Fabrication of Nano-Periodic Josephson Junction Array in High Temperature Superconductors

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1. Introduction

Whiskers can be used in the fabrication of new electronic devices using intrinsic Josephson effects and related phenomena. Growth and characterization of high temperature superconducting single crystal whiskers have always been focused by researchers. CuO_2 planes are one of the promoters for superconductivity in layered high temperature superconductors (HTS) [1-4]. $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212) crystal is a naturally grown Josephson junction. Conducting CuO_2 bilayer plane (≈ 0.3 nm) is separated by an insulator BiO-SrO layer (≈ 1.2 nm). This layered phenomenon gives highly anisotropy to Bi-2212 single crystal whiskers (comparable properties in *ab*- plane and *c*- axis). To study *c*-axis properties, we fabricated periodic Josephson junction array in single crystal whisker by 3D milling through focused ion beam (FIB).

We are reporting stack fabrication to study interlayer characteristics in high temperature superconducting single crystal whisker through focused ion beam (FIB). We fabricated a stack area of 2 μm x 2 μm and height of approximately 500 nm using FIB etching, which have several hundred of elementary Josephson junctions in *c*-axis. This stack has fabricated by rotation and tilt of sample stage in FIB. We measured resistance (R) - temperature (T) characteristics in *c*-axis as well as in *ab*-plane and found transition temperature (T_c) of 77 K, which indicates good quality of Bi-2212 single crystal whisker. We also measured current (I) - voltage (V) characteristics, which gives a well defined voltage gap ($V_g \approx 2.4$ V).

2. Growth and fabrication of sample

We prepared our sample from solid state reaction. We used 99.9% pure powder of Bi_2O_3, $SrCO_3$, CuO, and TeO_2. Te is used to enhance the growth of whiskers. We mixed these powders in the proportional ratio of $Bi_2Sr_2Ca_2Cu_{2.5}Te_{0.5}O_x$. The mixture was ground and put for calcination at 760°C for two times and at 820°C for one time only in presence of air. The calcinated powder pressed into a pellet at 60 kN. The pellet was 10 mm in diameter and 2~3 mm in thickness. The pellet kept in a pure alumina boat and annealed at 880°C for 100 hours. During the process we used oxygen atmosphere with constant flow of 150 ml/min [5]. The whiskers were grown on the surface of pellet. We found whiskers 0.5~3 mm in length and 10 to 30 μm in width.

We fabricated stack junctions in Bi-2212 single crystal whisker through FIB. Figure 1(a) shows schematic diagram of stack junction fabrication. We etched single crystal whisker in *ab*-plane with size of 2 μm x 2 μm. We tilted sample stage of FIB and etched single crystal whisker in *c*-axis with junction height of about 500 nm, which have several hundred of elementary Josephson junction. This stack has an array of Josephson junctions and all elementary junctions have arranged in the series. Figure 1 (b) shows the FIB image of stack junction. We performed resistance (R) - temperature (T) characteristics and current (I) – voltage (V) characteristics using four probe technique to characterize these junctions and superconductivity in *c*-axis (Fig. 1 (c)).

3. Experimental results

Figure 2 shows temperature dependence of resistance in *ab* - plane. The resistance drop starts ($T_{c,on}$) at 108 K and become zero at ($T_{c,off}$) 77 K. Inset shows extended scale near transition temperature. R-T characteristics showed two phase transition of whisker, which indicates the presence of other phase of single crystal whisker.

In *c*-axis we fabricated a stack of about 500 nm in height which contains several hundred of natural array of Josephson junction. Figure 3 shows typical I-V characteristics for superconducting Bi-2212 single crystal whiskers in *c*- axis at 30 K and estimated critical current density (J_c) of 4.7 x10^2 A/cm^2. The array of Josephson junction can be estimated from voltage gap of I-V characteristics. The voltage gap in I-V characteristics of 2.4 V shows several hundred of elementary Josephson junction in the stack.

4. Summary

We have succeeded to fabricate the array of natural Josephson junction in the area of 2 μm x 2 μm with the height of about 500 nm. A well defined voltage gap in I-V characteristics indicates superconducting state of the stack. Two phase transition in R-T characteristics indicates the presence of other phase in single crystal whisker.

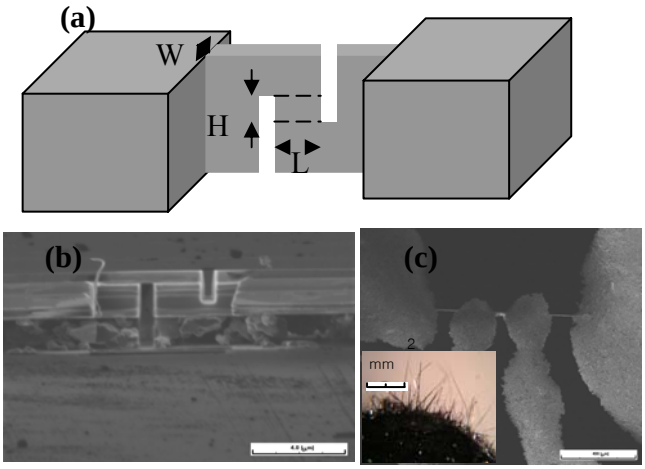

Fig. 1(a) Schematic diagram for array fabrication. (b) Image of *c*- axis junction through FIB (c) Four probe configuration on a whisker. The inset in (c) shows optical microscopy image of Bi-2212 single crystal whiskers on a precursor pellet

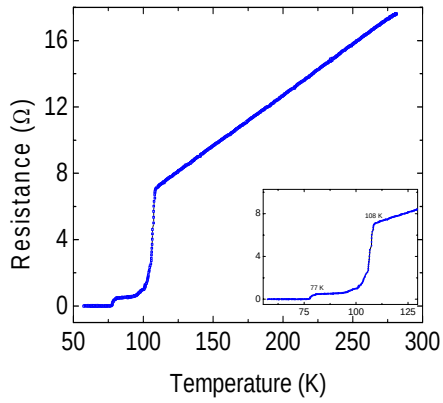

Fig. 2 R-T characteristics in *ab*- plane of Bi-2212 single crystal whisker

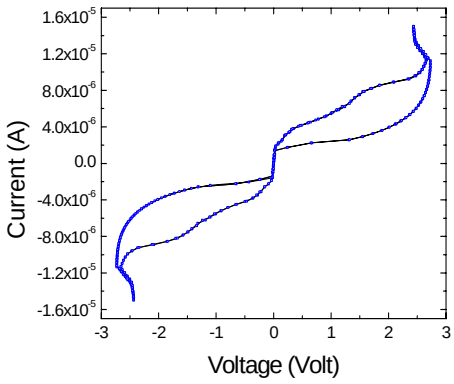

Fig. 3 I-V characteristics of Bi-2212 whisker at 30 K.

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