Progress in Superconductivity Vol.2 No.2 pp71-75 30 June 2001

The Formation of $YBa_2Cu_3O_7$ Step-edge Josephson Junction on $LaAlO_3$ and MgO Single Crystal Substrates by Using Step-edge Annealing

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Received 1 June 2001

$LaAlO_3$와 MgO 기판 위에 형성한 $YBa_2Cu_3O_7$ 모서리 죠셉슨 접합의 열처리 효과

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Abstract

The effect of annealing step-edges of $LaAlO_3$ and MgO single crystal substrates on $YBa_2Cu_3O_7$ junction has been studied. The step-edge was fabricated by argon ion milling and was annealed at 1050 °C in 1 atm oxygen pressure. We compared AFM image near step-edge of the substrates between before and after annealing process. And $YBa_2Cu_3O_7$ thin film was deposited on the step-edge by a standard pulsed laser deposition. The step-edge junctions were characterized by current-voltage curves at 77 K. The annealing of step-edges of MgO substrate improved the current-voltage characteristic of Josephson junction: double steps in the current-voltage characteristic disappeared. However the annealing for $LaAlO_3$ did not improve the junction property.

Keywords : Annealing, step-edge junction, $LaAlO_3$, MgO

I. Introduction

Since the discovery of high-T_c superconductors, tremendous effort has been made to develop superconducting thin film devices. Most of the superconducting devices use Josephson junction. Many applications, such as superconducting quantum interference device (SQUID) [1,2], single-flux-quantum (SFQ) circuits [3], and microwave device [4] require high quality Josephson junction. The fabrication technique of high quality film and

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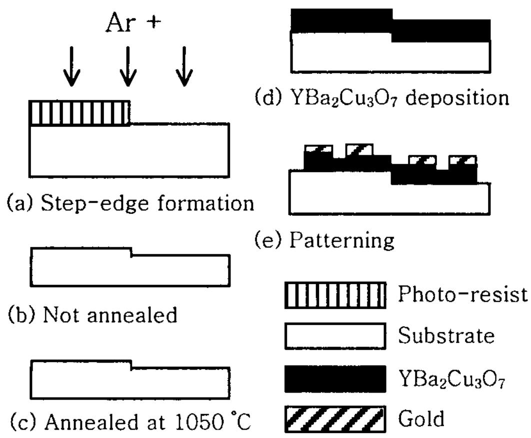


Fig. 1. The schematic diagram of fabrication process.

Josephson junction has been improved, however, the reproducibility of making good high-T_c device has been a big obstacle for practical use.

The Josephson junction of $YBa_2Cu_3O_7$ has been successfully fabricated by using bicrystal [5,6], step-edge [7-9] and ramp-edge [10,11]. Bicrystal junction is reproducible and excellent in noise property, and easy for fabrication. However, high cost and restricted topological freedom of the bicrystal substrate are major obstacles to devices. Particularly for $LaAlO_3$ single crystal, bicrystal substrate is not available because of its intrinsic twin boundaries. On the other hand, ramp-edge junctions have maximum topological freedom, but fabrication technology of reliable high quality junctions is not yet developed. Step-edge junction is usually used for wide application of high T_c devices because single crystal substrate is not only relatively cheaper than bicrystal one, but also the position and property of the junction can be easily chosen for suitable device.

However, technical problems for step-edge Josephson junction are low yield rate and reproducibility. During fabrication of junction, argon ion-milling creates damage on a step surface of substrate as well as the other area so that the quality of $YBa_2Cu_3O_7$ film and junction can be often degraded by the ion milling.

