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FABRICATION AND PERFORMANCES OF NbZr/Oxide/NbZr THIN FILM JOSEPHSON JUNCTIONS*

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ABSTRACT

We report on the fabrication of symmetrical NbZr-Ox-NbZr Josephson junctions by means of thin film RF magnetron sputtering deposition. The insulating barrier consisted of natural oxide thermally grown in air at room temperature. The variation of the superconducting gap Δ as a function of the temperature was measured by recording the I-V characteristics. The experimental data are in good agreement with the dependence numerically computed from the BCS theory. The magnetic behavior of the maximum Josephson current was measured and both the magnetic penetration depth and the Josephson penetration depth were computed. By means of the Kulik theory on the junction self-induced resonances the microwave quality factor Q of the junctions, and surface impedance of the films have been estimated.

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1- INTRODUCTION

The literature reports tunneling measurements on non symmetrical junctions ($NbZr/Al/Al_2O_3/In$ or NbZr/Ox/Pb), both to determine the electron-phonon coupling factor [1], and the superconducting energy gap [1,2] Δ. However the reported data are from tunnel junctions realized on thin NbZr foils. Very few data deals with NbZr thin films [3] which, in any case, have been fabricated by using different methods, i.e. co-sputtering from two cathodes or electron-beam evaporation, and the reported critical temperatures T_c are below 9 K. The use of artificial barriers is accounted for the poor insulating properties of the NbZr natural oxide.

To allow for a direct measurement of the superconducting properties of the NbZr films we realized symmetrical tunnel junctions. In fact the counterelectrode of the same material makes easier the measurements in a wider temperature range.

2- SAMPLE FABRICATION

The samples were realized by means of RF magnetron sputtering. The $Nb_{75}Zr_{25}$ cathode had a shape of 3 inches diameter disc. Before the deposition the vacuum was ranging in 2÷4 x 10^{-7} mbar with a cold LN_2 trap. The junction geometry was of the cross type, defined by metallic masks. The film thickness was ranging between 3000 Å and 5000 Å, controlled by a quartz microbalance. The lower electrodes were usually thinner than the upper to get good overlapping films. The sputtering is operated in a 5 x 10^{-3} mbar atmosphere of pure Ar gas. The deposition rates to realize tunnel junctions were 13.1 Å/s and 10.1 Å/s respectively for the lower and upper electrodes. The critical temperatures of the NbZr films were not strongly affected by the deposition rate in this range. Moreover, before each deposition, a 20 minutes pre-sputtering on a movable shield has been performed. The substrates were either Corning glass 7059 or sapphire, previously cleaned in an ultrasonic bath of acetone kept at 40 °C and dryed under nitrogen flow. During the sputtering the substrates were not heated. The tunnel oxide barriers were grown at room temperature by natural oxidization in air for 17 hours approximatively.

3- EXPERIMENT

The the I-V curves of the tunnel junctions were recorded biasing the junctions with a programmable current source and measuring the corresponding voltage by means of a high impedance differential nanovoltmeter. The measurements were managed by a computer which also stored data. The temperature was measured by means of calibrated carbon glass thermometer fed at 10 μA constant current.

Temperatures above the LHe temperature were attained keeping the sample into the He cold vapour, and checking the temperature was stable within ± 20 mK. Then the temperature is recorded at the beginning and at the end of the data storage to make further control. Temperatures lower than 4.2 K were reached lowering the bath pressure. In Fig. 1 a typical current voltage I-V characteristic at 4.2 K is plotted. The tunnel resistance above the gap voltage is R_{NN}≈0.06 Ω, but the low voltage dynamical resistance exihibits a rather low value indicating that there was a significant current leakage. However the gap voltages are well defined. In the same figure the derivative, numerically computed, of the I-V curve is shown.

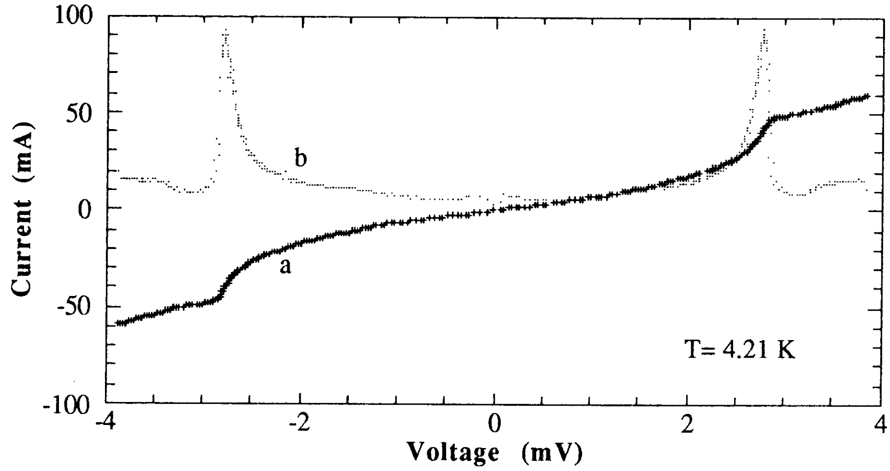

FIG 1 - I-V characteristic of a tunnel junction (curve a); the curve b shows the numerically computed dI/dV in a.u..

