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Josephson Effect in As-Grown $Ba_2YCu_3O_x$ Thin Films on Y_2O_3/YSZ/Si(100)

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High-Tc superconducting $Ba_2YCu_3O_x$ microbridges have been fabricated on silicon substrates patterned with trench, with Y_2O_3/YSZ buffer layers. The bridge are 4-10μm wide and 0.8μm long. The critical current density of the microbridges are more than 10^6A/cm^2 at 70K which is nearly equal to the one of bulk samples on Y_2O_3/YSZ/Si. The temperature dependence of J_c is found to be proportional to $(1-t)^{3/2}$ near Tc (t=T/Tc). These results are consistent with Aslamazov and Larkin's theory qualitatively.

1. INTRODUCTION

A number of more or less successful attempts were begun to develop superconducting devices from high-Tc superconducting oxides based on Josephson junction technology. In previous papers,[1] we reported on the successful fabrication of the superconducting microbridge junctions made by epitaxial $Ba_2YCu_3O_x$ thin films on YSZ/Si(100), using the silicon substrates patterned with the trench. These microbridge junctions behaved as Josephson junctions and microwave-induced steps were observed.

Josephson behavior of microbridges depends on the constriction size A compared with the coherence length ξ. In a wide bridge ($A \gg \xi$), the Josephson effects are predicted by the periodic motion of quantum vortices at the narrow region of the bridge. Our bridges have a width of about 4-10μm and thus are operating as wide bridges.

As-grown $Ba_2YCu_3O_x$ thin films on Y_2O_3/YSZ/Si(100) have a $T_{c(end)}$ of about 85K and a critical current density of 10^6A/cm^2 at 77K,[2] which is two orders larger than that of $Ba_2YCu_3O_x$ thin films on YSZ/Si(100). In the wide superconducting bridges made by $Ba_2YCu_3O_x$ thin films on Y_2O_3/YSZ/Si(100), it is expected that more clear Josephson behaviors are observed.

In this paper, we report I-V characteristics in the wide superconducting bridges made by as-grown $Ba_2YCu_3O_x$ thin films on Y_2O_3/YSZ/Si(100), compared with Aslamazov and Larkin's theory for the wide superconducting bridges.[3]

2. EXPERIMENTAL

The main steps in the fabrication process of superconducting microbridge junctions are described in Fig. 1. The Si substrate was patterned with a 3μm-deep trench by the established VLSI technology (a). Then, YSZ (9mol% Y_2O_3) and Y_2O_3 buffer layers were deposited sequentially on the patterned Si(100) substrate by electron beam evaporation (b), and finally, the $Ba_2YCu_3O_x$ thin film was deposited by rf magnetron sputtering (c). The thicknesses of the buffer layer and the $Ba_2YCu_3O_x$ films were typically 50-100nm (Y_2O_3:10nm, YSZ:40-90nm) and 40nm, respectively.

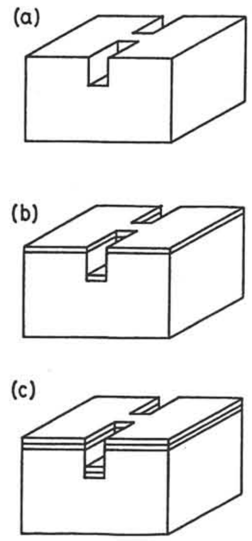

Fig. 1. Main steps in the fabrication process of the microbridge junction on a Si substrate patterned with the trench.

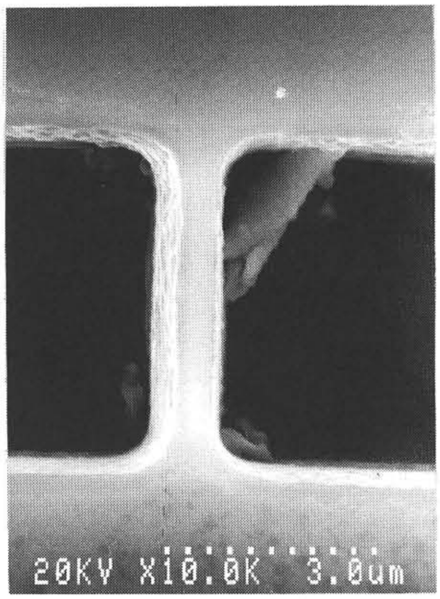

Fig. 2. Scanning electron micrograph of an obtained superconducting microbridge with L=5μm and W=0.8μm.

