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Electrical Properties of $Al/Al_2O_3/(Ba,Rb)BiO_3/SrTiO_3(Nb)$ Three Terminal Device

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A three terminal device of $Al/Al_2O_3/(Ba,Rb)BiO_3$/Nb-doped $SrTiO_3$ structure with superconducting base material was fabricated. The stable interface between $(Ba,Rb)BiO_3$ and artificial oxide barrier was obtained using in-situ Al_2O_3 deposition. The output characteristics were measured as functions of input current. Common emitter output characteristics showed the current gain greater than 2.

1. Introduction

Recently, "carrier injection" type transistors have been investigated for high gain and high frequency operation using microfabrication, thinner base layer and so on. Although quite a thin base layer is used to give a high gain, the large base resistance of the device prevents its high frequency operation. For solving the problem, a number of hot electron transistor (HET) such as the metal base transistors[1-3] (MBT) and heterojunction bipolar transistors[4] (HBT) have been proposed. One of these is the superconducting base transistor[5-7] that uses a superconductor as its base. The device allows the base to be thinner than that of conventional metal base transistors due to reduction of its resistance, and can be operated at ultrahigh frequencies[8] and lower consumption.

We have studied $(Ba,Rb)BiO_3$ (hereafter BRBO), which is more advantageous than conventional Cu-based superconductors in that it has a coherent length as long as 5 - 7 nm[9] without electrical anisotropy, and its film can be formed at such relatively low temperatures as 300-400°C.[10] Since a growth of superconducting thin film has a marked influence on device characteristics, we have established a deposition technique using the molecular beam epitaxy (MBE) method with distilled ozone.[11,12]

In this study, we have been investigated the electrical properties of three terminal devices using artificial Al_2O_3 insulator layer as a reproducible tunneling emitter barrier. The characteristics of Al/Al_2O_3/BRBO emitter junction and electrical properties of the three-terminal device with structure of Al/Al_2O_3/BRBO/Nb-doped $SrTiO_3$ are described in this paper.

2. Experimental

A schematic fabrication process and a top view of the three-terminal device are shown in Fig.1. The BRBO thin films were prepared on niobium doped STO(110) substrate (hereafter STO(Nb)) at a substrate temperature

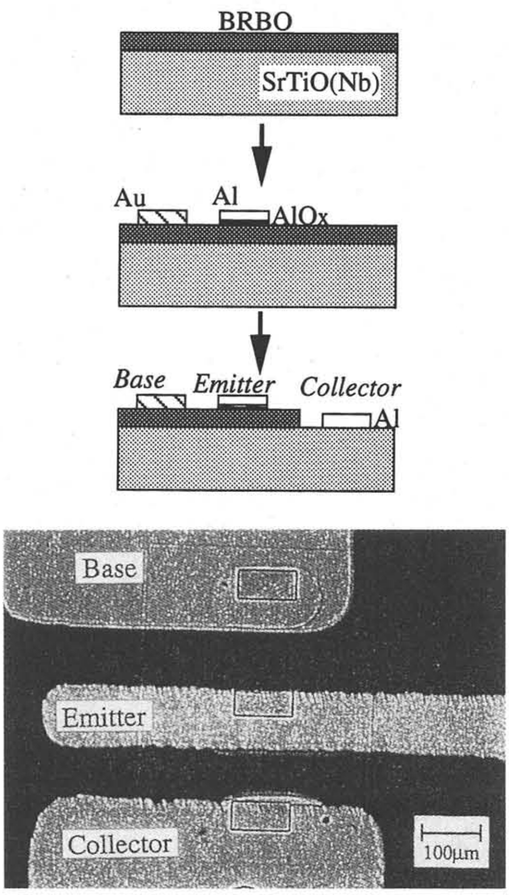

Fig.1 A schematic fabrication process and a top view of the $Al/Al_2O_3/(Ba,Rb)BiO_3/SrTiO_3(Nb)$ device.

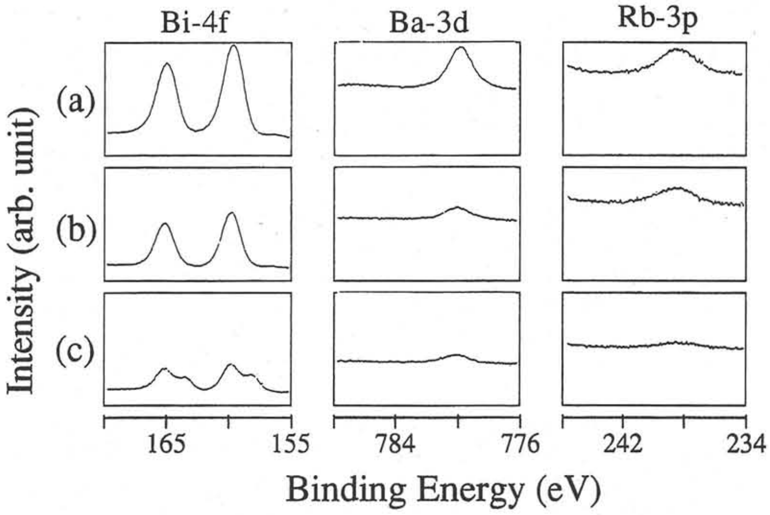

Fig.2 Bi-4f, Ba-3d and Rb-3p XPS spectra from BRBO thin films.
(a) as grown BRBO surface.
(b) after Al_2O_3 deposition on BRBO.
(c) after Al direct deposition on BRBO.

