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Barrier structure of ramp-edge-type Josephson junction made of La-doped ErBCO and SmBCO electrodes

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Abstract

We fabricated SQUIDs containing ramp-edge-type Josephson junctions using La-doped ErBCO and SmBCO. The structure of the barrier was investigated by means of transmission electron microscope (TEM). The sample piece for the observation was picked up from a chip exhibiting moderate junction characteristics as DC SQUID at 77 K. The image of high-angle annular dark-field scanning TEM (HAADF-STEM) for the barrier indicated that about 1.5-nm-thick barrier homogeneously formed and the ordered structure of the triple perovskite was lost. Using an energy dispersive X-ray analyzer, the composition at the barrier region was estimated to be Ba:La:Sm:Er:Cu=23:1:25:10:41. It was found that significant concentration of Sm occurred at the barrier region. The formation mechanism of the barrier is discussed on the basis of the fabrication process and the obtained results.

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Keywords: Josephson junction, Ramp-edge-type, barrier, transmission electron microscope, SQUID

1. Introduction

25 years ago, the first ramp-edge-type Josephson junctions (JJs) using YBCO electrodes were reported by Gao *et al.* [1]. After that, many research groups have reported successful fabrication of the junctions. However, the barrier material and structure have not been fully understood yet, though it must be a crucially important issue. Wen *et al.* [2] investigated the barrier structure in their interface-modified junction between YBCO electrodes using a transmission electron microscope (TEM) in detail. We also previously studied the barrier structure between La-doped electrodes of YBCO and La-doped YbBCO [3]. The use of electrodes having different elements provided us useful information to consider the barrier structure and its formation mechanism. The investigations in refs.2 and 3 were carried out for the junctions prepared with the aim of application to digital circuits working at 20–40 K. Recent years, we have concentrated on development of SQUIDs with an operating temperature of 77 K [4]. Several SQUID systems were successfully fabricated and they have been utilized in various fields [5–8]. To the best of my knowledge, no data on the barrier of the junction working at 77 K is found in the literature so far published. In this work, the structure of the barrier was investigated by means of transmission electron microscope (TEM) and its formation mechanism is discussed.

2. Experimental

The sample piece for the observation was picked up from a chip exhibiting moderate junction characteristics as DC SQUID at 77 K. Figure 1 shows its current-voltage (I - V) characteristics and magnetic modulation curve. $2I_c$ and $R_n/2$ were 30 μ A and 5.3 Ω , respectively and $I_c R_n$ product was estimated to be approximately 160 μ V. ΔV of 28 μ V was obtained in the modulation curve. Figure 2 shows an image of dark-field scanning TEM for the cross-section. For the counter- and base-electrodes, $\text{ErBa}_2\text{Cu}_3\text{O}_y$ (slightly La-doped; L1ErBCO) and $\text{SmBa}_2\text{Cu}_3\text{O}_y$ (SmBCO) were used, respectively. SrSnO_3 (SSO) was used for insulating layers. Ramp-edge-type JJ was prepared on a thick SSO layer. A Pr-Ba-Cu-Ga-O layer with a BaZrO_3 -buffer was inserted between the thick SSO and MgO substrate [9]. The image suggests that oxide multilayers are successfully constructed without appreciable macroscopic disorder. An interface portion indicated by arrow in the image was investigated in detail.

3. Results

Figure 3 shows the image of high-angle annular dark-field scanning TEM (HAADF-STEM) for the barrier region indicated by the arrow in Fig.2. In the portions of both the electrodes, clear contrast indicating the triple perovskite structure is seen. A rather homogeneous region in which the ordering structure is lost is seen between the electrodes, suggesting that this region works as a thin barrier. The thickness of the barrier is about 1.5 nm. Since the observed contrast in HAADF-STEM image is correlated with the atomic number of elements, it seems that regular arrangement of the atomically ordered perovskite is destroyed in the barrier.

Compositional analyses for the barrier and both the electrodes were carried out using an energy dispersive X-ray (EDX) analyzer. Spot size of the incident electron beam was approximately 0.2 nm. The obtained results are shown in Fig. 4. The composition at the barrier region was estimated to be Ba:La:Sm:Er:Cu=23:1:25:10:41. Appreciable Cu depletion is seen at the barrier region. Interestingly, Sm content gradually increases with approaching the barrier region, and exhibits a maximum at the barrier. We previously carried out the similar examination for the junction barrier between the YbBCO counter and YBCO base electrodes [10]. The obtained results exhibited similar tendency, that is, Y-concentration and Cu-depletion at the barrier.

4. Discussion

We thought that the obtained results must be correlated with our fabrication process [9]. Events happening in each step for junction preparation are schematically illustrated in Fig. 5.

- (i) A SmBCO film with *c*-axis orientation for the base-electrode is prepared.
- (ii) Ramp-edge of the SmBCO film is formed by argon ion irradiation. The ramp surface is bombarded by energetic ions and individual Sm-Ba-Cu-O atoms are sputtered out. Comparably lighter Cu ions are preferentially removed from the surface. Subsequently, the damaged surface is covered by amorphous Sm-Ba-O.
- (iii) The substrate is heated up in a deposition chamber in which oxygen gas is introduced. To reduce surface energy, reconstruction proceeds at the surface. It is considered that Sm₂O₃ is segregated to the surface, since it has larger heat of formation, $-\Delta H^\circ_{298}$, than BaO and CuO. (37.1 ± 0.8 kcal/mole for CuO, 139.0 ± 3.0 kcal/mole for BaO and 433.9 ± 2.5 kcal/mole for Sm₂O₃ [11] indicating

144.6 kcal/mole for $\text{Sm}_{2/3}\text{O}$)

- (iv) In our process, a thin Cu-poor precursor layer is deposited to adjust composition of the surface region [10].
- (v) During L1ErBCO counter layer deposition, both the electrodes are annealed and cationic ordering into triple perovskite structure is promoted. The interface of both the electrodes works as a sink of disgorged ions. Fortunately, these ions do not form any stable secondary phase as a precipitate which exists independently of the electrodes. The interfacial thin layer thus formed can work as a barrier.

5. Summary

We investigated the structure of the barrier between the L1ErBCO and SmBCO electrodes of the junction for SQUIDs by means of TEM. The barrier seemed to consist of a homogeneous layer with a thickness of about 1.5 nm. The ordered structure of the triple perovskite was lost there. The EDX compositional analyses revealed Sm-concentration and Cu-depletion at the barrier region. The formation mechanism of the barrier is discussed on the basis of the fabrication process and the obtained results.

Acknowledgements

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Figure captions

Fig. 1. (a) I - V characteristics; (b) magnetic modulation curve.

Fig. 2. Image of dark-field scanning TEM for the cross-section.

Fig. 3. Image of HAADF-STEM for the barrier.

Fig. 4. Compositional analysis for the barrier and electrodes.

Fig. 5. Schematic illustration of the barrier formation mechanism.

Fig.1 Adachi *et al.*

Fig.2 Adachi *et al.*

Fig.3 Adachi *et al.*

Fig.4 Adachi *et al.*

Fig.5 Adachi *et al.*