The I-V characteristics of the microbridge junctions were measured by the conventional four-probe method with dc current. The samples were cooled down in a cryostat with a mechanical compressor (Cryo Mini model D310). Microwaves with frequencies of 8-12GHz were generated by a reflex klystron and fed to the sample in the cryostat via an attenuator, waveguide and coaxial cable.

3. RESULTS AND DISCUSSION

Figure 2 shows a scanning electron micrograph of an obtained superconducting microbridge junction on a Si substrate patterned with the trench. The length L and width W of the microbridge in this micrograph are 5 μm and 0.8 μm, respectively. Resistivity between devices separated by the trench was several MΩ, and the isolation between devices by the trench was almost complete.

Figure 3 shows the I-V characteristic of the microbridges whose constriction sizes were L=0.8 μm and W=10 μm. Aslamazov and Larkin[3)] showed that for currents $I \lesssim 2I_c$, $V \propto (I-I_c)$ and for currents $I \gtrsim 2I_c$, $V \propto (I-I_c)^2$, which agree with our result for $Ba_2YCu_3O_x$ wide bridges on YSZ/Si. In present case, the nearly linear I-V characteristics ($V \propto (I-I_c)$) were observed.

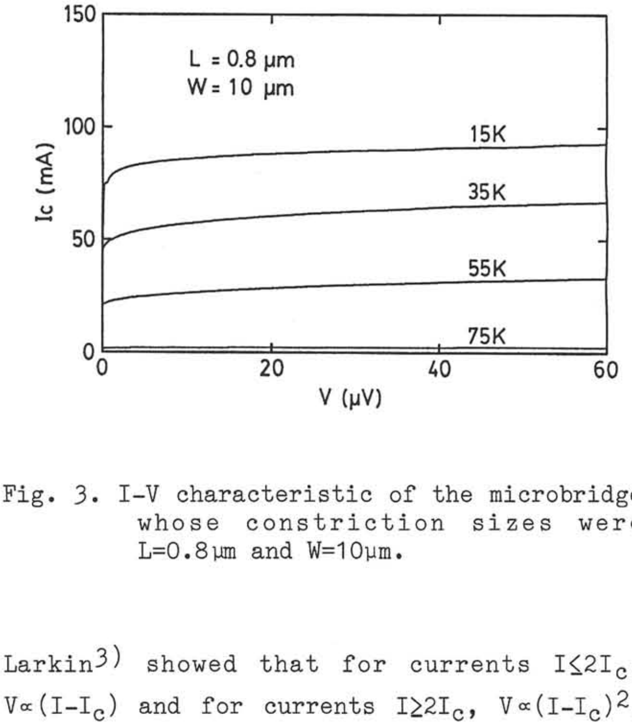

Fig. 3. I-V characteristic of the microbridge whose constriction sizes were L=0.8μm and W=10μm.

Figure 4 shows temperature dependence of the dynamic resistance R_n' of the micro-

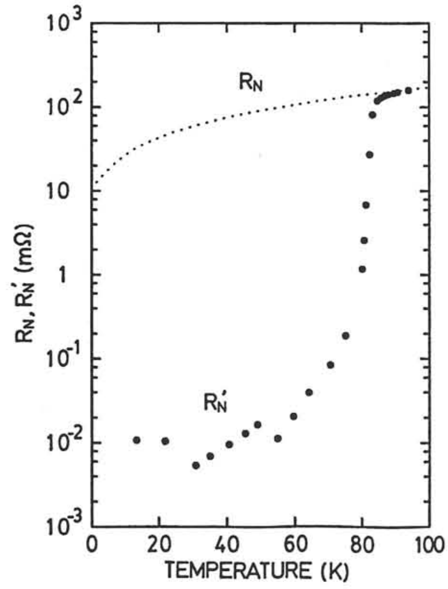

Fig. 4. Temperature dependence of the dynamic resistance R_n' and the normal resistance R_n of the microbridge as shown in Fig. 3.

