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Microwave Detector Using $YBa_2Cu_3O_{7-x}$ Grain Boundary Junction

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초 록 $YBa_2Cu_3O_{7-x}$ 결정입계 접합을 이용한 마이크로파 감지소자

$YBa_2Cu_3O_{7-x}$ 초전도체 박막을 화학증착법을 이용하여 $LaAlO_3$ 단결정 위에 증착하여 임계온도 90K 이상 임계전류밀도 $10^5A/cm^2$(77K) 이상의 우수한 박막을 제작하였다. 이를 포토작업과 이온밀링을 실시하여 수 마이크로미터 크기의 브릿지 형태로 만든 후 이들의 전류전압 특성을 조사하였다. 브릿지에 입사된 마이크로파의 크기에 따라 브릿지 간의 임계전류값의 저하가 관찰되었으며 동시에 샤피로스텝을 관찰할 수 있었다.

Abstract Microwave Detector Using $YBa_2Cu_3O_{7-x}$ Grain Boundary Junction

$YBa_2Cu_3O_{7-x}$ superconductor thin films were deposited on $LaAlO_3$ (100) single crystal substrates using a metal organic chemical vapor deposition (MOCVD) method. These films showed the critical temperature of about 90K and critical current density of over $10^5A/cm^2$ at 77K. These films showed granular structure with $0.5\sim1.5\mu m$ grains. Bridge-type junctions, $6\mu m$ in width and $6\mu m$ in length, were fabricated using the photolithography and the Ar ion milling techniques. Current-voltage (I-V) characteristics of these junctions with the microwave irradiation at 77K were studied. The critical current densities decreased as the irradiated microwave power increased. When microwaves were irradiated on the bridge at 77K, the I-V charateristics showed constant voltage steps(Shapiro steps) at $\Delta V = nh\upsilon/2e$.

1. Introduction

In 1962, Brian D. Josephson theoretically predicted Josephson effects which state that (1) at finite voltages, the usual DC current occurs, but there is also an AC supercurrent of frequency 2eV/h and (2) at zero voltages, a DC current up to a maximum of $|J_i|$ can occur in superconductor junction. If a DC voltage on which is superimposed an AC voltage of frequency υ is applied, the DC characteristic has a zero slope resistance part at $2eV/h = n\upsilon$, where n is an integer[1]. An AC supercurrent was detected in 1963 by Shapiro by observing constant voltage steps[2]. After the observation of Josephson effects at weak links[3], active researches were performed for the applications of the effects. The effective length, l, of the bridge should satisfy the condition of $l \leq 3\sim5\ \xi$ to observe Josephson effects, where ξ is the coherence length[3]. As the coherent lengths of the low Tc superconductors are about several hundreds to several thousands angstrom, Josephson junctions can be fabricated without much difficulty using many methods but the coherent lengths of the high Tc superconductors are a few angstrom, it is difficult to fabricate Josephson junctions with high Tc superconductors. Josephson junctions have been successfully fabricated using natural grain boundaries, but the reliability and the repro-ducibility of the junctions are poor[4].

The objective of this study is to fabricate a microwave detector using a bridge type Josephson junction of $YBa_2Cu_3O_{7-x}$ superconductor thin film deposited using metal organic chemical vapor deposition (MOCVD) method. In order to reach the objective, following researches were carried out in this study : (1) deposition of $YBa_2Cu_3O_{7-x}$ superconductor thin films using MOCVD method, (2) photolithography and etching of the films using an Ar ion milling system to fabricate the bridge, (3) verifying Josephson junction by observing Shapiro steps with microwave irradiation on the bridge, (4) studying the I-V characteristics of bridge with and without microwave irradiation.

2. Experimental

$YBa_2Cu_3O_{7-x}$ superconductor thin films used in this study were deposited using the metal organic chemical vapor deposition(MOCVD) method on $LaAlO_3$(100) single crystal substrates. The details of the film deposition procedure were reported in a previous paper[5]. $LaAlO_3$ single crystal substrates have been known as an excellent substrates for the microwave detection applications because of their low dielectric losses. The precursors used in this study were $Y(thd)_3$, $Ba(thd)_2$, $Cu(thd)_2$ (thd=2, 2, 6, 6 tetramethyl 3, 5 heptadionate).

