Modulation of I-V Curves of Nb Single and Double Junctions by 2D Scan of Magnetic Field

Akiyoshi Nakayama [a,1], Susumu Abe [a], Tomoko Shoji [a], Ryota Aoki [a], Norimichi Watanabe [a]

[a] *Faculty of Engineering, Kanagawa University, 3-27-1 Rokkakubashi, Kanagawa-ku, 221-8686, Japan*

Abstract

Modulation of current-voltage characteristics of niobium junctions by two-dimensional scan of the external magnetic field has been measured. Josephson current of superconducting junction can be modulated by applying an external magnetic field. The modulation of the Josephson current I_c of the superconducting junctions is usually observed by one-dimensional scan of the applied magnetic field. In this article, by using two pairs of the Helmholz coils, the external magnetic field H to the junction is scanned in two dimensions, and the dependence on magnetic field of the DC Josephson currents of Nb/Al-oxide /Nb single and double junction structures have been observed.

Key words: Niobium; Josephson current; Magnetic field; Superconducting junction; Helmholz coil

1. Introduction

Modulation characteristics of Josephson current of superconducting junctions by applying the external magnetic field are important both in their physics and in their applications [1]. These modulation patterns are usually measured by scanning the magnetic field in one dimension. More information of the critical current distribution of the junction can be obtained by applying the external magnetic field in two different directions [2,3]. In this article, by using two pairs of the Helmholz coils and two current sources, the dependence of the superconducting current and the current-voltage characteristics upon the x- and y-directional magnetic field have been measured. The magnetic field dependence of the maximum superconducting current of the Nb/Al-oxide/Nb single and double junction structures has been obtained.

2. Experimental

In order to fabricate the Nb junctions, niobium and aluminum layers are deposited by sputtering using a dc magnetron sputtering system with load-lock and oxidation chambers [4]. The Al-oxide layers are formed in pure oxygen atmosphere. The junction areas are defined using a selective niobium anodization process [5].

Diameter, separation length and the winding number are 0.56 [m], 0.28[m], 500 in the pair of H_x Helmholtz coils and 1.10 [m], 0.55[m], 215 in the pair of H_y coils, respectively. The first pair has the vertical axis and the second has the horizontal axis as shown in Fig.1. The first and the second pair produce the H_x and H_y external magnetic field. The junction in liquid He is placed at the center of the two pairs of the coils so that the two edges of the junction area would be parallel to H_x and H_y directions, respectively.

[1] E-mail:nakayama@ee.kanagawa-u.ac.jp

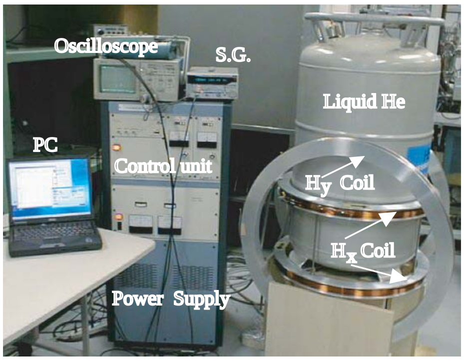

Fig. 1. Measuring apparatus.

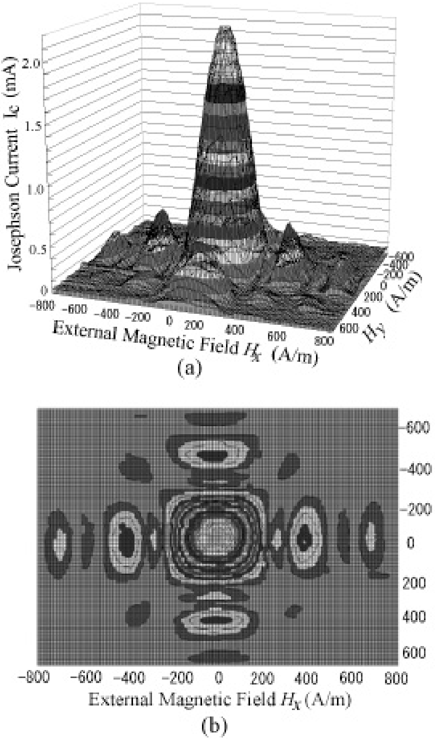

Fig. 2. Dependence of DC Josephson current of Nb/AlOx/Nb double junctions upon the magnetic field at T=4.2[K] (a):Bird's-eye view,(b):Contour plot.

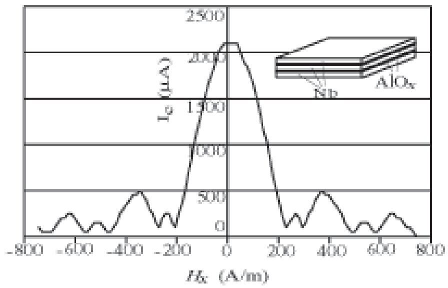

Fig. 3. Magnetic field dependence of the Josephson current Ic for a Nb/AlOx/Nb double junction Hy=0.

3. Results and discussions

Nb/Al-oxide/Nb single junctions have been fabricated, where the thickness of the Nb base electrode, Al over-layer and Nb counter-electrode is 200/6.2/50 nm, respectively. Dependence of the Josephson current of the Nb/Al-oxide/Nb single junction structure can be explained by the product of the two Fraunhofer patterns in H_x and H_y directions assuming the uniform critical current density of the junction area [3]. We have also fabricated Nb/Al-oxide/Nb double junction structure, where the thickness of Nb base electrode, Al over-layer, Nb middle electrode, Al over-layer, and Nb counter- electrode is 260/5/50/5/50 nm, respectively. Dependence of the Josephson current of the Nb/Al-oxide/Nb/ Al-oxide/Nb structure upon (H_x,H_y) magnetic field is shown in Fig.2. This dependence of the Josephson current can be explained by the model of the series connection of two Josephson junctions. Figure 3 shows the $I_c - H_x$ dependence as H_y =0. In this dependence there are two different periods of the Fraunhofer pattern, where one is 230 A/m and the other is 290 A/m. The capturing area of magnetic field by each Josephson junction is different. From the measured dependence, the sum of the penetration depth of the magnetic field of one junction is 144 nm, and the other is 114 nm.

Two-dimensional dependence on the external magnetic field of the Nb/Al-oxide/Nb single and double junction structures has been measured. The $I_c - H$ dependence of the Nb/Al-oxide/Nb single junction structures becomes the product of the two Fraunhofer pattern in the two directions parallel to the junction edges, which can be explained by the uniform barrier of the junction structure. The $I_c - H$ dependence of the Nb/Al-oxide/Nb double junction structures is also explained by series connected two junctions that have different periods of the magnetic modulation.

References

[1] A. Barone, G. Paterno, Physics and Applications of the Josephson Effect, Wiley-Interscience: New York, (1982)69.

[2] A. Nakayama, Okabe, T. Sugano, Jpn. J. Appl. Phys., 23 (1984)1007.

[3] A.Nakayama,S.Abe, T. Morita, M.Iwata, Y. Yamamoto, IEEE Trans. on Mag.36(2000)3511.

[4] A. Nakayama. Inaba, S. Sawachi, K. Ishizu, Y. Okabe,IEICE Trans. Electron., E77-C(1994)1164.

[5] H. Kroger, L.N.Smith, and D.W. Jillie, Appl. Phys. Lett.,39(1981)280.