Transactions of the Materials Research Society of Japan 29[4] 1331-1334 (2004)

Preparation of Josephson Junctions by MOCVD films

Yuuichi Nakajima [1,2], Hiroshi Kokubun[1], Takashi Amemura[1], Nobuyuki Iwata[2], Yoshinobu Tarutani[1], Keiichi Tanabe[1], Tadataka Morishita[1] and Hiroshi Yamamoto[2]

[1]ISTEC-SRL Address: 1-10-13 Shinonome, Koto-ku, Tokyo, 135-0062, Japan
Fax: 81-03-3536-5705, e-mail: y-nakajima@istec.or.jp
[2]Nihon Univ. Address: 7-24-1 Narashinodai, Funabashi-shi, chiba, 274-8501, Japan

With the aim of fabricating ramp-edge Josephson junctions (JJs) which include $NdBa_2Cu_3O_{7-x}$ (NBCO) superconducting electrodes and Sr_2AlTaO_6 (SAT) insulators, we have examined the fabrication processes and properties of NBCO and SAT thin films prepared by metalorganic chemical vapor deposition (MOCVD). Excellent insulating property of SAT films sandwiched by two superconducting layers was confirmed. NBCO ramp-edge JJs on $SrTiO_3$ substrates were fabricated using these films. Resistively-shunted-junction type current-voltage characteristics were observed, although they showed a large spread of characteristics.

Key words: MOCVD, NBCO, SAT, ramp-edge, Josephson junctions

1. INTRODUCTION

Single flux quantum (SFQ) digital devices that show high speed and low power consumption have been widely studied. To realize the SFQ devices using High-T_c superconductors, establishment of fabrication technique of ramp-edge Josephson junctions (JJs) having large I_cR_n products and a small spread of characteristics on a superconducting ground plane has been desired [1-2]. Films for SFQ devices have been prepared by a pulsed laser deposition (PLD) and sputtering methods so far. Metalorganic chemical vapor deposition (MOCVD) has some advantages such as good film coverage and large-area deposition capability. However, there has been no report on the fabrication of ramp-edge JJs by MOCVD. Figure 1 shows a schematic illustration of the device structure we study. Here, $NdBa_2Cu_3O_{7-x}$ (NBCO) and Sr_2AlTaO_6 (SAT) are chosen for superconducting electrodes and insulators, respectively. NBCO shows a high T_c and good surface stability [3,4]. SAT has been expected as a promising intermediate insulator because of its lattice constant approximately twice of the *a*- and *b*-axes of NBCO [5] and the low dielectric constant (ε =23-30) [6]. As preparatory experiments to fabricate the JJs shown in Fig. 1, we focus on two subjects; (1) properties of SAT films as an intermediate insulator and (2) fabrication of NBCO ramp-edge JJs without a ground plane. For the latter subject, JJs were fabricated by an interface-modified process [7].

2. EXPERIMENTAL

To examine the properties of SAT films as an intermediate insulator, we prepared SAT films sandwiched by two superconducting layers. A 10-μm-thick YBCO film with *c*-axis orientation prepared by liquid phase epitaxy (LPE) on an MgO substrate was used as a lower superconducting layer. The LPE-YBCO has an atomically flat surface and is expected to be a promising candidate for a ground plane. SAT films were deposited on the YBCO by MOCVD. The preparation conditions are listed in Table I.

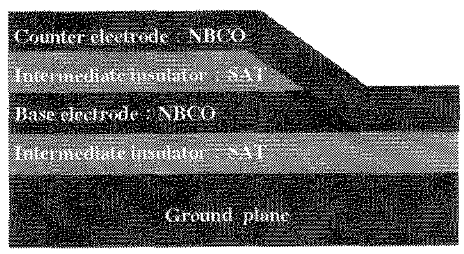

Fig. 1. Schematic illustration of the device structure.

Table I
Preparation conditions for SAT films by MOCVD.