An X-ray diffractometer with Cu Kα radiation monochromatized by a graphite single crystal was used to analyse the orientation of the films. The microstructure of the thin film and the bridge were observed using a scanning electron microscope(SEM). The superconducting transition temperature and the current voltage(I-V) characteristics of the bridges were measured using a four-point probe method. The point contacts were made with indium. Bridge type natural grain boundary Josephson junctions were fabricated using a photolithography technique and dry etching using an Ar ion milling. The Ar ion beam was parallel to a bridge and tilted by 60° to the normal of the surface. The etching rate of Ar ion milling was about 140 Å/min.

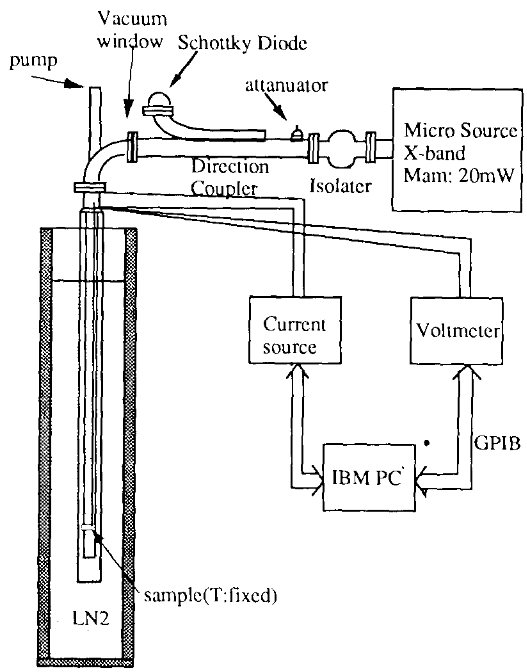

Fig. 1. A schematic diagram of the microwave detecting system used in this study.

Figure 1 shows a schematic diagram of the microwave detection system. The microwave detection system consists of four parts : a microwave source, wave guides, a cryostat, and an I-V characteristics measurement system. The microwave source(Wavetec model 955) generates frequencies of 7.50GHz~12.40GHz.

The microwave power was measured using a Schottky diode located at the one end of the directional coupler. The wave guide was rectangular type, and the propagating wave was a TE mode. After a specimen was mounted on the mount located on the position of approximately quarter of the wavelength apart from the bottom of the wave guide, the cryostat filled with He gas was cooled down to 77K in liquid nitrogen. With and/or without the microwave irradiation, the I-V characteristics of the bridges were measured using a computer interfaced measurement system consisting of a currrent source(Keithley model 228A) and a voltmeter(Hewlett-Packard model 3441A).

3. Results and Discussion

Figure 2 shows an X-ray diffraction(XRD) pattern of a thin film deposited on $LaAlO_3$ (100) single crystal substrate. The XRD pattern consists of mainly (001), some(h00) and small other peaks, which indicate that the a-b planes of dominant superconductor grains in this film are parallel to the $LaAlO_3$ substrate. The films showing only (001) peaks in their XRD patterns were also successfully deposited on the $LaAlO_3$ substrate, but Shapiro steps in I-V curves were detected for the films showing some misorientation rather than the films showing only (001) peaks. This observation may indicate that the weak links in grain boundaries were originated from the misorientation between the grains.

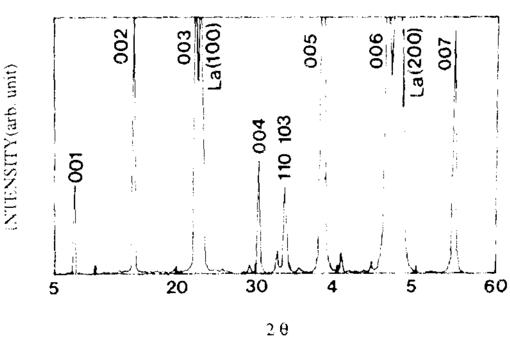

Fig. 2. An X-ray diffration pattern of the $YBa_2Cu_3O_{7-x}$ thin film deposited on $LaAlO_3$(100) single crystal substrate.

Figure 3 shows the resistance vs. temperature curve of the films deposited on the $LaAlO_3$ (100) single crystal substrate. The films had Tc of about 90 K and small tails. The film showing only (001) peaks in their XRD patterns showed Tc of above 90 K and the transition width was within 0.5K without tail. But the films showing some misorientation were better for observing Shapiro steps. The critical current density(Jc) of the films on $LaAlO_3$ substrate at 77K was over $10^5 A/cm^2$ which was one order lower than that of the films showing only (001) peaks in their XRD patterns.

