Properties of Superconducting Variable-Thickness Bridges Fabricated by Anodic Oxidization

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Properties of Superconducting Variable-Thickness Bridges Fabricated by Anodic Oxidization

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We have fabricated superconducting Nb variable-thickness bridges using sputter process and anodic oxidization, and have obtained some properties of the bridges by experiments about the temperature dependence of critical currents, the effect of microwave radiations and dc-SQUID. These results show that our fabrication procedure can make Josephson junction with very short bridge length.

1. Introduction

In recent years, applications of Josephson junctions have actively been investigated. Some examples of applications are those in the computers, oscillators and detectors of electromagnetic radiation and magnetometers. The object of our research is to develop the Josephson junctions applied to the sensitive magnetometers.

Tunnel junctions, point contacts and bridges as Josephson junctions are well known. The tunnel junction has a structure that a very thin insulator film (several tens of angstroms) is sandwiched between two superconductors as shown in **Fig. 1(a)**. This junction

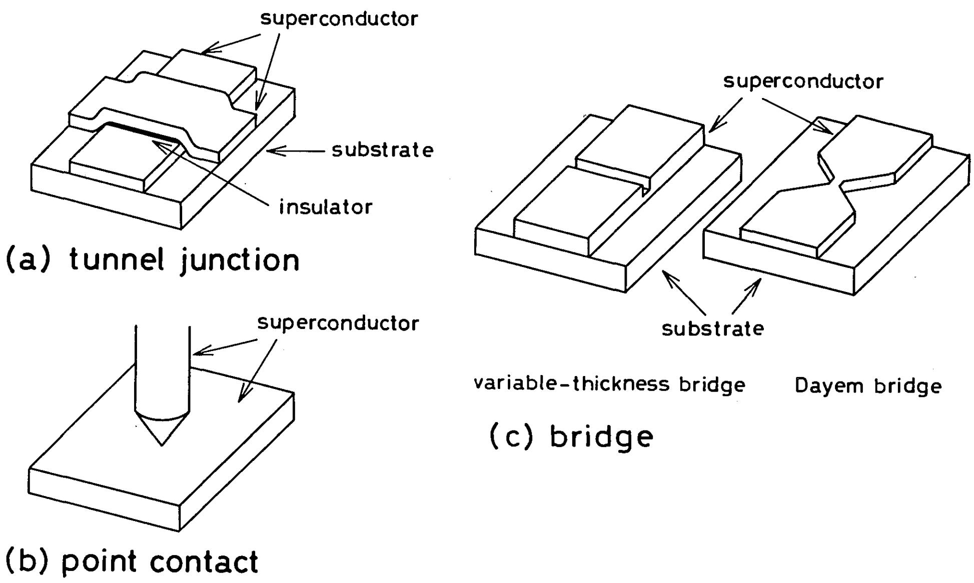

Fig. 1 Examples of Josephson junctions.

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has extensively been studied as the device of computers because of its properties. But due to its capacitance and difficulties to fabricate reproducible device with a high critical temperature we did not select tunnel junctions in this work. **Figure 1(b)** shows the structure of a point contact device that two superconductors contact slightly. Although some point contacts sometimes have excellent properties, we did not choose them. This is the reason why their properties are not reproducible and their structure is unintelligible. Two kinds of bridge are shown in **Fig. 1(c)**. Bridges have a narrow part in a superconducting film. They have low capacitance and are made with good reproduction.

A variable-thickness bridge having the variation of thickness is constrained only to a bridge length L as long as a bridge width is not very wide; $L \leq \xi(T)$. Here $\xi(T)$ is the coherence length at a temperature T. On the other hand, a Dayem bridge which has a constant thickness is constrained to not only bridge length L but also its width W; Max $(L, W) \leq \xi(T)$. So the variable-thickness bridge can be fabricated more easily than the Dayem bridge. Judging from the above, we adopted the variable-thickness bridge as the Josephson junctions.

We fabricated variable-thickness bridges using Nb and make experiments about the temperature dependence of critical currents, the effect of microwave radiations and dc-SQUID (direct current - Superconducting QUantum Interference Device), in order to know whether they were Josephson junctions and which efficiency they had. From the results of the above experiments it was found that those bridges were Josephson junctions which had the properties comparable to the variable-thickness bridges reported previously or a little better than them.

2. Fabrication Procedure of Variable-Thickness Bridge

Variable-thickness bridges which show ideal properties must have a very short bridge length $L \leq \xi(T)$ and for Nb $\xi(0)$ is about 20nm. Then we used the fabrication procedure described below, to get the variable thickness bridge which has the very short bridge length.

