Fabrication Process and Calculated Characteristics of In/(Ba,Rb)BiO₃/Sr(Ti,Nb)O₃ Normal Conductor and Superconductor Base Transistors

Tomoyuki YAMADA, Ryoudou KAWASAKI and Hitoshi ABE
Research Laboratory, Oki Electric Industry Co., Ltd.
550-5, Higashiasakawa-cho, Hachiouji-shi, Tokyo 193, Japan

Fabrication process of In/(Ba,Rb)BiO₃/Sr(Ti,Nb)O₃ transistors was studied. It was found that Au and In deposit on BRBO films without the exposure to the air lead to low contact resistance pₑ and good reproducibility. Dry-etched Sr(Ti,Nb)O₃ surface generated high pₑ and was recovered by acid etching. Devices of about 30μm size were successfully fabricated by photolithography and lift-off method. A calculation with experimental results showed that the power gain is much increased by the transition to a superconducting state.

1. INTRODUCTION
Superconducting base transistors have an extraordinary ability due to an extremely low base resistance. We have obtained transistor operation in oxide devices using (Ba,Rb)BiO₃ (hereafter BRBO) superconductor films. However, we have not yet observed the improvement in the characteristics by the transition to a superconducting state. To obtain it, we need low contact resistance pₑ, small-size device, and so on. In this paper, we study the fabrication process to get better performances and the improvement from the point of view of electronic circuit.

2. FABRICATION PROCESS
In order to reduce the influence of process damage on BRBO film, we have used dry and low temperature (<80°C) process in the fabrication of transistors.
(i) Process with metal deposit through metal mask
We designed a fabrication process as shown in Fig.1. For devices larger than a few hundreds μm size, we could first deposit Au and In films through metal masks on BRBO film to reduce the influence of the degradation of BRBO surface. Nevertheless the exposure of BRBO surface to the air generates the rather high pₑ and the poor reproducibility of In/BRBO junction. Thus we tried to deposit metal films through metal masks on as-grown BRBO film without the exposure to the air.
We obtained the ohmic contact to BRBO films by the deposit of Au film through metal mask which was put on BRBO film in N₂ atmosphere. pₑ was 5×10⁻⁵ Ωcm² at 11K, as shown in Fig.2. XPS measurement for as-grown BRBO surface indicated that Ba was a little poor at the surface while Rb was rather constant, as shown in Fig.3. Heating BRBO film in a vacuum at about 520K for 15min. did not bring forth the

Fig.1 Outline of fabrication process with metal masks for In/BRBO/STO(Nb) transistor.
reduction in $p_c$, resulting in the spread of Ba-poor region. To control the surface and to select contact metal will lead to lower $p_c$.

Figure 4 shows current-voltage characteristics of an In/BRBO junction at room temperature, which was in situ formed at a background pressure of $10^{-4}$-$10^{-5}$ Pa. The junction showed a rectifying property. This indicates that the natural barrier of BRBO surface give little influence on the rectification itself.

The combination of In and Au deposits through metal masks are useful for the fabrication of devices, because the in-situ alignment of metal masks is possible.

It was found that Ar$^+$ dry etching in the formation of BRBO base region(Fig.1b) degrade the surface of Sr(Ti,Nb)O$_3$ (hereafter STO(Nb)) and the surface was recovered by acid wet etching. The temperature dependence of $p_c$ in CR/STO(Nb) contact is shown in Fig.2. $p_c$ of 2.5x10$^{-5}$ $\Omega$cm$^2$ was obtained at 11K.

(ii) Process with photolithography and lift-off method

For the fabrication of smaller devices, we have developed the process with photolithography and lift-off method. An outline of the process is shown in Fig.5. Lift-off method was useful in reducing the process damage to BRBO film and simplifying the process. We used LMR resist because of the good lift-off and the waterless use. Indium was first deposited through a metal mask on BRBO film to reduce process damage(a). After the formation of a base region(b,c), SiO$_2$ passivation film pattern was formed by the photolithography and lift-off method(c,d). SiO$_2$ was deposited by electron-beam method. Ohmic contact and contact pad patterns were formed in the same way(e-g).

Considering the adhesion to SiO$_2$ film, we used Au alloy as an ohmic contact to BRBO film and used Au/Cr as an ohmic contact to STO(Nb) and an contact pad to In. Figure 6(a) shows a top view of a device. Small, medium, large and largest rectangles are the windows of the SiO$_2$ passivation film, the In film, the ohmic contact(contact pads) and the BRBO film respectively. In the device, Au/BRBO contact had rather high $p_c$.  

![Fig.4 Current density vs voltage characteristics in In/BRBO junction at room temperature. Indium film was in situ deposited on BRBO film and was positively biased.](image)

![Fig.2 Contact resistance of Au/BRBO and Cr/STO(Nb) as a function of temperature.](image)

![Fig.3 XPS intensities of Ba4d(90eV), Rb3d(110eV), Bi4f(160eV) and O1s(530eV) as a function of 1/sin$\theta$. $\theta$ is an angle between the sample surface and the detection direction.](image)
In deposit through metal mask
Photolithography
Dry etching
Photolithography
SiO₂ deposit by EB
Lift-off
Photolithography
Au alloy deposit
Lift-off
Photolithography
Au/Cr deposit
Lift-off

Fig. 5 Outline of process of smaller-size devices by photolithography and lift-off method.

To reduce $\rho_c$, it is desirable that Au alloy should be deposited at the early stage of the process. The size of device is limited by the size of metal mask. Device structures of ~30 μm size were successfully fabricated without the first In deposit through metal mask. Figure 6(b) shows a part of the device.

3. CALCULATED CHARACTERISTICS

We have already measured DC and AC characteristics of BRBO/STO(Nb), In/BRBO junctions 2) and DC characteristics of In/BRBO/STO(Nb) transistor. From the result, we calculated the maximum available power gain $G$ of the transistor using an equivalent circuit model 1) by D.J. Frank et al. It was found that $G$ in a superconducting state (<29K) is 12 times as large as that in a normal conductor state (>29K) in a device of 25x100 μm size and a contact resistance $\rho_c$ of $10^{-6} \Omega \text{cm}^2$ though $G$ is 6 times in a device of 400x500 μm size and $\rho_c$ of $10^{-4} \Omega \text{cm}^2$.

4. CONCLUSION

Fabrication process of In/(Ba,Rb)BiO₃/Sr(Ti,Nb)O₃ transistors was studied. In-situ metal deposit was useful for the reduction in contact resistance $\rho_c$ and the good reproducibility. The etching of dry-etched Sr(Ti,Nb)O₃ surface with an acid also led to the reduction in $\rho_c$. Devices of about 30μm size were successfully fabricated by photolithography and lift-off method. The calculation with experimental results showed that the power gain of the device is much increased by the transition to a superconducting state.

ACKNOWLEDGEMENT

This work was supported by NEDO.

REFERENCES