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HYSTERETIC EFFECTS IN THE D.C. CURRENT-VOLTAGE CHARACTERISTIC OF NORMAL Nb/Pb TUNNEL JUNCTIONS

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ABSTRACT

High resistance normal Nb/Pb tunnel junctions have been studied. Both at 300 K and at 77 K an hysteresis in the I-V characteristic has been measured: the presence of negative or positive bias voltages changes the tunnelling probability. At every fixed bias current value, a voltage drift with time appears. The drift velocity increases as the voltage or the temperature increases. Moreover at 77 K anomalous low frequency oscillations arise in the junction when some positive or negative threshold voltages are exceeded.

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Superconducting Nb/Pb tunnel junctions have been widely studied for analogical and digital applications$^{(1)}$. Moreover, in the last few years some interest has arisen on possible applications in the field of ionizing particle detection$^{(2,3)}$. For this purpose we have analized Nb/Pb tunnel junctions, which have different area and different oxide thickness. In the literature detailed studies of superconducting properties have been reported; on the contrary, only lately the normal tunneling I-V characteristic of Nb/Pb have been analized in details$^{(4-7)}$. In these junctions the tunnel barrier is often obtained by oxidation of the first Nb electrode. The Nb films do not show a very dense surface structure and a large number of Nb oxides exist$^{(4,7)}$ so that a rather complex barrier structure arises and different contributions to the tunnel current have been identified$^{(4,7)}$. Moreover, the details of the tunnel barrier and weights of the different current contributions strictly depend on the particular oxidation process and on the thickness of the oxide.

In this paper the I-V characteristics of high resistance junctions are reported.

On a corning glass (7059) substrate, the first 4000-6000 Å Nb film has been obtained by r.f. sputtering in a diffusion oil vacuum system with an ultimate pressure of about 2 x 10^{-8} Torr. The second 6000 Å Pb film has been thermally evaporated in a different vacuum system. The geometry of the two films has been defined by usual photolithographic techniques. Greater details on the fabrication process can be found elsewhere$^{(8)}$.

To minimize edges effects large area junctions have been studied. Cross junctions of three different areas (respectively 50 x 50, 150 x 150, 750 x 750 μm^2) have been fabricated on the same substrate. In particular, after a 1000 Å back sputtering of the Nb film the r.f. plasma oxidation process has been used. An Argon-Oxygen (respectively 95.3% and 4.7%) mixture at a pressure of 4.5 x 10^{-3} Torr with bias voltage Vb = 20 V has been employed for 30 minutes.

D.C. current-voltage characteristics have been measured by the usual four-contacts configuration. At low temperature the junctions show very lar ge resistance values (tipically $R > 500$ Kohm at $T = 77$ K for voltage values $V < 5$ mV). Voltage measurements have been performed by a low noise True Instrumentation Amplifier with an input impedance greater than 10^{13} ohm//1pF and an input bias current lower than 1 pA(9).

In Fig. 1 the I-V characteristics of the junction 138H4M at two different temperatures (300 K and 77 K) are shown. The voltage is the difference between the Nb and Pb film voltages. The usual asymmetric behavior can be observed, but unusual hysteretic loops appear: each I-V curve measured for increasing values of the current (I↑) is different from the curve obtained for decreasing current values (I↓). Moreover at 77 K for voltage values greater than some positive or negative thresholds ($V > +0.65$ Volts and $V < -0.83$ Volts), very strange oscillations arises.

