Superconducting Properties of \( \text{Nb}_{0.75}\text{Zr}_{0.25}\)-Oxide-\( \text{Nb}_{0.75}\text{Zr}_{0.25} \) Tunnel Junctions

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We have fabricated symmetrical \( \text{Nb}_{0.75}\text{Zr}_{0.25}/\text{Oxide}/\text{Nb}_{0.75}\text{Zr}_{0.25} \) tunnel junctions having cross type geometry. The superconducting films constituting the electrodes of the junctions were obtained by RF magnetron sputtering, and the tunnel barrier was grown by natural oxidation in air. From the current-voltage characteristics of the junctions, we have measured the temperature dependence of the energy gap of \( \text{Nb}_{0.75}\text{Zr}_{0.25} \) and compared this dependence with BCS-theory results. The magnetic-field diffraction pattern of the Josephson current of the junctions allows us to evaluate the penetration depth of the superconducting films. We also estimate the surface impedance of the NbZr film by measuring the quality factor of the junctions. We discuss the results within the framework of the realization of superconducting tunnel devices and coatings for superconducting accelerating cavities.

1. INTRODUCTION

There exists growing interest in the fabrication of superconducting thin films to be used in microwave devices or as coating materials in RF superconducting accelerator cavities.\(^1\)\(^2\) Among the materials that have received attention in these areas, NbZr has been one of the most extensively studied for practical and fundamental physics-oriented purposes.\(^3\)\(^4\) The \( \text{Nb}_{1-x}\text{Zr}_x \) bulk system has a critical temperature\(^5\) of \( T_c \approx 10.8 \text{ K} \) for \( x = 0.25 \)
and shows a weak dependence on the exact composition, which is important for device fabrication and reproducibility. A limited amount of data is available from NbZr thin films fabricated by using different methods, i.e., co-sputtering from two cathodes or electron-beam evaporation; in these cases the measured critical temperatures were below 9 K.

In order to explain the noticeable increase in the critical temperature of Nb_{0.75}Zr_{0.25} with respect to the critical temperature of the two components, tunneling measurements on asymmetrical junctions (NbZr/Al/Al_{2}O_{3}/In or NbZr/Ox/Pb) were performed: these studies allowed a determination of the electron-phonon coupling factor $\lambda$ and of the superconducting energy gap $\Delta$ of the NbZr. So far, however, the data that have been reported are from tunnel junctions realized on thin NbZr foils. Unfortunately, in measurements of the energy gap in asymmetrical junctions having In or Pb as a counterelectrode, there are limitations both in the high temperature range due to the low $T_c$ of the counterelectrode and in the low-temperature range where the only significant gap variation is not due to the NbZr. The use of artificial barriers has been considered because of the poor insulating properties of the NbZr natural oxide. However, when using the NbZr as a coating material, one deals with the underlying surface effects that result from NbZr oxide; thus it is interesting to investigate its superconducting features under more realistic operating conditions.

In this work we report the fabrication of thin Nb_{0.75}Zr_{0.25}/Ox/Nb_{0.75}Zr_{0.25} film tunnel junctions realized by means of RF magnetron sputtering. The paper is structured as follows: in the next section we describe details of the fabrication process. In Sec. 3 we present the results of direct $\Delta(T)$ measurements in the temperature range 8.5–2.2 K; the $\Delta(T)$ behavior is compared with theoretical BCS results. In Sec. 4 we discuss the microwave properties of the NbZr film as estimated from the Josephson self-resonances of the junctions (our junctions exhibit indeed Josephson effect). The estimate of the surface impedance is compared with previous data obtained for a Nb_{0.75}Zr_{0.25} film measured in a cylindrical TE cavity.

2. FABRICATION OF THE JUNCTIONS

The films were RF magnetron sputtered on Corning glass 7059 or sapphire substrates. The cathode was a three-inch-diameter, melted Nb_{0.75}Zr_{0.25} disc. Aided by a LN$_2$ cold trap, the vacuum prior to deposition of the films was in the range $(2-4) \times 10^{-7}$ mbar. The sputtering was performed in $5 \times 10^{-3}$ mbar of Ar. Before each deposition, we pre-sputtered on a movable shield for 20 minutes. The pre-sputtering was carried out both to clean the target surface and to benefit from the NbZr gettering action in the vacuum chamber. While the cathode was water-cooled during the