Source temperature and carrier Ar flow rate	
$Sr(DPM)_2$	200 ℃
	30 sccm × 2
$TaAl(O\text{-}iC_3H_7)_8$	70-80 ℃
	70-140 sccm
Substrate temperature	740 ℃
Total gas flow rate	1000 sccm
Deposition pressure	10 Torr
O_2 pressure	1 Torr
Deposition rate	200 nm/h
Thickness	300 nm

A 200-nm-thick NBCO film for the upper superconducting layer was deposited by PLD at 770 ℃. Circle-shaped planer capacitors with Au electrodes were made for characterization. Dielectric constant and conductance of the SAT films were measured by using an HP4194A impedance analyzer after oxygenation of the superconducting layers by post annealing. Crystallinity and surface morphology of the multilayer films were examined by Rutherford backscattering spectroscopy (RBS) and atomic force microscopy (AFM), respectively. Resistivity for the upper NBCO was measured by a four-probe method.

To fabricate NBCO ramp-edge JJs without a ground plane, we firstly deposited NBCO and SAT films on $SrTiO_3(100)$ substrates by MOCVD. Table II lists the preparation conditions for NBCO films. For NBCO deposition, dpm-H was added to the carrier gas in order to prevent $Cu(DPM)_2$ from decomposing before it reaches the substrate. Next, ramp-edge structures with the angle to the substrate surface of 30° were fabricated by using photolithography and Ar ion milling. Then amorphous layers were formed on the NBCO ramp surfaces by Ar ion irradiation for 90 sec at an acceleration voltage of 500 V and the incident angle to the substrate of 90°. A counter NBCO layer was deposited under the same preparation conditions for the base NBCO layer. A 600-nm-thick Au film was sputtered on the counter NBCO layer. Finally, the Au layer and the counter NBCO layer were patterned to a width of 5 μm by photolithography and Ar ion milling. Current-voltage (*I-V*) characteristics of JJs were measured by a four-probe method in a magnetic shield.

3. RESULTS AND DISCUSSION

3.1 Properties of SAT films as an intermediate insulator

Figure 2 shows the conductance of the SAT films in 300 μm ϕ capacitor structures at room temperature. Measurements were carried out for 15 pieces of capacitors with and without an NBCO film on the SAT film. In both cases, 11 pieces exhibited conductance below 10^{-6} S. Figure 3 shows the dielectric constant and conductance for the SAT film with an NBCO film at low temperatures. Below 40 K, the dielectric constant is approximately 23 and the conductance is lower than 10^{-6} S.

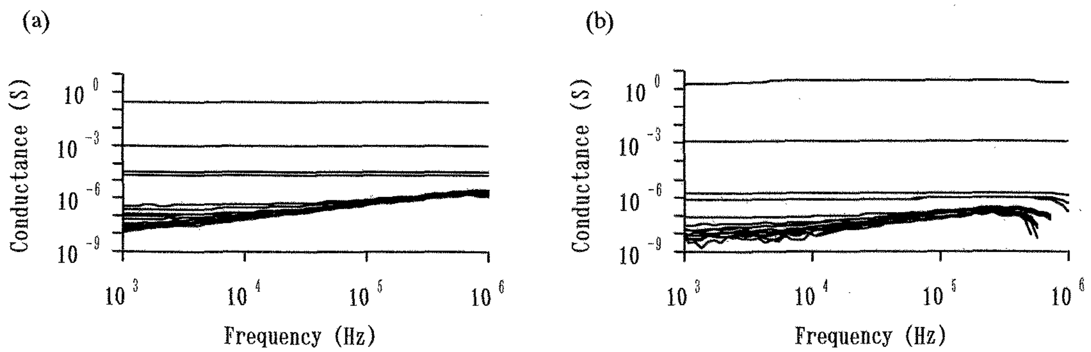

Fig. 2. Conductance of the SAT films at room temperature. Measurements were carried out for 15 pieces of capacitors (a) with and (b) without an NBCO film on the SAT film.

Table II
Preparation conditions for NBCO films by MOCVD.