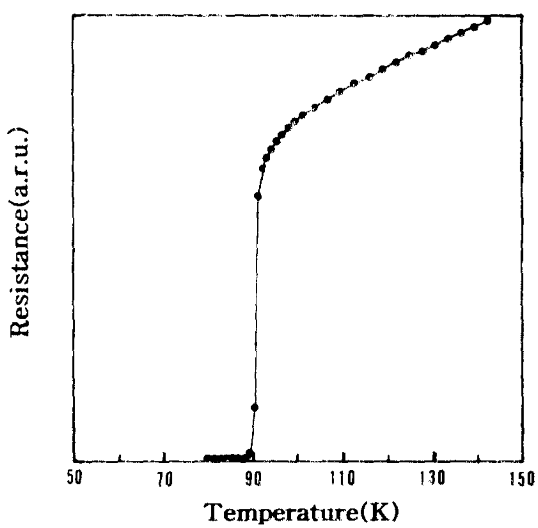

Fig. 3. Resistance vs. temperature curve of the film deposited on a $LaAlO_3$(100) single crystal substrate.

Figure 4 shows a bridge fabricated with a thin film on $LaAlO_3$(100) substrate using the photolithography and the Ar ion milling techniques. The size of the bridge is 6μm in width and 6μm in length. As shown in Fig. 4, diameter of grains on the bridge region is in the range of 0.5～1.5μm.

Figure 5 shows the I-V characteristics of the bridge made of the superconductor film on the

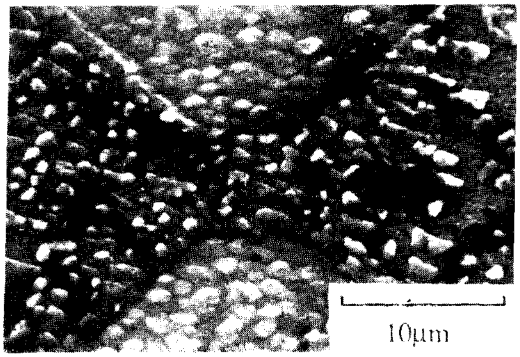

Fig. 4. SEM photomicrograph of the 6㎛ bridge fabricated on the superconductor film deposited on a $LaAlO_3$(100) single crystal substrate.

$LaAlO_3$(100) substrate with and without microwave irradiation at 77K(whose XRD pattern and microstructure are shown in Fig. 2 and Fig. 4, respectively). The I-V curves showed flux flow type behavior. But without the microwave irradiation, constant current steps which can be the proof of the flux flow type junction were not observed[9]. Neither the subharmonic steps in the I-V curve were observed which also can be the proof of the flux flow type junction[10,11,12]. With the irradiation the critical current decreased and constant voltage steps which were consistent with the frequency of microwave were observed.

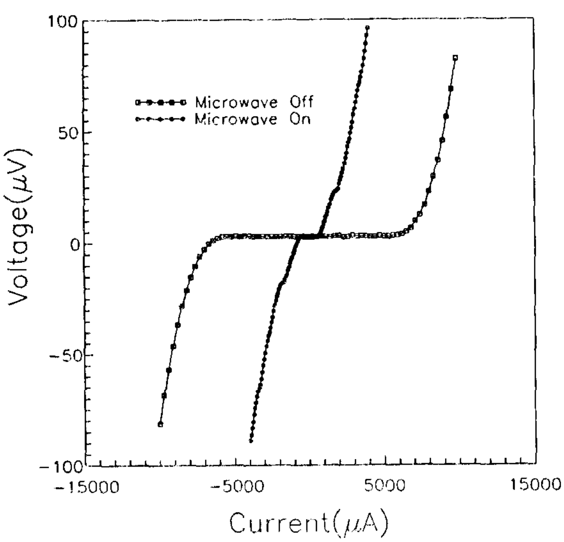

Fig. 5. I-V characteristics of the bridge fabricated on the superconductor film with and without a microwave irradiation at 77K.

Figure 6 shows the I-V characteristics of the bridge when microwaves were irradiated at 77K. Constant voltage steps are observed at the voltage intervals of about 20.6μV and 16.2μV when the microwave frequencies are 9.95GHz and 7.83GHz, respectively. The arrows indicate the constant voltage steps. These values are consistent with the step voltages calculated using the relationship : $\Delta V = nhf/2e$, where h is the Planck constant, e is the electric charge, f is the frequency of the microwave, and n is an integer. If there are several junctions in series in a bridge, we may observe enhanced voltage steps in the voltage spacings, $\Delta V = nhf/2e$[6]. The observed voltage steps suggest that only one Josephson junction is effective in the bridge region. The reason for only effective Josephson junction in the relatively long bridge(about 6㎛) in this study is not clear at the moment.