In Fig. 2 it is reported the reduced gap as a function of the temperature for the sample of Fig. 1. The normalizing coefficient Δ_0 for the $Nb_{75}Zr_{25}$ is the value measured at 2.28 K, i. e. $\Delta(2.28)=1.63$ mV. In Fig. 2 it is also reported (solid line) the reduced BCS data theoretically computed [4]. The agreement between the theory and experiment is satisfactory. On different samples we observed the same BCS behavior but we measured lower $\Delta(0)$ and the T_c to be used to get good agreement with theory was lower. This may be accounted for surface effects on the NbZr film.

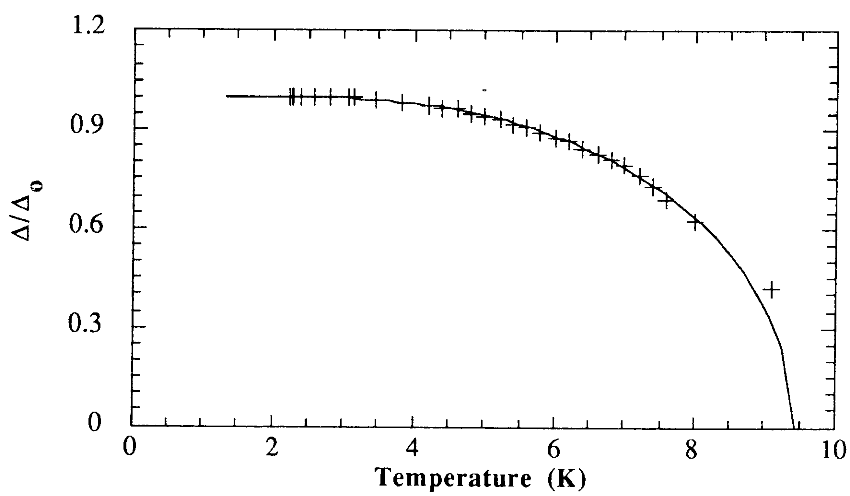

FIG. 2 - Temperature behavior of Δ: crosses are experiments; solid line represents the theoretical BCS curve.

Finally we measured in a magnetic shielded room the Josephson current behavior of our samples. In Fig. 3 it is reported the magnetic behavior of both the maximum Josephson amplitude and of the first Fiske step in a junction having $L\approx 200$ μm and $\lambda_J \approx 320$ μm. From the magnetic pattern of the Josephson current we estimate a magnetic penetration depth $\lambda_{eff} \approx 1100$ Å. However in view of the non zero modulation of the current we recognize a non uniform current distribution through the barrier.

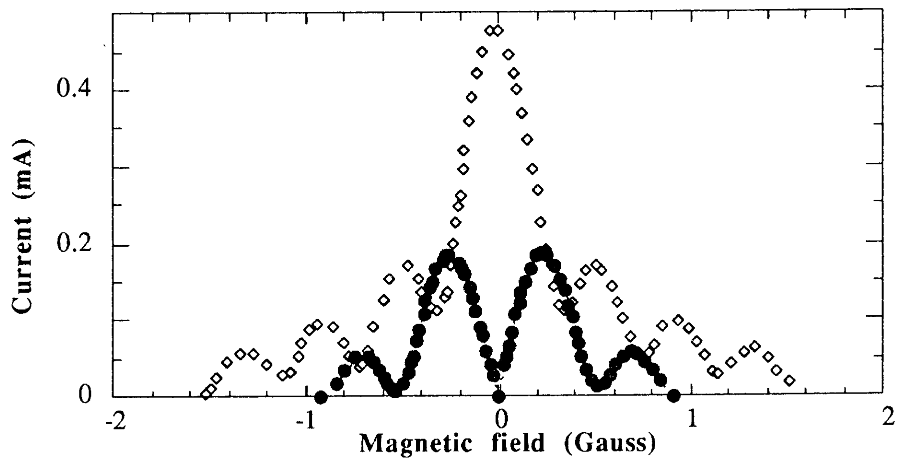

FIG. 3 - Magnetic field dependence of the Josephson current (open romb); magnetic field dependence of the 1st Fiske step (full circle).

Finally from the Fiske step, occuring at a voltage $V_1 \approx 18$ μV, we evaluate the junction quality factor Q as in ref. [5]. The computation gives $Q_1 \approx 20$, and considering as the main losses term the surface impedance, we get a surface resistance R_S of NbZr of $R_S \approx 230$ μΩ at a frequency of 9 GHz and a T=4.2 K.

4- CONCLUSION

We have realized symmetrical NbZr Josephson tunnel junctions. From the I-V we measured the dependence of the enrgy gap on the temperature. Moreover from the Josephson features we get preliminary results both for the magnetic penetration depth and the microwave performance of the material. However further improvements on the fabrication process are in progress in order to match the requirements of device fabrications by using photolitography in patterning the first electrode and lift off technique for the second one.

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