(Ts) of 370°C by MBE using distilled ozone. For an emitter barrier, ~40Å thick Al_2O_3 film was formed on BRBO/STO(Nb) by electron beam at room temperature. Aluminum (Al) was then deposited using resistive heating evaporation through metal masks as an emitter electrode. The size of the emitter junction was 100x300 μm^2. These elements were coated with a photoresist, and the BRBO film was formed into a 400x400 μm^2 pattern by photolithography followed by Ar^+ dry etching. An additional Al film of 500 nm in thickness was deposited as an ohmic electrode for the STO(Nb), and finally, the entire surface was protected with a photoresist.

3. Results

3.1 XPS measurements

X-ray photoelectron spectroscopy was used to investigate the chemical bond states between BRBO and oxide barrier. Figure 2 shows Bi-4f, Ba-3d and Rb-3p spectra from as grown BRBO (a) and BRBO after Al_2O_3 deposition on it (b). To compare artificial and natural barriers, the chemical bond state of BRBO after metal Al direct deposition on it was shown in Fig.2 (c). Figure 2 (c) indicated that the chemical bond state of Bi-4f from BRBO films can be explained by multiple-valence states. From results of the signal processing, the peak at around 157.4eV and the shoulder at around 156.2eV were obtained. The XPS spectra of Al also showed multiple-valence states, though it was not shown in Fig.2. This may suggest that the BRBO surface reacts with metal Al, and the natural barrier is formed between BRBO and Al. On the other hand, Fig.2 (b) indicates that the Bi peak position does not change with Al_2O_3 deposition, and a stable interface between BRBO and artificial Al_2O_3 barrier is obtained without the degradation of BRBO surface. These results mean that the *in situ* Al_2O_3 deposition is effective for the formation of emitter barrier.

3.2 Diode characteristics

Figure 3 shows diode characteristics of the $Al/Al_2O_3/BRBO$ junction. It was found that the junction shows rectifying characteristics, and the forward and backward currents are proportional to a square of the voltage.

3.3 Output characteristics

Figure 4 shows output characteristics (Ic-Vce) of the device of common emitter configuration. The current begins the flow from the emitter to the collector at around 2.2 V. It was found that the current gain β of the device is 3 or less for the base current of 2.25μA at

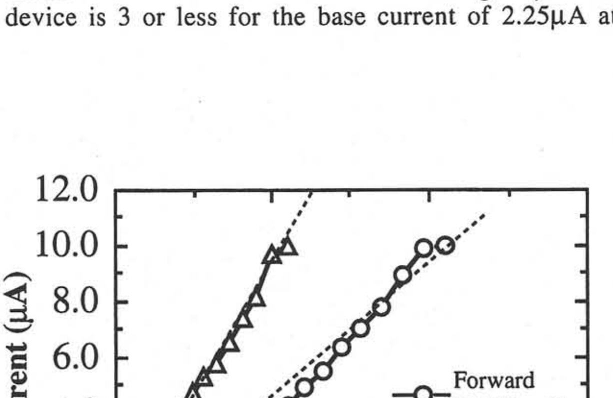

Fig.3 Diode characteristics of the $Al/Al_2O_3/BRBO$ junction.

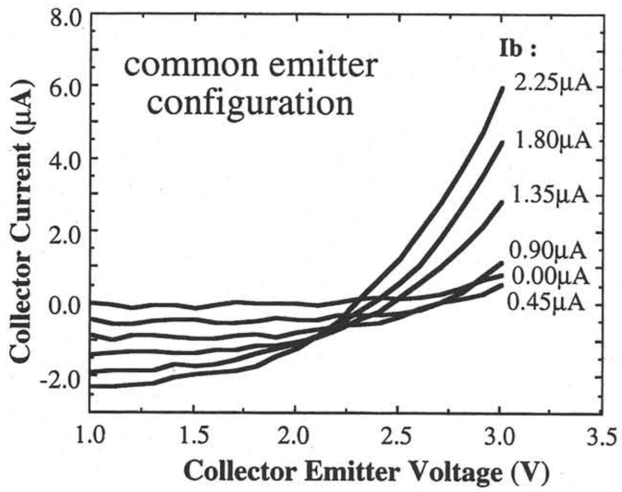

Fig.4 Output characteristics of the device of common emitter configuration.

Vce=3.0V. This figure shows non-saturating characteristics and the output resistance is of the order of a few hundred kilohms. On the other hand, Input voltage - Output voltage characteristics with constant base current indicated that leakage currents increase with increasing Vce. This limited the voltage gain of this device to several percentages. It is necessary to reduce the leakage for better performance.

4. Discussion

The operation mechanism in this device is discussed below. Many experimental works had performed on active devices with amplification.[2,13-18] Some groups pointed out that a "hot electron" ballistic transport may occur in the metal base. However, there is no evidence for the "hot electron" ballistic transport through the base.[2,13-15] Recently, several papers described that the structure with conducting paths between the emitter and the collector regions can be considered as a field effect type transistor.[16-18] In this device, i) emitter barrier is amorphous layer, ii) growth of BRBO thin film as base layer is a three-dimensional growth,[12] iii) ballistic transport is not yet confirmed. Therefore, we can not deny that the current flow through pinholes under the potential of the base (like a field effect transistor).

5. Conclusions

A three terminal device of Al/Al_2O_3/BRBO/STO(Nb) structure with superconducting base material was fabricated. A stable interface between BRBO and artificial oxide barrier is obtained using *in situ* Al_2O_3 deposition. The output characteristics were measured as a function of input current. Common emitter output characteristics showed a current gain greater than 2.

Acknowledgments

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