For the application of microwave device, $LaAlO_3$ [12] and MgO [13] substrates are generally used because of their low dielectric constant. The formation of step-edge junction on the substrates,

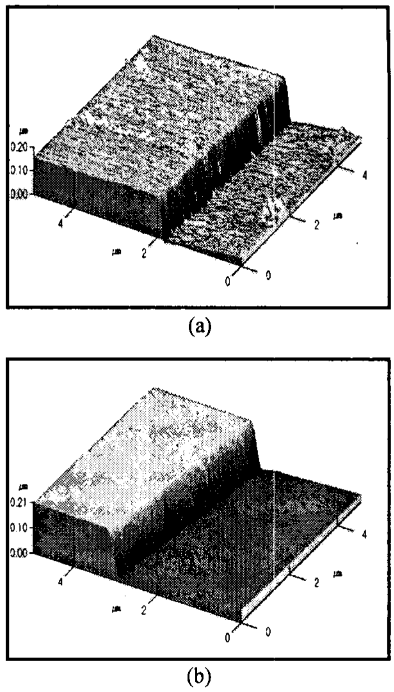


Fig. 2. AFM images near the step-edge of $LaAlO_3$ before and after annealing at 1050 °C. (a) is before and (b) is after annealing. The AFM scanning length along X and Y are 5 μm.

however, has not been studied in detail.

Here we study the annealing effect of the step-edge of the substrate (particularly $LaAlO_3$ and MgO) damaged by argon ion-milling, and the fabrication yield for junctions. The degree of surface damage has been investigated by scanning the surface of $LaAlO_3$ and MgO with an Atomic Force Microscope (AFM), and by measuring current-voltage characteristic (I-V) of the step-edge junction.

II. Experiment

The steps of $LaAlO_3$ and MgO substrates are fabricated by argon ion-milling and the step height is 180 to 200 nm. The step height is measured by using an optical microscope and AFM. The step angle is about 60 to 70° for both substrates. The details of step fabrication are described elsewhere [14]. In order to see milling and annealing effects, the surface of argon ion-milled $LaAlO_3$ and MgO near the step edge are checked with AFM. Each substrate damaged by argon ion milling is cut into two pieces. One of the two pieces is heated at 1050 °C in flowing oxygen and the other one is not heated. $YBa_2Cu_3O_7$ film is deposited on the two pieces of substrate. $YBa_2Cu_3O_7$ film of 200 nm thick is deposited on $LaAlO_3$ and MgO single crystal substrate by using standard pulsed laser deposition. Oxygen partial pressure is 400 mTorr and the temperature for substrate is kept at 810 °C. The energy density of the laser is 1.2 J/cm^2. After laser ablation, $YBa_2Cu_3O_7$ film gets fully oxidized by annealing at 500 °C in 1 atm oxygen pressure for 1 hour. The $YBa_2Cu_3O_7$ film is patterned to a micro-bridge (3, 5, 10 μm wide) by photolithography and argon ion milling. In order to reduce contact resistance, gold film of 80 nm thick is deposited for contact pads and annealed at 500 °C in flowing oxygen [15] before patterning. The sample preparation procedure is shown in Fig. 1. Then $YBa_2Cu_3O_7$ junctions on the two substrates are characterized through their I-V curves at 77 K.

III. Results and Discussion

In order to investigate the degree of damage from argon ion milling, AFM images near the step-edges of $LaAlO_3$ and MgO are taken before and after annealing, which are displayed in Fig. 2 and 3. The upper figure (a) is for the substrates not annealed and the lower one (b) is for the substrates annealed at 1050 °C. Overall the sharpness and smoothness of the step-edge are improved by the annealing, the step angle is not changed. Note that we have checked many regions to get the typical step image.

Fig. 4 is the I-V curve of $YBa_2Cu_3O_7$ step-edge junction at 77 K, showing the annealing of the step-edge of $LaAlO_3$ substrate does not improve junction property. I-V curves of the junction before and after annealing are similar, which indicates that the annealing of $LaAlO_3$ substrate may create re-crystallization as well as additional twinning. Usually a re-crystallization of the step-edge of the substrate should help the formation of the Josephson

