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C — 2 — 2 Fabrication of High Quality NbN/Pb Josephson Junction

Fujitoshi SHINOKI, Susumu TAKADA, Shin KOSAKA and Hisao HAYAKAWA
Electrotechnical Laboratory
5-4-1 Mukodai-Machi, Tanashi-shi, Tokyo 188, JAPAN

In this paper, we report high quality Josephson tunnel junctions on niobium nitride (NbN) by using a microfabrication technique. Niobium nitride is one of promissing materials for Josephson devices since it has a high superconducting transition temperature (T_c= 16 K) and the film can be easily obtained by reactive sputtering. Moreover, it is expected that the use of mechanically hard materials such as NbN as a base electrode of the junction can provide us stable tunnel junctions against thermal cyclings and long term storage.

Figure 1 shows the fabrication process of NbN/Pb tunnel junctions. In order to get a base electrode pattern for NbN films, we employ a ZnO film as a mask material which can be used at high substrate temperature during the deposition of NbN films. About 2 μm thick ZnO film was sputtered on a Si substrate, then patterned using an usual photoresist process. The ZnO film was etched in 1 % H_3PO_4 solution to form a base electrode pattern of the junction.[1] Approximately 300 nm of NbN was deposited on the patterned ZnO film by rf reactive sputtering at the substrate temperature of 500°C. The sputtering was carried out under following conditions; P_{N_2} = 5.32 x 10^{-2} Pa, P_{N_2+Ar}= 6.65 x 10^{-1} Pa, and the deposition rate of about 23 nm/min. Then, the sample was rinsed in 1 % H_3PO_4 solution to remove the ZnO film, and a complete electrode pattern of the NbN film was formed.
The upper electrode pattern was defined by using a photoresist(AZ-1350J). Before the deposition of about 320 nm thick Pb film, the junction area is sputter-cleaned to remove a polluted layer from the NbN surface and oxidized in pure oxygen gas (1 atm) at rocm temperature for 1 ~ 17 hours.

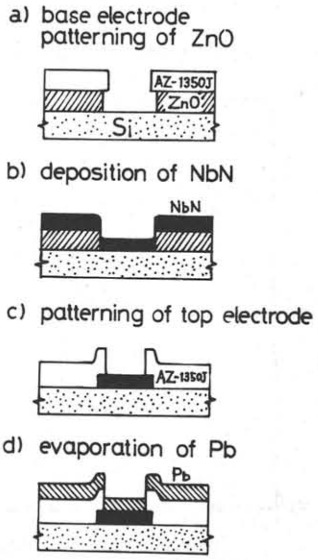

Fig.1. Fabrication process of a NbN/Pb junction.

Figure 2 shows a photograph of the I-V characteristics of one of Josephson junctions fabricated by using the above process. From observed gap and sub-gap voltages ($\Delta_{NbN}+\Delta_{Pb}$= 3.8 mV, $\Delta_{NbN}-\Delta_{Pb}$= 1.3 mV), the superconducting gap of the NbN film was estimated to be Δ_{NbN}= 2.55 mV. The maximum Josephson current was 0.6 mA for the junction(R_N= 3.3 Ω) shown in Fig.2. In the limit of the weak coupling, the maximum Josephson current at T = 0 K is given by

$$I_{J,max} = \frac{\pi}{eR_N} \frac{\Delta_{NbN} \Delta_{Pb}}{\Delta_{NbN} + \Delta_{Pb}} , \qquad (1)$$

where R_N is the normal tunneling resistance. Using Eq.(1) as an approximation to $I_{J,max}$ at 4.2 K, $I_{J,max}$= 0.8 mA is obtained. The measured value is reduced to about 75 % of the calculated one. This reduction may be explained by a consequence of the strong coupling correction.[2)]

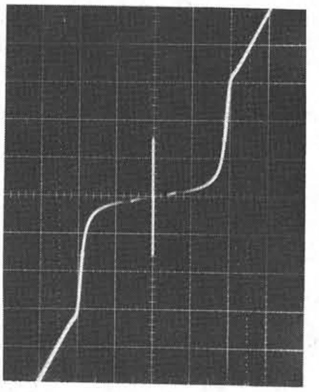

Fig.2. I-V characteristics of a NbN/Pb junction. (Horiz.: 2 mV/div., Vert. : 0.4 mA/div.)

The oxidation time dependence of the normal tunneling resistance is shown in Fig.3. The normal resistance depends linearly on the oxidation time, indicating that the oxide layer grows as a logarithmic function of the oxidation time as in the usual thermal oxidation. The uniformity of junction characteristics in junctions integrated on the same wafer was fairly good, i.e., the scatter of R_N was only within 5 %.

Figure 4 shows the change of R_N against the sample storage time in air and thermal cyclings between 4.2 K and the room temperature. The resistance change is extremely small(< 1%) which shows that the junction is quite stable as shown in Fig.4.

In conclusion, we have fabricated high quality NbN/Pb Josephson junctions using the ZnO film for patterning NbN films. High T_c materials such as NbN would be promissing materials for Josephson devices in future electronic devices.

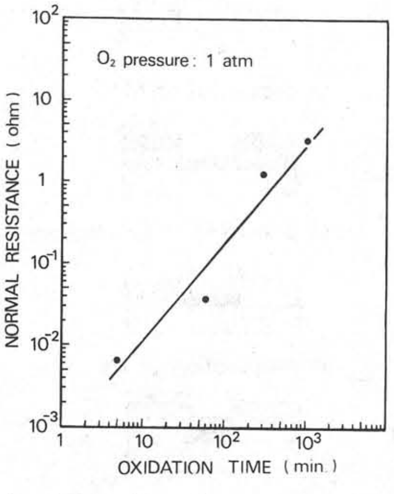

Fig.3. Normal resistance as a function of the oxidation time.

References
1) K.Asakawa and K.Nishikawa;Japan.J.Appl.Phys., 16 (1977),Suppl.16-1,p.487.
2) T.A.Fulton and D.E.McCumber;Phys.Rev.,175(1968) 585.

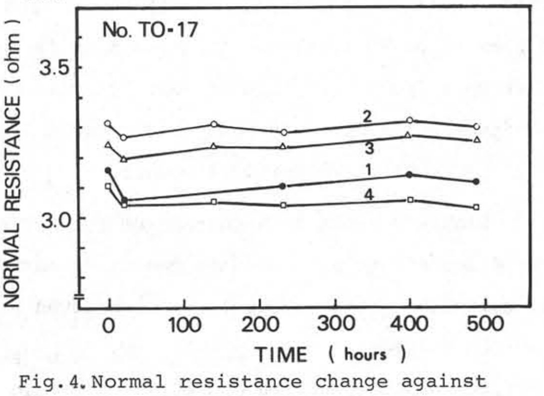

Fig.4. Normal resistance change against the sample storage time.