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HTS Josephson Junctions with Deionized Water Treated Interface

S. H. Moon* [a], W. K. Park[b], J. I. Kye[a], J. D. Park[a], and B. Oh[a]

[a] *LG Electronics Institute of Technology, Seoul 137-724, Korea*

[b] *Francis Bitter Magnet Laboratory, Massachusetts Institute of Technology, 170 Albany Street, Cambridge, MA 02139, USA*

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증류수 계면처리를 이용한 고온초전도체 죠셉슨 접합 제작

문승현* [a], 박완규[b], 계정일[a], 박주도[a], 오병두[a]

Abstract

We have fabricated $YBa_2Cu_3O_{7-x}$ (YBCO) ramp-edge Josephson junctions by modifying ramp edges of the base electrodes without depositing any artificial barrier layer. $YBa_2Cu_3O_{7-x}/SrTiO_3$ (YBCO/STO) films were deposited on $SrTiO_3$(100) by on-axis KrF laser deposition. After patterning the bottom YBCO/STO layer, the ramp edge was cleaned by ion-beam and then reacted with deionized water under various conditions prior to the deposition of counter-electrode layers. The top YBCO/STO layer was deposited and patterned by photolithography and ion milling. We measured current-voltage (I-V) characteristics, magnetic field modulation of the critical current at 77 K. Some showed resistively shunted junction (RSJ)-type I-V characteristics, while others exhibited flux-flow behaviors, depending on the dipping time of the ramp edge in deionized water. Junctions fabricated using optimized conditions showed fairly uniform distribution of junction parameters such as I_cR_n values, which were about 0.16 mV at 77 K with $1\sigma \sim 24$ %. We made a dc SQUID with the same deionized water treated junctions, and it showed the sinusoidal modulation under applied magnetic field at 77 K.

Keywords : Josephson junction, HTS, Interface, DI water, SQUID

I. Introduction

For the fabrication of electronic devices based on high temperature superconductors (HTS) there have been a great number of efforts to establish a reliable fabrication process of Josephson junctions (JJ). Due to the extremely short coherence length of HTS the control of interface on that scale is crucial. Since the coherence length in *ab*-plane is longer than that in the direction of *c*-axis in $YBa_2Cu_3O_{7-x}$ (YBCO), JJ of this material have been made usually in *ab*-direction with the ramp-edge geometry. Artificial layered tunnel barrier was not very successful. The low quality and the poor reproducibility of these junctions are mainly due to the fact that HTS thin films grow

* Corresponding author; Fax: +82 2 571 3863,
e-mail: smoon@LG-Elite.com

with various defects such as pinholes, outgrowths, etc. So self-limiting barrier concept has been considered as a breakthrough in HTS junction technology.

Several years ago Moeckly *et al.* fabricated interface-modified ramp-edge type HTS JJ without depositing any artificial barrier [1]. The main idea is that the YBCO surface can be modified into non-superconducting material after being exposed to appropriate ion damage. Since this report, there have been many research activities on interface-modified ramp edge type HTS JJ using various methods for interface-modification such as plasma treatment [1], ion beam damage [2-7], chemical treatment [6], and base electrode doping [8].

It has been known that YBCO decomposes to CuO, $Ba(OH)_2$, and Y_2BaCuO_5 in water and evolves oxygen [9][10]. Therefore in this study we tried to modify the YBCO ramp-edge using deionized water in order to make JJ and dc SQUID.

II. Experimental

Josephson junctions were fabricated using thin films deposited by KrF (248 nm) pulsed laser deposition. The optimized parameters for deposition of $YBa_2Cu_3O_{7-x}$ (YBCO) thin films were P_{O2} = 750 mTorr, $T_{substrate}$ = 800 °C, laser energy density = 1.4 J/cm^2. The zero-resistance critical temperature was ~ 90 K with the transition width of ~ 1 K [4]. The deposition parameters for $SrTiO_3$ (STO) thin films were not much different from those for YBCO. YBCO (200 nm) / STO (150 nm) bi-layers are deposited onto single crystal STO substrates.

After conventional photolithography for the base electrode, Ar-ion milling was performed using a Kaufmann-type ion source by an incidence angle of 65° to obtain ramp edges with small angles. The most important step in the photolithography process of base electrode is to reflow the PR edges by baking at elevated temperature. This is necessary for the formation of small-angle edges in the base electrode. The energy of the ion beam was 400 eV and the current density was 1.0 mA/cm^2. Resulting step angles were 20 ~ 25° with AZ1518 or AZ6612 photoresists. After edge formation, the dead surface layer was removed by a subsequent ion-milling cleaning with a little lower energy ion and incident angle of about 20°. Then we immersed sample in deionized water at room temperature (RT). The immersing time in the deionized (DI) water (resistance ~ 16 MΩ) was around 10 minutes in steady state or with ultrasonic agitation.

