Josephson Effect in High-T_c superconductor $YBa_2Cu_3O_x$

Toshio BANDAI, Miki GOTO and Hiroji MITSUHASHI

Abstract

A high-T_c superoconductor $YBa_2Cu_3O_x$ of T_c (zero)=91.5 K was prepared. Weak-link Josephson junctions were fabricated from rods of $YBa_2Cu_3O_x$ ceramics. The dc and ac Josephson effect effects were observed at the liquid nitrogen temperature.

1. Introduction

The discovery of high-critical-temperature (hereafter abbreviated to high-T_c) superconductivity with an onset temperature of 30 K in the La-Ba-Cu-O[1] system has stimulated wide interest in the research of superconductive oxides. It was identified that the superconductive phase was a layer-like K_2NiF_4 type $La_{2-x}Ba_xCuO_4$ compound.[2] Cave *et al.*[3] reported the superconductivity of $La_{2-x}Sr_xCuO_4$ of an onset temperature of 36 K. Wu *et al.*[4] reported the superconductivity in the Y-Ba-Cu-O system with an onset temperature of 93 K well above the liquid nitrogen temperature (77 K). This surprisingly high-T_c superconductive phase was identified as an orthorhombic, oxygen-deficient perovskite of stoichiometry $YBa_2Cu_3O_{7-y}$.[5] Maeda *et al.*[6] reported the superconductivity in the Bi-Sr-Ca-Cu-O system with an onset temperature of 105K. Z.Z. Sheng and A.M. Hermann[7] reported the superconductivity in Tl-Ba-Ca-Cu-O systm with an onset temperature of 120K. Research of these Bi-Sr-Ca-Cu-O and Tl-Ba-Ca-Cu-O systems is now in progress in the world.

There were reports of the Josephson effects in the $YBa_2Cu_3O_x$ system[8~10]. The Josephson junction in general is a macroscopic quantum phase detector capable of probing the wave nature of the superconductive system. It can be shown by such junctions that the superconductive condensate has charge $2e$ in spin-singlet state.

In this paper, the Josephson junctions were fabricated by the high-T_c superconductor $YBa_2Cu_3O_x$. This is of interest because it may help in investigating the mechanism that causes the superconductivity, and lead to the development of practical superconductive devices which operate at 77 K.

2. Preparation and resistivity measurement

Ceramics of $YBa_2Cu_3O_x$ were prepared through the solid state reaction. A powder of reagent grade Y_2O_3, $BaCO_3$ and CuO was weighted in a ratio of Y : Ba : Cu=1 : 2 : 3, crushed and mixed with a mortar and pestle. The mixed powder was placed in alumina crucibles and calcined at 850℃ for 9 h in a flowing oxygen atmospher. The calcined powder was pulver-

Received September 28, 1988

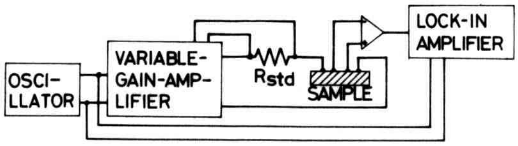

Fig. 1. A block diagram of the apparatus for measuring the resistance by the ac "four-lead" method.

ized with the mortar and pestle and calcined again at 850℃ for 9 h. The powder was pulverized and poured into a die and pressed into a pellet. The pellet was sintered at 950℃ for 12 h in a flowing oxygen atmosphere.

A "four-lead" method was used to measure the electrical resistance of the superconductive ceramics. In Fig. 1, an ac current from a variable-gain-amplifier at a frequency of 30Hz passed through a standard resistor R_{std} and a sample. The gain of variable-gain-ampifier varied so that a constant rms current passed through the standard resistor and the sample. The voltage across the sample was measured by using a differential amplifier and a lock-in amplifier. This ac technique avoided thermal and contact emf's and could increase the S/N ratio by filtering out noise. Silver paste was used to apply leads to samples.

The temperature of the sample was measured by an Au+0.07% Fe-chromel thermocouple.

Figure 2 shows the temperature dependence of the resistivity for the sample of $YBa_2Cu_3O_x$. The sample was cut to a rod of $0.10\times0.13\times0.80$ cm^3 in size by a diamond-edged cutting wheel. The resistivity at room temperature was 1.3 mΩ・cm. A narrow supercon-

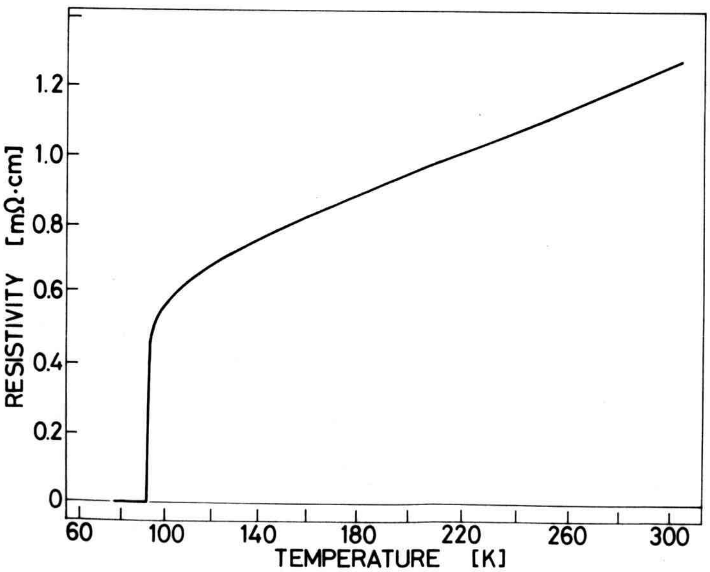

Fig. 2. The temperature dependence of the resistivity of the high-T_c superconductor $YBa_2Cu_3O_x$.

