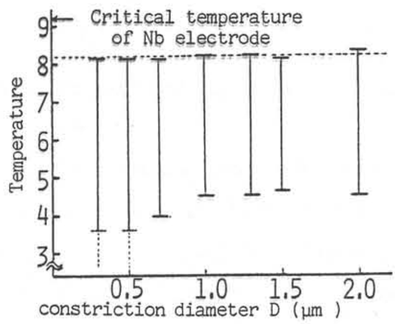


Fig.3. The relation between the temperature range for Josephson operation and the constriction diameter.

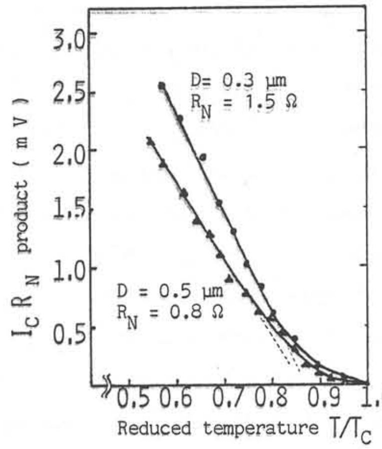


Fig.4. Temperature dependence of $I_C R_n$ product.

Although we have not made systematic measurements on stability, our weak links were mechanically stable for several times of liquid Helium - room temperature thermal cycling and almost no change in characteristics was observed after months of storage in room ambient condition.

The authors would like to thank T. Takeuchi and K. Koyabu for electron-beam lithography.

(References)

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