Base electrodes with the modified edges were immediately attached onto a heater block and transferred to the deposition chamber. The counter-electrode YBCO (220 nm) / STO (40 nm) thin films were deposited using the same

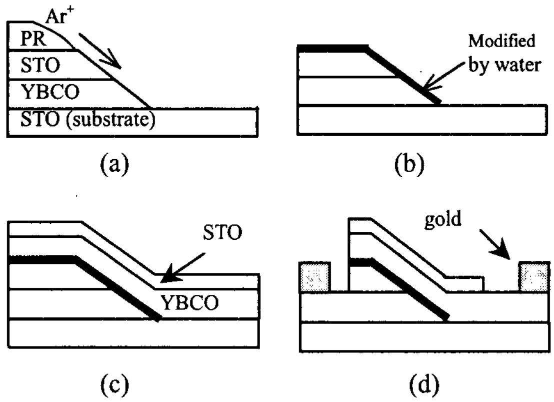

Fig. 1. Schematic diagrams of the overall process for junction fabrication; (a) formation of ramp edge, (b) ramp -edge modification by water, (c) deposition of counter -electrode, (d) lift-off of gold contact pad.

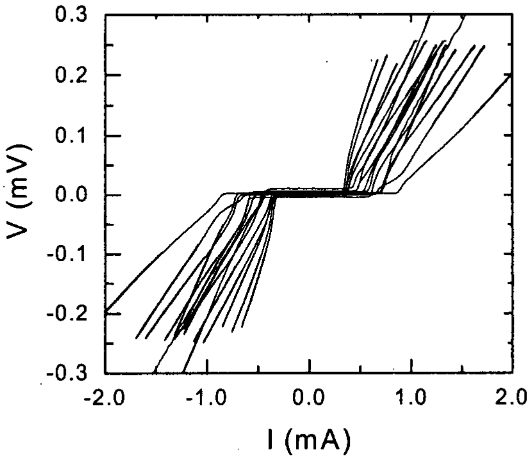

Fig. 2. Current-voltage characteristics of 16 junctions fabricated by immersing 6 miniutes in ultrasonic agitated DI water. Measured temperature was 77 K.

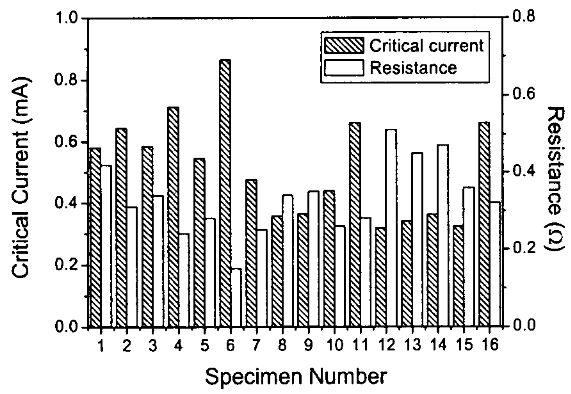

Fig. 3. Statistical distribution of critical currents (I_c) and normal state resistance (R_n) of RSJ-type junctions shown in Fig. 2.

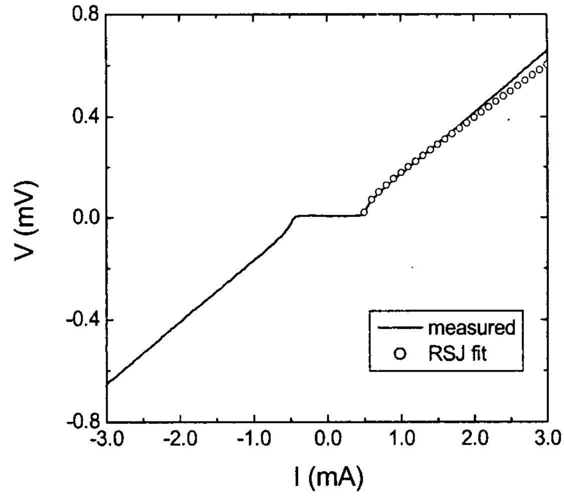

Fig. 4. The solid line shows current-voltage characteristics of number 10 junction in figure 3. The symbols indicate RSJ fit of the measured data.

parameters as for the base electrode. The samples were patterned into structures of ramp-edge type junctions by using photolithography and Ar-ion milling. Finally, gold contact pads were formed by conventional lift-off process. The process sequence is shown schematically in Fig. 1.