Source temperature and carrier Ar flow rate	
$Nd(TMOD)_3$	140-143 ℃
	50 sccm
$Ba(DPM)_2$ · Pentaene	134-147 ℃
	100 sccm × 2
$Cu(DPM)_2$	110-115 ℃
	50 sccm
Substrate temperature	820 ℃
Total gas flow rate	670 sccm
Deposition pressure	10 Torr
O_2 pressure	1 Torr
Deposition rate	20-25 nm/h
Thickness	300 nm

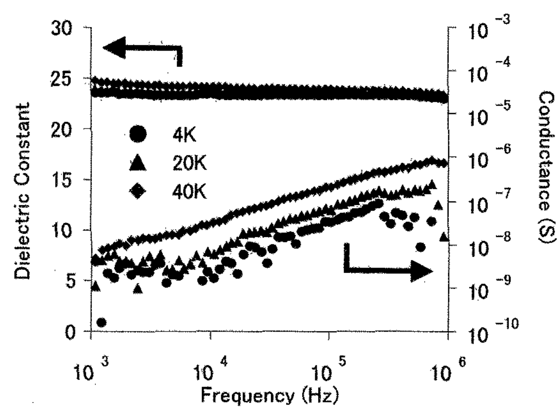

Fig. 3. Dielectric constant and conductance for the SAT film with an NBCO film at low temperatures.

Figure 4 shows the RBS spectra of the NBCO film on an SAT/YBCO bilayer. The RBS minimum yield, χ_{min}, is 3.1 %. For comparison, an NBCO film on $SrTiO_3$ substrate was deposited by PLD. For the NBCO film, the FWHM value of the NBCO(005) rocking curve was 0.1° and the χ_{min} was 4.8 %. It is thus considered that the NBCO film on SAT/YBCO bilayer has good crystallinity. Figure 5 shows the surface morphologies of SAT/YBCO and NBCO/SAT/YBCO films observed by AFM. The NBCO surface was flatter than SAT one. The root mean square (RMS) of surface roughness for the NBCO is 0.65 nm in a 2 μm square area. Figure 6 shows the temperature dependence of the resistivity for the NBCO film on an SAT/YBCO bilayer. The zero-resistance T_c is 90.8 K.

3.2 Fabrication of NBCO ramp-edge JJs without a ground plane

Among measured 14 JJs on the sample at 4.2 K, one junction showed resistively-shunted-junction (RSJ) type *I-V* characteristics, as shown in Fig. 7.

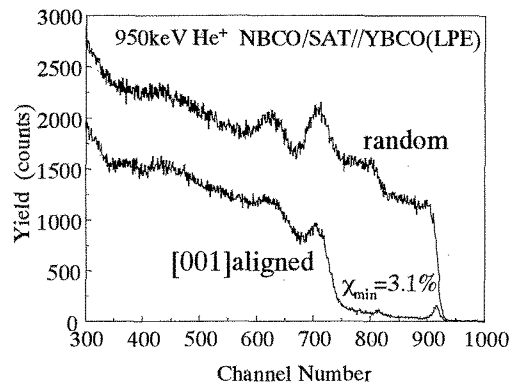

Fig. 4. RBS spectra of the NBCO film on SAT/YBCO bilayer.

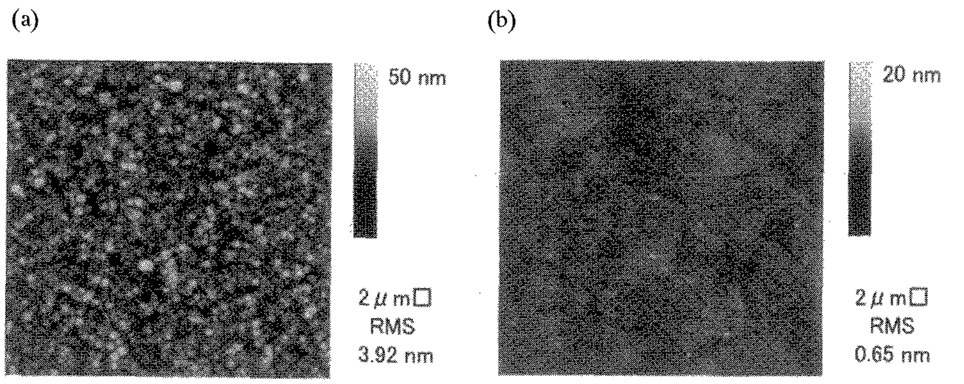

Fig. 5. Surface morphologies of (a) SAT/YBCO and (b) NBCO/SAT/YBCO films observed by AFM.