ducting transition of 4K width with an onset temperature of 95 K and zero resistivity at 91.5 K was observed.

3. Fabrication of Josephson junctions and its characteristics

In Fig. 3, a superconductive $YBa_2Cu_3O_x$ rod of $0.10\times0.13\times8.6$ cm^3 in typical size was bonded to a glass substrate by using an epoxy resin to support the sample mechanically. The diamond-edged cutting wheel was used to cut a 0.5 mm slot in the sample, leaving a small link connceting the two "islands" of superconductor. Then the link was cut carefully by hand, using a razor blade. The Josephson critical current of the junction was related to its resistance at room temperature. We could obtain favorable result when the resistance of the junction was about 1Ω at room temperature. We could not observe the supercurrent

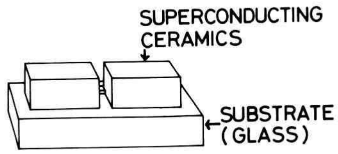

Fig. 3. A shematic view of the Josephson junction.

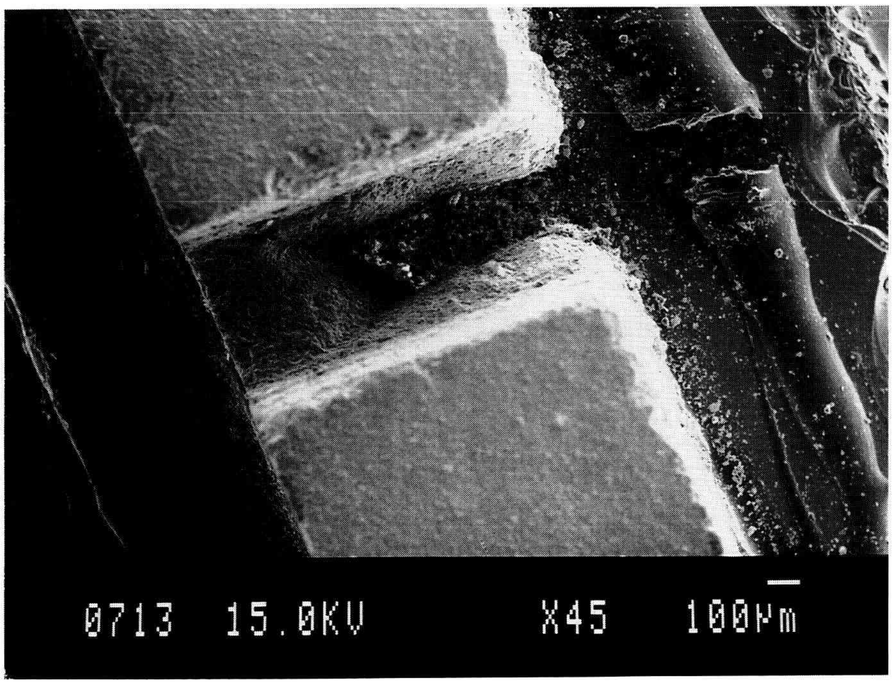

Fig. 4. A SEM photograph of the Josephson junction fabricated from the high-T_c superconductor $YBa_2Cu_3O_x$.

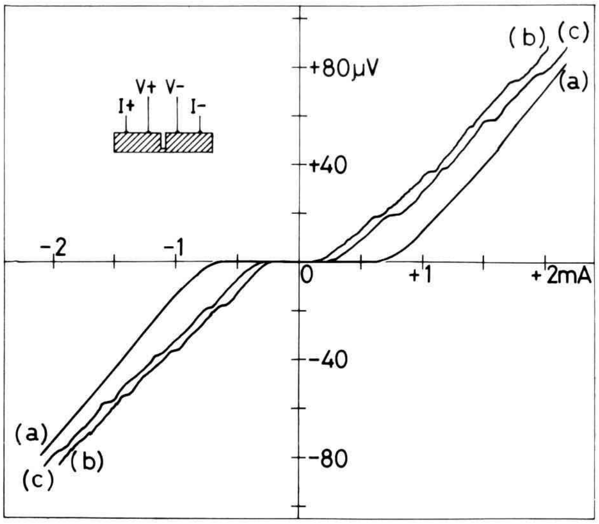

Fig. 5. The I-V characteristics of one of the Josephson junctions at 77K, (a) when a microwave radiation is turned off, (b) when a microwave radiation (f=8.80GHz) is applided to the junction, (c) when a microwave radiation (f=9.32GHz) is applied to the junction.

at 77K when the resistance of the junction was greater than 5Ω at room temperature.