III. Results

Without immersing in DI water, we observed a good superconducting contact between two electrodes. The critical current densities of the contacts were larger than 1×10^6 A/cm^2, while typical critical current densities of base electrode and top electrode were 4×10^6 A/cm^2 at 77 K. The 6-minute immersed junctions with ultrasonic agitation showed resistively shunted junction (RSJ) like I-V characteristics at 77 K. Typical characteristics of 16 junctions in one chip are shown in Fig. 2. Most junctions show RSJ type, but some junctions shows flux flow like characteristics at high bias with RSJ-like behavior at low bias region. The distribution of critical currents and the normal state resistances for these 16 junctions are plotted in Fig. 3. The average values of I_c, R_n, and I_cR_n are 514 μA, 0.33 Ω, and 161 μV, respectively. The standard deviation(1σ) spreads of these parameters are 32%, 28 %, and 24 %, respectively.

The I-V characteristics of the number 10 junction in Fig. 3 and its RSJ fitting of the data are shown in Fig. 4. Thermal noise rounding is not observed due to large critical current value of 490 μA, but RSJ fitting deviates from the data at high bias region. Not like bicrystal Josephson junction that shows nearly ideal RSJ behavior, rather linear behaviors are clearly seen in this type of junctions. The critical current of the

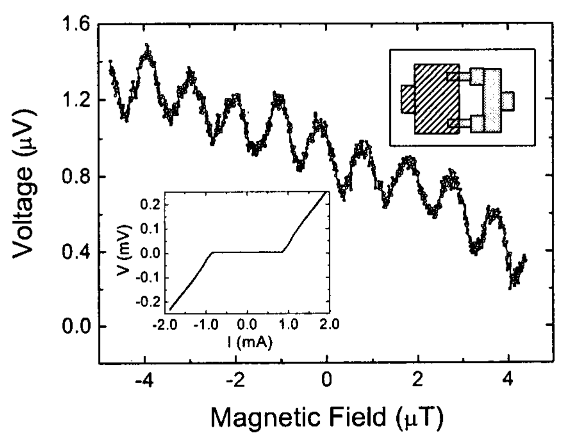

Fig. 5. SQUID output voltage as a function of applied magnetic field. The inset at the upper right corner shows the schematics of the SQUID made of 4 μm wide DI water immersed junctions. The inset at the left bottom shows the I-V characteristics of the SQUID. All the SQUID measurements performed at 77 K.

junctions were reduced up to ~ 70 % by applying dc magnetic field, but showed non-ideal modulation.

These results imply the inhomogeneity of the interface barriers and possible origin of linear I-V behavior. Most of the other junctions immersed DI water in steady state showed widespread of junction parameters, even if they were in the same chip. The I-V characteristics show RSJ-like to flux flow behaviors with I_c values of 0.1 to several mA ranges.

We made a dc SQUID based on these junctions. Figure 5 shows the dc SQUID voltage output as a function of applied magnetic field at 77 K. It consists of two 4 μm wide junctions immersed in DI water with the same conditions in Fig. 2. One inset shows the schematic of the SQUID. The inductance of this SQUID was estimated about 20 pH, and $2I_c$ ~ 860 μA, R_n /2 ~ 0.1 Ω were shown in another inset. The amplitude of the SQUID modulation was about ~ 0.4 μV, and the effective area calculated from the measured periodicity was 2300 μm^2. Calculated SQUID amplitude considering the thermal noise rounding i.e. $\alpha I_c R_n/(1+\beta)$ is about 3 μV. The discrepancy between this calculated value and the experimental one is mainly due to the non-ideal I-V characteristics of the SQUID.

IV. Discussion

After decomposition of YBCO surface by water the reaction product $Ba(OH)_2$ dissolves in water easily [9], and the other products i.e. CuO and Y_2BaCuO_5 remain as a barrier for JJ. We speculate the decomposition reaction did not seem to occur uniformly on the surface, which resulted in excess currents in JJ and a discrepancy between the experimental value and the calculated one for the magnetic field modulation amplitude of dc SQUID voltage.

In summary we have made JJ by modifying the YBCO ramp-edge using deionized water. Junctions fabricated using optimized conditions showed RSJ-type I-V characteristics and I_cR_n values were about 0.16 mV at 77 K with 1σ ~ 24 %. We made a dc SQUID with the same deionized water treated junctions, and it showed the sinusoidal modulation under applied magnetic field at 77 K.

Acknowledgments

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