The fabrication procedure is explained in due order. First a Nb film of thickness about 40nm was deposited on a glass substrate by rf sputtering [**Fig. 2(a)**]. Next, a photoresist

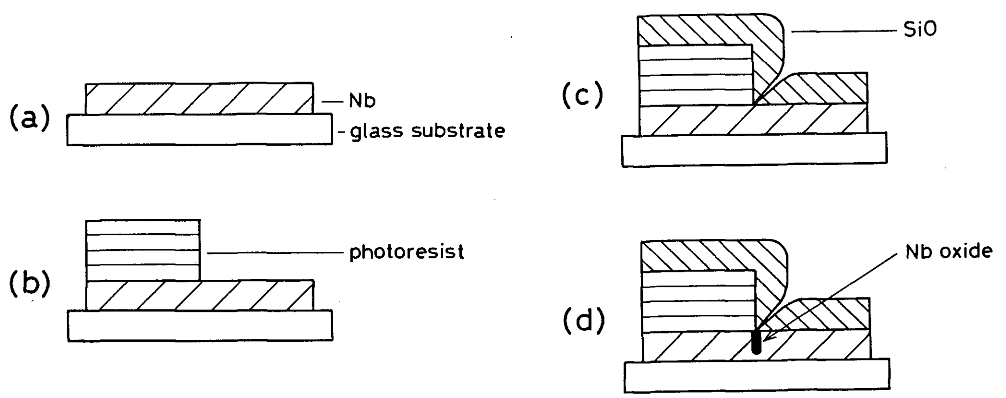

Fig. 2 Fabrication procedure of Nb variable-thickness bridge.

about 1500nm thick was spun on the Nb film and exposed to light. As the result the half of Nb film was masked as in **Fig. 2(b)**. In the third step a SiO about 20nm thick was sputtered. The SiO film has such a shape as shown in **Fig. 2(c)**, because the mean free path of the sputtered particle is so short that the deposition rate is roughly proportional to the solid angle[1]. Lastly the Nb film was oxidized by anodic oxidization in 1N H_2SO_4. When a potential difference between a sample and counter electrode in the anodic oxidization was about 40V, the thinnest part of SiO film was broken down dielectrically and the Nb film under this part was oxidized [**Fig. 2(d)**]. In this way the Nb film had a constrict part with an insulator of Nb oxide. This corresponds to the variable-thickness bridge.

After the photoresist had been removed, the variable-thickness bridge fabricated by the procedure described above was patterned as in **Fig. 3**. In this case the sample masked by the photoresist was milled by sputter etching. The sample of form in **Fig. 3(b)** is called a dc-SQUID.

3. Experimental Results

A few comments will be made on the experimental method about the current—voltage

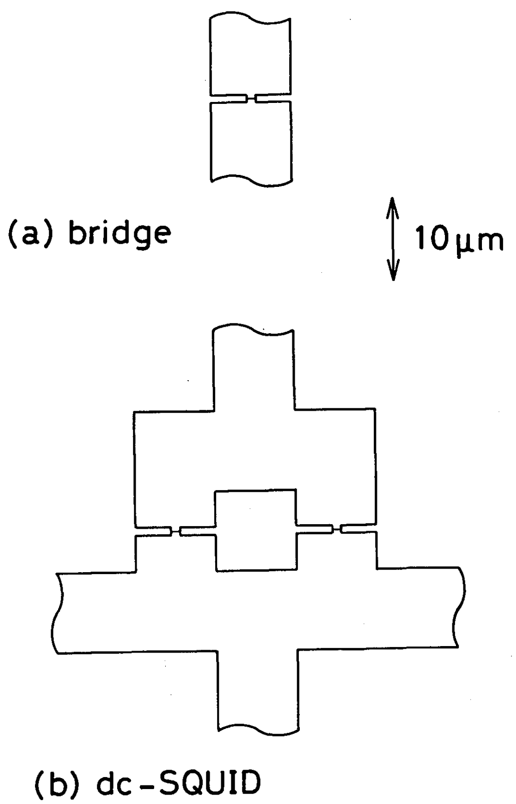

Fig. 3 Schematic of samples.

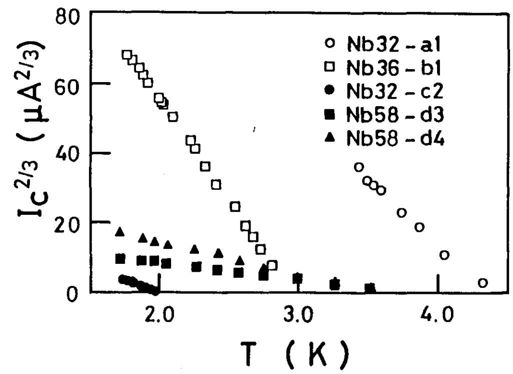

Fig. 4 Temperature dependence of the critical current.