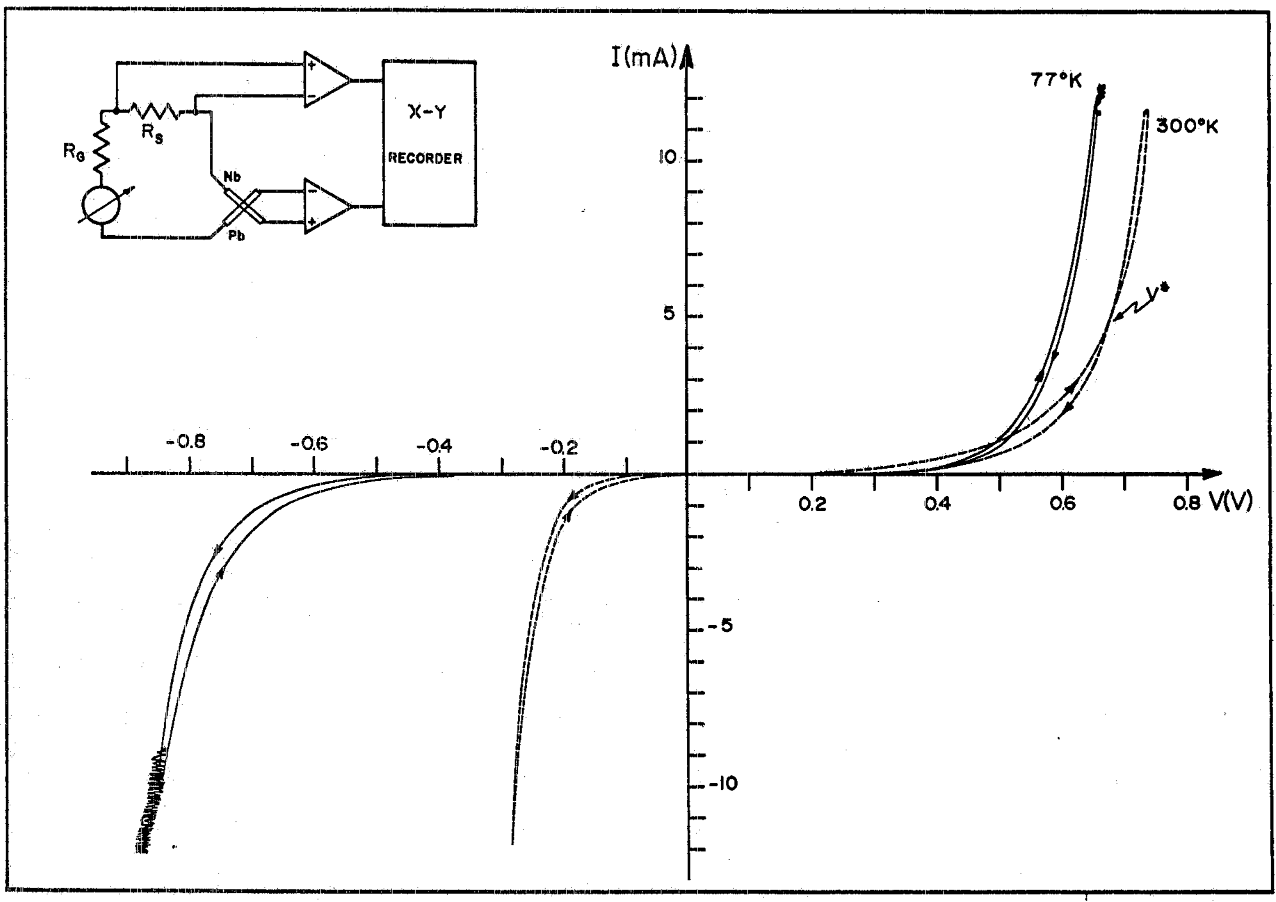

FIG. 1 - DC, I-V characteristic of the junction 138H4M. $A = 150 \times 150\ \mu m^2$; $R_{NN}(77°K) = 650\ K\Omega$; $R_{NN}(300°K) = 4.2\ K\Omega$. Experimental set-up.

At 77 K for any positive voltage, we have: $I^{+}\uparrow > I^{+}\downarrow$; on the contrary the inverse relation $I^{-}\downarrow > I^{-}\uparrow$ holds. At 300 K a similar behavior is observed, but if some positive voltage $V^{*} = V(I^{*})$ is exceeded, the relation $I^{+}\uparrow < I^{+}\downarrow$ is found.