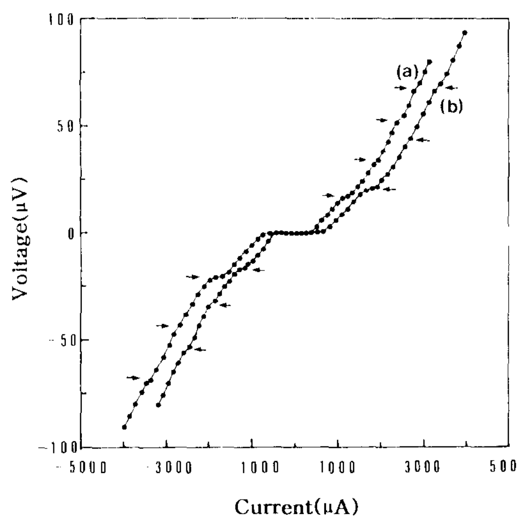

Fig. 6. I-V characteristics of the bridge fabricated on the superconductor film with microwave of (a) 7.83GHz and (b) 9.95GHz irradiations at 77K. The arrows indicate the constant voltage steps.

Figure 7 shows the I-V characteristics of the bridge with 9.95GHz microwave irradiation having different microwave power levels at 77K. As the microwave power increased, the current height of the constant voltage step at n=o decreased to zero, but the current height at n=1 increased for relatively low microwave power levels and then decreased to zero for relatively high microwave power levels. It has been known that the width of the constant voltage steps depends on the value of normalized frequency[7]. The normalized frequency, Ω, is defined as $\Omega = h\upsilon/2eI_cR_N$, where I_c is the critical current of the bridge, and R_N is the normal resistance of the bridge. For a relatively high Ω, the width of the steps is large and more steps can be observed. As the Ω value decreases, the width of the steps decreases and the step finally disappears at $\Omega=0$ for a limiting case. The Ω value of the film deposited on the $LaAlO_3$ substrate was 0.064 (where f=9.95GHz, I_c=8mA, and R_N=40mΩ) which is about 10^{-3} order lower than the value reported in other studies[7-8]. Relatively small width of the constant voltage steps observed in this study is consistent with the Russer's prediction in which a low value of normalized frequency produces a small width[7].

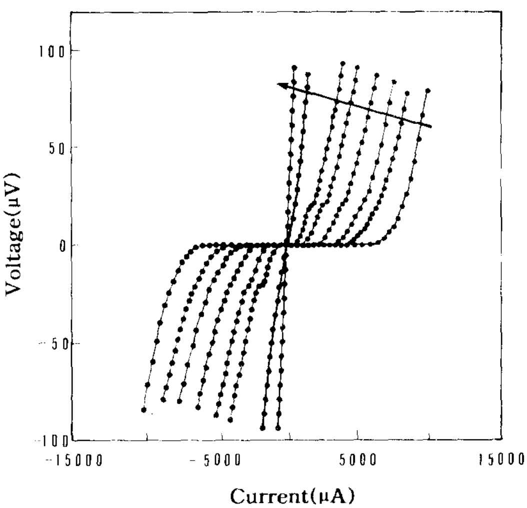

Fig. 7. I-V characteristics of the bridge fabricated on the superconductor film irradiated at 9.95GHz microwave having different microwave power levels the arrow indicates the increase in the microwave power at 77K.

4. Conclusions

We studied the Josephson junction fabricated on $YBa_2Cu_3O_{7-x}$ superconductor thin film deposited by an MOCVD method. Microbridges, which are 6μm in width and 6μm in length, were fabricated using the photolithography and the dry etching using an Ar ion milling. The establishment of the bridge type Josephson junction was verified by observing Shapiro steps. The constant voltage steps corresponding to the Josephson frequency were observed when the microwave was irradiated on the bridge. Even though the bridge included many grain boundaries, substeps did not appear on the I-V charateristics, and only one Josephson junction was effective in the bridge region. Because Ω was very small for the bridge, the current height of the constant voltage step was relatively small. The microwave detector fabricated with bridge type natural grain boudary Josephson junction would be useful to detect the microwave.

Acknowledgements

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