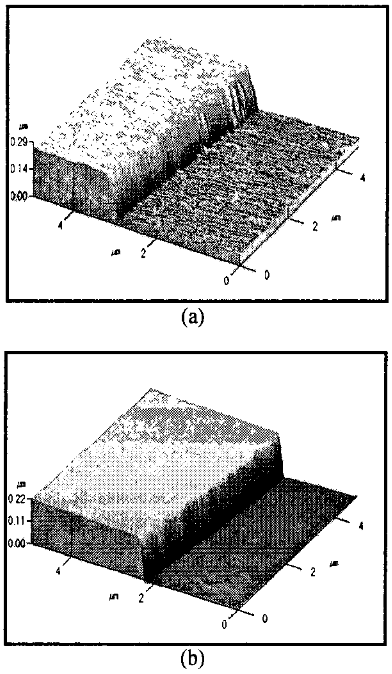


Fig. 3. AFM images near the step-edge of MgO before and after annealing at 1050 °C. (a) is before and (b) is after annealing. The AFM scanning length along X and Y are 5 μm.

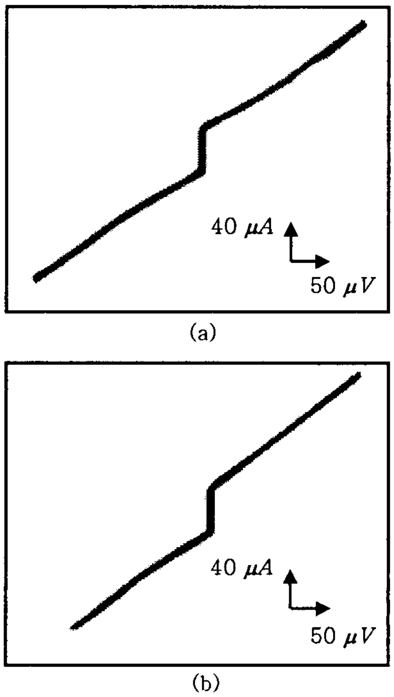


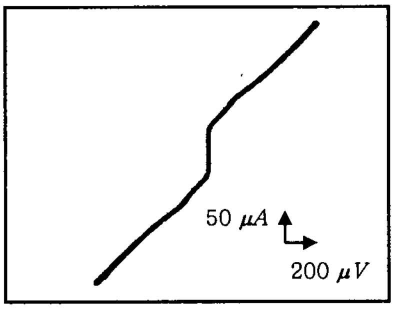
Fig. 4. I-V curve of $YBa_2Cu_3O_7$ step-edge junction on $LaAlO_3$ substrate at 77 K. (a) I-V curve before and (b) after annealing. Junction width is 5 μm.

junction that has a resistively shunted junction (RSJ) behavior in I-V characteristic [16], suggesting that the additional twinning near step-edge gives bad effect for junction formation.

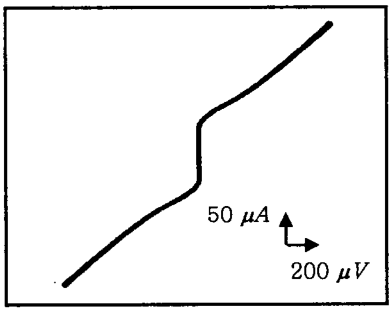
On the other hand, the annealing improves the step-edge junction property for MgO substrate (Fig. 5). The upper one shows a typical I-V data; double junctions are usually formed when the step of MgO is not annealed. The lower panel displays the I-V curve after the annealing. The dramatic annealing effect of MgO substrate is to remove the double steps in I-V curve and to form a step in the I-V curve which shows RSJ like behavior.

IV. Summary

The step-edges of $LaAlO_3$ and MgO substrates are fabricated by argon ion milling. The typical shape of the step-edge is visualized in AFM images. The I-V characteristics of $YBa_2Cu_3O_7$ step-edge junctions fabricated on MgO usually show double steps. However, the annealing of the step-edge of MgO substrate removes the double junctions and I-V characteristic shows a resistively shunted junction (RSJ) behavior. In the case of $LaAlO_3$, however, annealing does not improve step-edge junction property. These results will be very useful for making high quality and reproducible high T_c Josephson junction devices.



(a)



(b)

Fig. 5. I-V curve of $YBa_2Cu_3O_7$ step-edge junction on MgO substrate at 77 K. (a) I-V curve before and (b) after annealing. Junction width is 5 μm.

Acknowledgments

This work was supported by KRISS. [project # : 01-0503-150]

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