As shown in Fig. 1, for voltages greater than + 500 mV, the resistance of the sample 138H4M is an increasing function of the temperature. For $V > V^{*}$ the resistance along $I^{+}\downarrow$ is lower than the corresponding value along $I^{+}\uparrow$, so that the loop above $V(I^{*})$ cannot be generated by a self heating effect. The general behavior of the hysteresis loop is very similar in any measured junction; on the contrary the temperature dependence of the I-V characteristic doesn't follow a general rule. For instance, in Fig. 2 the I-V characteristics of the sample 137E7M are shown respectively at 300 K, and at 77 K. In this junction for any measured positive voltage one gets: $R(77\ K) > R(300\ K)$. In this case it is reasonable to think that also the hysteresis loop below I^{*}, V^{*} cannot be generated by self-heating.

The presence of the hysteresis is strictly correlated to the appearing of temporal voltage drifts for any fixed bias current. For low voltages ($V < 300$ mV) the values of $|dV/dt|$ seem to be increasing functions of both the temperature and the voltage. In any case for any positive or negative bias current the drift leads the voltage value along the $I\uparrow$ curve toward the corresponding voltage along the $I\downarrow$ curve and viceversa. In this way at 300 K along the $I^{+}\uparrow$ curve we have: for low current values $dV/dt > 0$, and for high currents $dV/dt < 0$.

Due to the presence of the voltage drifts, at 77 K, the amplitude of the hysteretic loop is an increasing function of the maximum measured voltage in the I-V characteristic. At 300 K the presence of two opposite drifts generates a more complicated behavior. Moreover the presence of the drift makes any measured I-V characteristic strongly dependent on the time necessary for measurements. In Fig. 1 and Fig. 3 (dashed line) about 20 seconds have been necessary to draw I-V characteristic. In the dashed-dot line of Fig. 3 the I-V characteristic of the same junction measured by a single triangular current pulse in a total time of 20 msec is shown. In

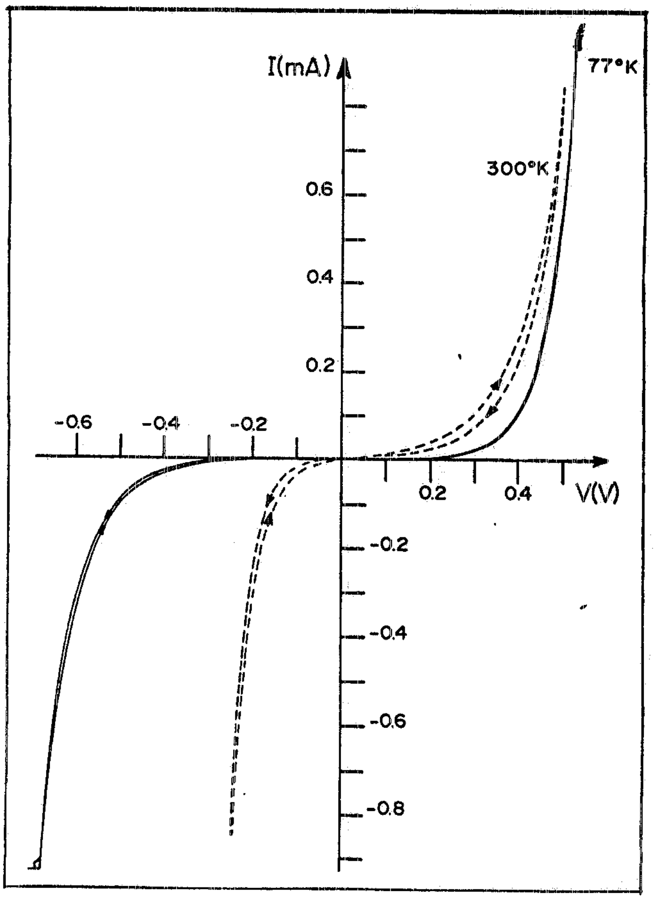

FIG. 2 - D.C. I-V characteristic of the junction 137E7M.

