The measurement of Josephson current of double Josephson junction

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Abstract. We have investigated the relation between the Josephson current and the thickness of Nb middle layer of double Josephson junction. The characteristic of the sample is somewhat different even though the sample is made on the same condition. So we have changed only the thickness of Nb middle layer of the double Josephson junction on the same substrate with the shutter between the sample and the target. We fabricated the double Josephson junction completely on the same condition except for thickness of Nb middle layer. Josephson current has increased as Nb middle layer is thin. However, no Josephson current was observed without Nb middle layer.

1. Introduction
Superconducting current of Josephson junction is modulated by the external magnetic field. We have studied the current-voltage characteristics of single Josephson junction and double Josephson junction.1,2 This time, we have fabricated double Josephson junction that had different thickness of middle Nb layer. In Nb/MoSi/Nb/MoSi/Nb double Josephson junction, the value of the Josephson current is not dependent of the thickness of Nb middle layer, when the thickness of Nb middle layer is more than 20nm. Change of the current-voltage characteristics appear when the thickness of middle Nb layer is less than 20nm.3 We have investigated the relation between the middle Nb layer and Josephson current about Nb/Al-AlOx/Nb/Al-AlOx/Nb structure and Nb/Al-AlOx/Al-AlOx/Nb structure. In order to measure the influence of the thickness of middle Nb layer, we have to make and compare the samples that had different thickness of middle Nb layer. However, it is difficult to fabricate a sample with the same conditions repeatedly. Therefore, it is hard to investigate an exact tendency. This time, we fabricate the sample using the method of giving change to the thickness of middle Nb layer by the motion of a shutter. These samples were produced completely on the same condition except for thickness of middle Nb layer at the one sheet of silicon substrate.

2. Experimental
In order to fabricate the Josephson junctions, Nb and Al layer are deposited by sputtering, using DC
magnetron sputtering with load-lock system. This system consists of three chambers. Nb layer and Al layer are deposited at first chamber and second chamber, respectively. The third chamber is oxidation chamber. Sample is moved by using the magnetic transfer rod to keep each chamber a high vacuum. Therefore, it is possible to deposit a clean film. The thickness of Nb base electrode, Al over-layer, Nb middle layer, Al over-layer, and Nb counter electrode are 300/5/0–15/5/0~15/5/50nm respectively on one sheet of silicon substrate. The thickness of the Nb middle layer was controlled by moving the shutter at the 0.68cm/sec continuously. Al over-layer surface was oxidized to make the insulation layer. The junction areas (50 \mu m \times 50 \mu m) are defined using anodization process. These samples were produced completely on the same condition except for the thickness of Nb middle layer. This time, we fabricated the double Josephson junctions that thickness of Nb middle layer was 14.8nm 13.4nm 11.9nm 10.5nm 4.7nm and 0nm. The Josephson junction that Nb middle layer is 0nm becomes Nb/Al-AlOx/Al-AlOx/Nb structure. Nb/Al-AlOx/Nb/Al-AlOx/Nb structure and Nb/Al-AlOx/Al-AlOx/Nb structure are shown in Fig1.

The characteristic of the sample was measured by the following methods. Josephson current was modulated by using two pairs of Helmholz coils. The first pair produce \textbf{H_x} direction external magnetic field parallel to the junction. And the second pair produce \textbf{H_y} direction external magnetic field parallel to the junction. The sample is set to the center of two pairs of coils. We measured the magnetic field dependence of the Josephson current and the current-voltage characteristics by two-dimensional external magnetic field scanning.

3. Result and discussion
Josephson current was observed when the thickness of Nb middle layer was 4.7nm. The current-voltage characteristics at that time are shown in Fig.2. Josephson current was observed at two steps, as shown in that figure. The figure is the usual characteristics of the double Josephson junction without the external magnetic field (H_x, H_y). This phenomenon is peculiar to double Josephson junction, and it doesn't occur in single junction.

Fig.2 Current-voltage characteristics of the double Josephson junction. The thickness of Nb middle layer is 4.7nm.
Josephson current was modulated by scan of the two-dimensional magnetic field and Fraunhofer patterns were measured in $H_x$ direction and $H_y$ direction as shown in fig3. Two-dimensional dependence of Josephson current upon the external magnetic field has two mirror symmetries both in $H_x$ direction and $H_y$ direction. These figures are the typical characteristics of two-dimensional external magnetic field dependence. The peak of Josephson current was 0.83mA, and magnetic field modulation period was 200A/m. Josephson current of each junction of double Josephson junction has each magnetic modulation period. Modulation period of the Josephson current in each junction of the double Josephson junction measured this time was almost same.

The Josephson current of the sample with different thickness of Nb middle layer is measured. When the thickness of Nb middle layer was 14.8nm 13.4nm 11.9nm and 10.5nm the corresponding Josephson current was 0.63mA 0.68mA 0.7mA and 0.71mA, respectively. When the middle layer is thinner, the Josephson current is increased, as shown in Fig.4. When the thickness of Nb middle layer was 14.8nm 13.4nm 11.9nm and 10.5nm the corresponding magnetic modulation period was 230A/m 220A/m 230A/m and 200A/m, respectively. The thickness of Nb middle layer and the relation of a magnetic modulation period are shown in fig.4. We have confirmed that magnetic modulation period was not dependent of the thickness of Nb middle layer.

On the other hand, no Josephson current was observed without Nb middle layer. Figure.5 shows current-voltage characteristics when the thickness of Nb middle layer was 0nm.
Josephson junction is composed of Super-conductor (S) Normal-metal (N) and Insulator (I). In general, the thickness of the oxidization layer by oxidizing the Al in pure oxygen is about 3nm. Nb/Al-AlOx/Nb/Al-AlOx/Nb structure is S/NI/S/NI/S structure, because 5nm Al layer is composed of 3nm insulator and 2nm normal-metal. Similarly, Nb/Al-AlOx/Al-AlOx/Nb structure that Josephson current cannot flow is S/NI/NI/S structure. With S/NI/NI/S structure, because the oxidization layer was too thick, Josephson current may not have flowed. We need to investigate the thickness of an oxidization layer. We have observed Josephson current of the single Josephson junction when the thickness of oxidization layer was 6nm. We use XPS (X-ray Photoelectron Spectroscopy) to analyze the surface of deposited films, and then we are investigating the thickness of an oxidization layer. However, it is difficult to determine the thickness of an oxidization layer. On the other hand, Josephson current was observed with S/NI/S/NI/S structure and Josephson current was not observed with S/NI/NI/S structure. So, it is also considered that Josephson current do not flow because of the S/NI/NI/S structure.

4. Conclusion
We have examined the relations between the thickness of Nb middle layer and the characteristics of double Josephson junction. When the thickness of Nb middle layer was 14.8nm 13.4nm 11.9nm 10.5nm and 4.7nm, the corresponding Josephson current was 0.63mA 0.68mA 0.7mA 0.71mA and 0.83mA, respectively. When Nb middle layer is thinner, the Josephson current is increased. Josephson current was observed with S/NI/S/NI/S structure. However, Josephson current was not observed with S/NI/NI/S structure that have no middle Nb layer. So, it is also considered that S/NI/NI/S is the structure where Josephson current is not passed. When the thickness of Nb middle layer was 14.8nm 13.4nm 11.9nm 10.5nm and 4.7nm the corresponding magnetic modulation period was 230A/m 220A/m 230A/m 200A/m and 200A/m, respectively. We have confirmed that magnetic modulation period was not dependent of the thickness of Nb middle layer.

Acknowledgments
This work supported by High-Tech Research Center, Kanagawa University.

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