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B-3-5 Fabrication and Properties of High-Current-Density Nb Josephson Junctions

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Niobium and its oxide as tunnel type Josephson devices have the advantage of chemical and physical stability. The main drawback of niobium Josephson junctions is high shunt capacitance caused by high permittivity of niobium-oxide. The influence of the capacitance would be reduced by high current density junctions, because the capacitance is inversely proportional to the thickness of the oxide whereas the tunnelling current have exponential dependence on the thickness.

High current density also means feasibility of miniature Josephson devices which are attractive for the purpose of a large scale integrated circuit and ultra high frequency devices.

This letter describes the experimental results on the fabrication and properties of Nb-NbO_x-Pb type high current density Josephson junctions.

The diagram of Nb-NbO_x-Pb Josephson junction is shown in Fig.1. The lower electrode was deposited on the substrate through metal mask using the dc biased sputtering. Then the junction area was trimmed by thick anodized Nb_2O_5 layer using photolithography. In such structure, it is easy to reduce the junction area and it is also possible to reduce the Joule heat generated in the junction. After rf sputter-cleaning of the niobium film, tunnel barrier was formed by thermal oxidation in atmosphere. The upper electrode of lead was patterned accurately using lift-off techniques.

The I-V characteristics of a low-current-density (j_o=970 A/cm^2) junction is shown in Fig.2. The measured critical current was found to be 80% of the calculated one(j_o) which was derived from normal resistance of the junction[1]. The curve labeled "×10" is the quasi-particle characteristics which is the case when magnetic field of 100(Oe) is present. The current scale is 1/10 that of the case without magnetic field. The R_3/R_2 ratio (R_2 and R_3 are resistances calculated by dividing 2mV and 3mV by the corresponding currents respectively) of this junction is 0.06 indicating low leakage current at the subgap voltages.

The I-V characteristics of high-current-density(j_o=3.5×10^{5}A/cm^2) junction is shown in Fig.3. In this case, the thickness of niobium and lead electrode were 0.3μm and 1.4μm respectively, and the junction geometry was elliptic having an area of 5.5×10^{-8}cm^2. The upper curve was obtained with zero magnetic field. The hysteresis in the I-V characteristics is reduced owing to the small β_c[2] ($\beta_c \simeq 1$). The lower curve labeled "He=130 Oe" shows the characteristics in the presence of magnetic field of 130(Oe) which suppresses the Josephson current. From this results, it can be seen that tunnelling current is still dominant in such a junction. It seems that the increase in normal resistance at voltage above 3mV is due to the partial transition to the normal state in one of the electrodes. The dependence of the maximum dc Josephson current on magnetic field is shown in Fig.4. In spite of its thin barrier, it is formed uniformly. The R_3/R_2 ratio of the high-current-density junction has a tendency to increase with current density (see Fig.5). However, as shown in Fig.5, it can be lowered by decreasing the area of junction.

In summary, niobium tunnel junctions having current density up to 6×10^5 (A/cm^2) were made, and were found to carry tunnel current. They should be applicable to miniature and high-speed computer elements.

Ref. 1) V.Ambegaokar and Baratoff : Phys. Rev. Lett., vol. 10 (1963) 486
2) D.E.McCumber : J. Appl. Phys., vol. 39. (1968) 3113

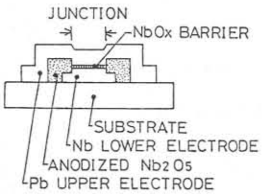

Fig.1. Sectional view of Nb-NbOx-Pb type Josephson junctions.

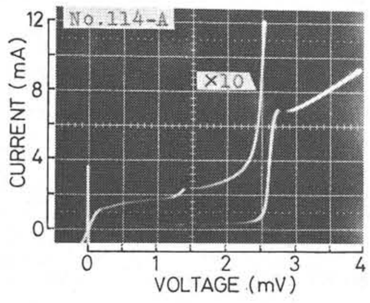

Fig.2. I-V characteristics of a low-current-density junction.

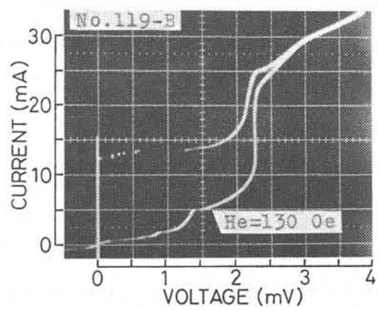

Fig.3. I-V characteristics of a high-current-density junction.

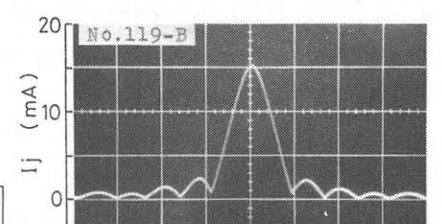

Fig.4. Magnetic field dependence of the maximum dc Josephson current.

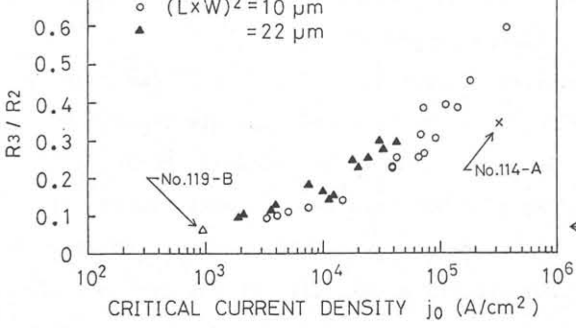

Fig.5. R3/R2 vs critical current density. LxW represents the junction area.