$A = 150 \times 150\ \mu m^2$;

$R_{NN}(77°K) = 25\ k\Omega$;

$R_{NN}(300°K) = 1.4\ k\Omega$.

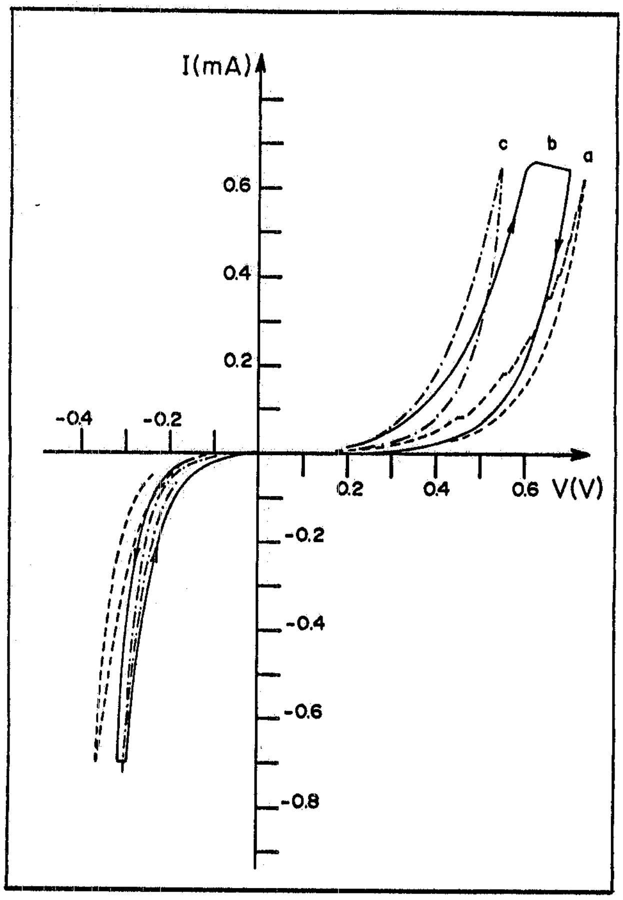

FIG. 3 - I-V characteristic of the junction 138H4S.

$A = 50 \times 50\ \mu m^2$;

$R_{NN}(300°K) = 40\ k\Omega$.

a) D.C.;

b) Pulsed, trapezoidal,

$T_R = T_F = 100$ ms;

$T_W = 1.2$ s.

c) Pulsed, triangular,

$T_R = T_F = 10$ ms.

the full line of Fig. 3 a trapezoidal current pulse (total time 1.02 sec, rise time 10 msec, fall time 10 msec) has been used, and a very large hysteresis appears.

Voltage induced variations of tunneling barrier have been reported in the literature some years ago for Al/Al junctions$^{(10)}$, and recently for Pb/Bi/In-oxide-Pb/Bi$^{(11)}$ tunnel junctions. These effects have been ascribed to ion migrations in the metal-oxide interfaces.

In our junctions at 300 K at least two effects appear along the I curve for positive voltages: the first one is dominant for low voltages values ($V < V^*$), and produces a positive voltage drift; the second one is dominant for higher voltages and produce negative voltage drift.

At 77 K for $V > 0.65$ Volt anomalous oscillations arise : they seem to be generated by some superposition of the two drift effects which do not leave the junction in a stable state. In Fig. 4 the oscillating voltage for a fixed current value is shown. The details of the oscillations (frequency, amplitude, shape, etc.) are a function of the particular bias conditions (current value, true impedence of the current generator, etc.).