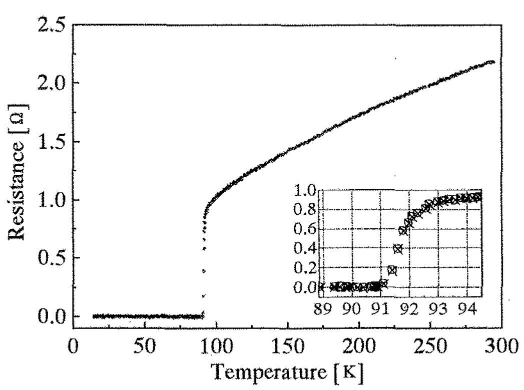

Fig. 6. Temperature dependence of the resistivity for the NBCO film on SAT/YBCO bilayer.

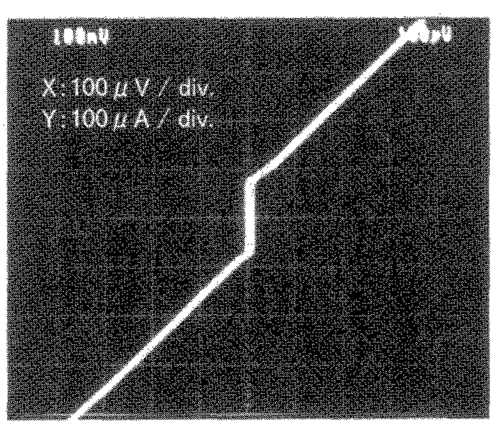

Fig. 7. *I-V* characteristics at 4.2 K.

Other JJs showed flux-flow type or linear *I-V* characteristics, indicating superconducting contact or resistor, respectively. We speculate that this spread in characteristics may be caused by difference in the preparation conditions for the counter NBCO layer at individual ramp surfaces in a sample. Non-uniformity of Cu distribution in NBCO films is also considered as a possible cause.

4. CONCLUSION

Excellent insulating property of SAT films sandwiched by two superconducting layers was confirmed. For the NBCO ramp-edge JJs without a ground plane fabricated by MOCVD, RSJ type current-voltage characteristics were observed. We proved that ramp-edge JJs could be fabricated by MOCVD.

5. ACKNOWLEDGEMENTS

The authors would like to thank S. Hoshi, T. Izumi and Y. Shiohara of ISTEC-SRL for providing YBCO thick films grown by LPE. This work was supported by the New Energy and Industrial Technology Development Organization (NEDO) as Collaborative Research and Development of Fundamental Technologies for Superconductivity Applications.

6. REFERENCES

[1] T. Satoh, M. Hidaka and S. Tahara: IEEE Trans. Appl. Supercond. **9** (1999) 3141.
[2] A. Fujimaki, K. Kawai, N. Hayashi, M. Horibe, M. Maruyama and H. Hayakawa: IEEE Trans. Appl. Supercond. **9** (1999) 3436.
[3] M. Murakami, S. I. Yoo, T. Higuchi, N. Sakai, J. Weltz, N. Koshizuka and S. Tanaka: Jpn.J. Appl. Phys. **33** (1994) L715.
[4] M. Badaye, W. Ting, K. Hukushima, N. Koshizuka, T. Morishita and S. Tanaka: Appl. phys. Lett. **67** (1995) 2155.
[5] C. D. Brandle and V. J. Fratello: J. Mater. Res. **5** (1990) 2160.
[6] A. T. Findikoglu, C. Doughty, S. Bhattecharya, Q. Li, X. X. Xi, T. Venkatesan, R. E. Fahey, A. J. Strauss and J. M. Phillips: Appl. Phys. Lett. **61** (1992) 1718.
[7] B. H. Moeckly and K. Char: Appl. Phys. Lett **71** (1997) 2526.

(Received October 13, 2003; Accepted March 5, 2004)