CONDUCTANCE STUDIES ON DIFFERENT TYPES OF Nb/Al,AlO_x(/Al)/Nb JOSEPHSON TUNNEL JUNCTIONS

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The conductance-voltage characteristics of different types of Josephson tunnel junctions have been measured at 4.2 K: symmetric Nb/Al,AlO_x/Al/Nb, asymmetric Nb/Al,AlO_x/Nb and Nb/Al/AlO_x-/AlO_x/Nb, containing a double oxidation layer. The symmetric junctions can be described very well by a trapezoidal potential barrier model. The asymmetric junctions show less agreement with theory. In these junctions resistance switching occurs, possibly due to charge trapping. The resistance is lower than in symmetric junctions. The conductance measurements on double oxidation layer junctions show, that this type of junction has an inhomogeneous oxide layer.

1. INTRODUCTION

The conductance-voltage dependence of metal-insulator-metal junctions provides information about the dielectric separating the metallic electrodes. An idealized physical picture of the insulator is a trapezoidal potential barrier with effective thickness d , average height $\bar{\varphi}/e$ and asymmetry $\Delta\varphi/e$ over the barrier (1). The parameters d , $\bar{\varphi}$ and $\Delta\varphi$ can be deduced from conductance (σ) vs. voltage (V) curves. Besides this, tunneling measurements supply information about the presence of localized states and organic impurities in the dielectric (1,2).

We have examined the σ - V dependences of junctions with four different barrier types sandwiched between a Nb base electrode, superconducting below 9.3 K and covered by a 4 nm Al overlayer, and a Nb counter electrode. The barrier in junctions of type S1 was formed by thermal oxidation of the Al in 267 mbar O₂ at 10°C. In type S2 junctions the Al overlayer has also been oxidized at 267 mbar, but at a temperature of 70°C, leading to a higher junction resistance. In type S3 the oxidized Al film (at 10°C in 267 mbar O₂) is covered by 3 nm of Al, in order to make a symmetric junction. Finally, double oxidation layer junctions have been prepared, in which the oxidation of the Al overlayer at 10°C in 0.64 mbar O₂ during only 15 minutes was followed by deposition of 11 Å of Al, which has been oxidized completely in 16 mbar O₂ at 10°C. This procedure results in thicker oxide layers (3).

The junction trilayer was formed in a whole wafer process by dc magnetron sputtering in a vacuum system with a background pressure of 10⁻⁷ mbar, mainly due to water. With help of anodization and standard photo-lithography, junctions with different areas were obtained simultaneously. A more detailed description of the fabrication process can be found in ref. 3.

2. EXPERIMENTAL CHARACTERISTICS

In all measurements the junctions were current biased. The current I through the junctions, as well as the induced voltage V were measured by computer. In this configuration σ was calculated numerically with a rather poor resolution. A higher resolution could be obtained by using a standard lock-in technique.

The results for the single and double oxidation layer junctions will now be discussed separately.

a) single oxidation layer junctions

Typical σ - V characteristics at 4.2 K of junctions of type S2 and S3 are visualized in fig. 1. In this figure a positive voltage corresponds to a current flow from the base to the counter electrode. The theoretical curves were calculated with help of the parabolic σ - V relation given in ref. 4. The barrier parameters d , $\bar{\varphi}$ and $\Delta\varphi$ were adjusted to obtain the best fit in the range from $|V| = 100$ to 450 mV, where the influence of inelastic tunneling and rounding of the barrier shape on $\sigma(V)$ are small (1). The parameters are listed in table 1. From this table it shows out, that a higher oxidation temperature leads to higher values of d and $\bar{\varphi}$. An extra Al layer between AlO_x and the Nb counter electrode also causes d and $\bar{\varphi}$ to increase, and results in a smaller $|\Delta\varphi|$, as expected.

Two differences between the measured curves in fig. 1 are remarkable. Firstly, the σ - V dependence of the asymmetric junction cannot be fitted very good by the theoretical curve, indicating that the insulating layer in this

table 1: junction parameters as obtained from σ - V measurements for single oxidation junctions.

junction	type	d (Å)	$\bar{\varphi}$ (eV)	$\Delta\varphi$ (eV)
SNIS 10	S1	9.2	1.41	-0.2
SNIS 70	S2	9.4	1.53	-0.2
SNINS 10	S3	9.5	1.55	+0.1

fig. 1: σ -V characteristics of type S2 and S3 junctions (area = $25 \mu\text{m}^2$)

junction cannot be represented by a trapezoidal potential barrier. Secondly, at $|V| \geq 300$ mV the measured σ of the asymmetric junction shows quite some noise. This noise appears to be due to switching of the resistance R between two or more distinct values R_i with $|R_i - R_{i-1}|/R_i \approx 10^{-3}$ in $5 \times 5 \mu\text{m}^2$ junctions at frequencies of 0.1 - 1 kHz, increasing with V . In symmetric junctions this switching was not observed.

Using the lock-in technique steps in σ vs. V in the order of 0.5 % of σ at $|V| \approx 110$ mV were observed in all single oxidation layer junctions. This indicates the presence of a substantial amount of OH groups in the barrier (1).

The non-parabolic σ -V dependence of asymmetric junctions as well as the lower values of $\bar{\phi}$ and d of the junctions of type S1, as compared to the symmetric junctions, indicate, that the Nb counter electrode interacts with the AlO_x layer or with the hydroxyl adsorbed by this dielectric (5). The observed switching in asymmetric junctions may be due to electron traps introduced by the Nb/ AlO_x interface.

b) double oxidation layer junctions

The σ -V characteristic of a double oxidation layer junction is depicted in fig. 2. Obviously, the theoretical σ -V relation cannot be fitted to the measured curve. From fig. 1 and 2 it shows out, that for the double oxidation layer junctions σ is larger than for junctions of type S2 at $|V| > 50$ mV. However, at 4 mV the normal resistance of these two types of junctions is the same within 5 %, despite of the lower pressure at which the double oxidation layer junctions were oxidized. We suggest, that the double oxidation layer can be represented by a potential barrier containing low barrier channels with $\bar{\phi} \approx 0.05$ eV. This would imply, that the second AlO_x film does not cover the oxidized Al overlayer completely, possibly due to a 'droplet'-like structure of the second Al film.

fig. 2: σ -V characteristics of a double oxidation layer junction (area = $25 \mu\text{m}^2$)

3. CONCLUSIONS

Symmetric SNINS junctions of type S3 can very well be represented by a trapezoidal potential barrier with small asymmetry $\Delta\phi/e$. In asymmetric SNIS junctions the barrier asymmetry is larger and the agreement with theory is less good. The barrier height and thickness of these junctions are smaller than the corresponding values for junctions of type S3. The barrier heights, as listed in table 1, agree with literature. In junctions of type S1 and S2 switching of the resistance between distinct values occurred, which was not observed in junctions of type S3.

The σ -V characteristics of double oxidation layer junctions indicate, that the dielectric in these junctions is not homogeneous. At voltages larger than about 0.05 V low barrier channels seem to open up resulting in a much higher conductivity, than one would expect for a barrier consisting of two oxidation layers. The normal resistance at 4 mV however, can significantly be increased by using the double oxidation technique, which can be of importance in special application of Josephson junctions (3).

Our junction fabrication process leads to the presence of hydroxyl in the insulating layer.

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