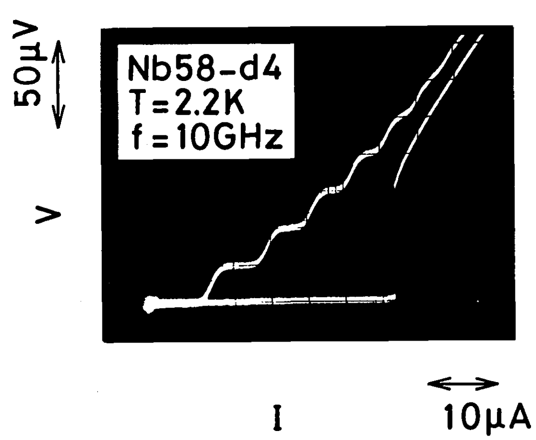

Fig. 5 $I-V$ characteristics without and with microwave radiation.

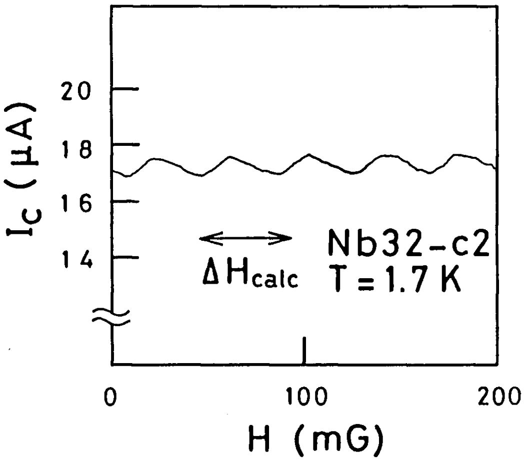

Fig. 6 Quantum interference pattern of dc-SQUID : I_c of dc-SQUID as a function of H.

($I-V$) characteristic and the critical current I_c. They were measured by four-terminal measurements about the sample immersed in liquid helium. The I_c was detected automatically by an equipment which holds a voltage proportional to current when the voltage of junction appears. The microwave was led to a sample by a shielding wire and was terminated with a resistor (50 Ω). The magnetic field H was applied to the sample perpendicularly by a solenoid. The temperature of samples was controlled by the vapor pressure of helium and was determined by the carbon resistor which had been calibrated by the manometer.

Temperature dependences of I_c of five bridges are shown in **Fig. 4**. Here, for dc-SQUIDs, I_c is a half of a maximum critical current. Although their bridge widths are roughly equivalent, their dependences are classified in two types by the magnitude of the I_c. The type of the larger magnitude of I_c was a S-S′-S bridge whose constrict part was superconducting and the other type was a S-N-S bridge whose one was normal. For S-S′-S bridges the I_c was found to exhibit a temperature dependence well described by a $(T_c-T)^{3/2}$ law,[2] where T_c is the critical temperature of bridges.

Figure 5 shows the typical $I-V$ characteristics without and with a microwave (10GHz) radiation. Constant voltage steps appeared when microwaves were present. It agreed with the expected ac Josephson effect that the voltage of the steps was about 20 μV. When the frequency was varied, the voltage of the steps was proportional to the frequency. One of the bridges had more than ten steps. We find from those results that the variable-thickness bridges fabricated as described before were Josephson junctions and one of them had an excellent characteristic.

An I_c-H characteristic of the dc-SQUID is shown in **Fig. 6**. As seen from **Fig. 6**, a quantum interference pattern was observed and its period was roughly equivalent to the calculated value ΔH_{calc} from the loop area. Therefore those results also show that Josephson junctions are realized by our fabrication procedure.

4. Discussions

The bridge using Nb has the advantages of the high-T_c and stability, but it has the design constraint that $L \leq \xi(T)$. Then we fabricated the variable-thickness bridge using both direction of sputtering deposition and anodic oxidization. Our fabrication procedure gave the two types of bridges which were the S-N-S bridge and S-S′-S bridge shown in the experimental result of temperature dependence of critical current. The experimental results for microwave radiation and dc-SQUID exhibit that we can fabricate Josephson junctions by this procedure and one of the sample has the excellent characteristic.

We have, however, two problems about the fabrication of variable-thickness bridge. One of them is the existence of the two bridge types. This means that the properties of the bridges are dispersed in spite of the same fabrication. The other problem is that the accurate thickness of bridge and its length are unclear. We will try to solve these problems and develop this research.

Acknowledgments

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