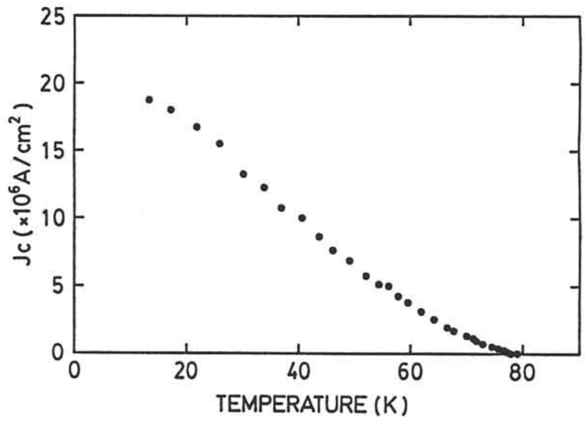

Fig. 5. Temperature dependence of the critical current density of the microbridge as shown in Fig. 3.

bridge, obtained from I-V curves as shown in Fig. 3. A dushed line shows the normal resistance R_n obtained by the extrapolation of the normal resistance above $T_{c(onset)}$. From the theoretical analysis, it is derived that the relation between R_n' and R_n is $R_n' \ll 6R_n(\xi/W)$. The dynamic resistance R_n' is 3 orders of magnitude smaller than the extrapolated value of the normal resistance R_n and this relationship is satisfied.

Figure 5 shows the temperature dependence of the critical current density J_c of the $Ba_2YCu_3O_x$ microbridge shown in Fig. 3. In this case, we find that the law $I_c \propto (1-t)^{3/2}$ with t being the reduced temperature, applies for most of the bridges, and the critical current densities of these bridges were greater than 10^7A/cm^2 below 40K.

Aslamazov and Larkin have discussed the critical current I_c in wide superconducting bridges. However, they assumed that the size of the bridges is less than the penetration depth λ in the film which is not valid for our bridges. It must be noted that their theoretical analysis for the critical current I_c is valid irrespective of this assumption, because the I_c is determined the creation of a vortex at the edge of the bridge. Exactly, the creation of a vortex is due to the force acting the vortex in the region distant from the edge of the bridges with the order of coherence length ξ. Then, the expression for I_c is valid also for the case $\xi \ll \lambda$ which holds for as-grown $Ba_2YCu_3O_x$ thin films.

Aslamazov and Larkin have derived the formula

$$I_c = I_0(\xi/W)^n, \tag{1}$$

where W is the width of the bridges and I_0 is the order of magnitude of the critical current of a bridge of width $\sim\xi$. For a bridge in the shape with an aperture angle 2α, n is nearly equal to 1 for the case $\alpha \gg \sqrt{\xi/W}$ which holds for our bridges. Then, we can see that the critical current density J_c in wide superconducting bridges is nearly equal to the one of bulk samples which was verified experimentally. These discussions demonstrate that Josephson like behaviors in wide superconducting bridges is not due to the weak links of grain boundaries of the films.

To confirm Josephson effect in wide bridge made by high-J_c $Ba_2YCu_3O_x$ thin films on Y_2O_3/YSZ/Si, we applied microwaves close to the bridge. The microwaves, however, failed to induce the constant-voltage current steps on I-V characteristic. In a previous paper,[1] the critical current density at 15K is about $1x10^5 A/cm^2$ which is nearly equal to the one of bulk samples on YSZ/Si. In present paper, the critical current density for wide bridges and the one of bulk samples on Y_2O_3/YSZ/Si is about $1x10^6 A/cm^2$ at 70K and more than $10^7 A/cm^2$ below 40K as shown in Fig. 5. This high critical current density results in the disappearance of an ac Josephson effect, except for the higher frequency of about 100GHz, or the higher input powers of microwave.

4. CONCLUSIONS

High-Tc $Ba_2YCu_3O_x$ superconducting microbridges have been fabricated on silicon substrates patterned with trench, with Y_2O_3/YSZ buffer layers. The bridge are 4-10μm wide and 0.8μm long. The critical current density of the microbridges are more than $10^6 A/cm^2$ at 70K which is nearly equal to the one of bulk samples on Y_2O_3/YSZ/Si. The temperature dependence of J_c is found to be proportional to $(1-t)^{3/2}$ near Tc (t=T/Tc). These results are consistent with Aslamazov and Larkin's theory qualitatively. The high critical current density of $10^7 A/cm^2$ results in the disappearance of an ac Josephson effect, except for the higher frequency of about 100GHz, or the higher input powers of microwave.

5. ACKNOWLEDGEMENT

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6. REFERENCES

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