Figure 4 shows the one of the fabricated Josephson junctions observed by using a JXA 840A scanning electron microscopy (SEM). The left side in Fig. 4 is the link connecting the upper and lower superconductive ceramics. The right side of the link is cut by using a rasor blade. The link sizes are typically 0.5 mm in length, 0.4 mm in width and 0.2 mm in thickness.

A dc current was supplied through the junction and the voltage across the junction was measured by using a microvoltmeter. A microwave radiation was lead to the junction by using a coaxial cable.

Figure 5 shows the typical current-voltage (I-V) characteristics of the Josephson junction at 77K. An (a)-curve represents the I-V characteristics of the junction when a microwave radiation is turned off. The Josephson critical current is about 1.2 mA. In Fig. 5, (b)- and (c)-curves represent the I-V characteristics when 8.80 GHz and 9.32 GHz microwave radiations are applied to the junction, respectively. Constant voltage steps, called the Shapiro-steps produced by the ac Josephson effect are observed up to four steps. The voltage differences between the observed steps for (b)- and (c)-curves are 18.4 μV and 19.3 μV, respectively.

The theoretical voltage difference is $hf/2e$, where the h, f and e are the Planck constant, applied microwave frequency and electron charge, respectively. Calculated voltage differences are 18.2 μV and 19.3 μV for the microwave frequencies of 8.80 GHz and 9.32 GHz, respectively. The observed voltage differenes agree well with the calculated values. This agreement shows that the superconductive condensate in this oxide has charge $2e$. The dominant carriers in the normal state in $YBa_2Cu_3O_x$ were exhibited to be holes from measurements of the Hall coefficient.[11] The mechanism leading to such high-T_c superconductivity of this materials is now under debate.

This type of Josephson junction is called a weak-link Josephson junction. We also attempted to make a point-contact Josephson junction by pressing a sharpend rod of $YBa_2Cu_3O_x$ against a flat pellet of $YBa_2Cu_3O_x$, but no superconductive current was observed at 77 K, regardless of the pressure of the point-contact.

As the coherent length of this material is ~34A,[12] the junction fabricated in this way is really very large. It is imagined that the bulk sample we used consits of a great number of grains contacting each other randomly and forming a complicated network of Josephson junctions.

4. Conclusions

We fabricated bulk ceramic Josephson junctions by using the high-T_c superconductor $YBa_2Cu_3O_x$. Both dc and ac Josephson effects were successfully observed in liquid nitrogen temperature.

Acknowledgements

We would like to thank Dr.Y. Ikuma for his advice and using his diamond-edged cutting wheel, Mrs.M. Tazaki for her operation of SEM, Mr.T. Kobayashi for lending us his microwave oscillator and Messrs. M. Anzawa, T. Ishii, H. Mitsuyasu, Y. Takahashi and K. Taoka for their help in preparation and measurements.

References

1) J.G. Bednorz and K.A. Muller : Z. Phys. B**64** (1986) 189
2) H. Takagi, S. Uchida, K. Kitazawa and S. Tanaka : Jpn. J. Appl. Phys. **26** (1987) L123
3) R.J. Cava, R.B. van Dover, B. Batlogg and E.A. Rietman : Phys. Rev. Lett. **58** (1987) 408
4) M.K. Wu, J.R. Ashburn, C.J. Torng, P.H. Hor, R.L. Meng, L. Gao, Z.J. Huang, Y.Q. Wang and C.W. Chu : Phys. Rev. Lett. **58** (1987) 908
5) R.J. Cava, B. Batlogg, R.B. van Dover, D.W. Murphy, S. Sunshine, T. Siegrist, J.P. Remeika, E.A. Rietman, S. Zahurak and G.P. Espinosa : Phys. Rev. Lett. **58** (1987) 1676
6) H. Maeda, Y. Tanaka, M. Fukutomi and T. Asano : Jpn. J. Appl. Phys. **27** (1988) L209
7) Z.Z. Sheng and A.M. Hermann : Nature **332** (1988) 138
8) I. Iguchi, A. Sugishita and M. Yanagisawa : Jpn. J. Appl. Phys. **26**, (1987) L1021
9) Y. Higashino, T. Takahashi, T. Kawai and S. Naito : Jpn. J. Appl. Phys. **26** (1987) L 1211
10) P.H. Wu, Q.H. Cheng, S.Z. Yang, J. Chen, Y.Li, Z.M. Ji, J.M. Song, H.X. Lu, X.K. Gao, J.Wu and X.Y. Zhang : Jpn. J. Appl. Phys. **26** (1987) L1579
11) S.W. Tozer, A.W. Kleinsasser, T. Penney, D. Kaiser and F. Holtzberg : Phys. Rev. Lett **59** (1987) 1768
12) T.K. Worthington, W.J. Gallagher and T.R. Dinger : Phys. Rev. Lett. **59** (1987) 1160