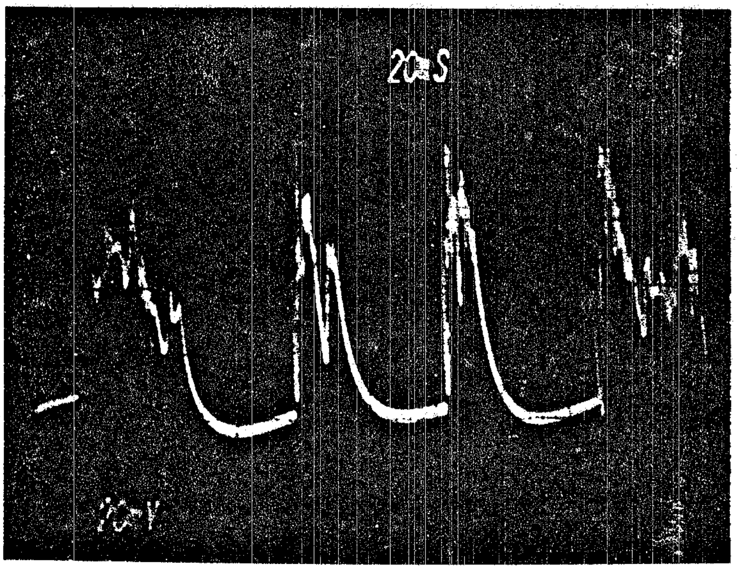

FIG. 4 - Voltage oscillations for high voltage-current value in the I-V characteristic ($y = 2$ mV/div.; $x = 20$ ms/div.).
Junction 138H4M: $T = 77°K$; $I = +12.32$ mA; $V = +676$ mV,
$R_g = 1100\,\Omega$, $R_s = 10\,\Omega$.

In any case, even for low voltage values the observed behavior of the Nb/Pb junctions is quite different from the Al/Al junctions: for these latter the hysteresis can be found only above some threshold voltage and the change of the I-V characteristic is permanent, so that a thermal cycle is necessary to reset the junctions to initial conditions. In our Nb/Pb junctions both the hysteresis and the voltage drift exist for every voltage value. Moreover at 77 K the change of the characteristic is only partially permanent, and the junction resetting can be obtained by biasing the junction with an opposite voltage. At 300 K no real "memory" effect can be observed in the reported voltage range.

We believe that the understanding of the observed effects requires a better comprehension of the details of the tunnel barrier, of the particular structure of Nb oxides, and of the main contributions to the tunneling current. To perform this analysis a more detailed study of the I-V characteristic and of its temperature dependence is necessary. In particular the instability effects which appear in the tunnel barrier at higher voltage values need deeper investigation as to their origin and causes.

REFERENCES

(1) A.Barone and G.Paternò, Physics and Application of the Josephson Effect (Wiley, 1982).

(2) M.Kurakado, J. Appl. Phys. 55, 3185 (1984).

(3) A.Barone et al., Nuclear Instr. and Meth. A234, 61 (1985).

(4) J.Halbritter, Proceedings of Applied Superconductivity Conference, San Diego, California, 1984; to be published on IEEE Trans. on Mag.

(5) J.H.Magerlein, J. Appl. Phys. 55, 4027 (1984).

(6) R.W.Beattie, G.B.Donaldson and D.F.Moore, J. Appl. Phys. 56, 819 (1984).

(7) J.Halbritter, KfK-Report-3728 (Kernforschungszentrum, Karlsruhe, 1984).

(8)V.Lacquenti, G.Marullo and R.Vaglio, IEEE Trans. Magn., Mag.15, 593 (1979).

(9) F.Celani, S.Pace et al., A simple low noise True Instrumentation Amplifier for high resistance tunnel junctions, Frascati Report, to be published.

(10) J.Kadlec and K.H.Gundlach, Thin Solids Films 11, 423 (1972).

(11) K.H.Gundlach and H.Konishi, Appl. Phys. Letters 46, 441 (1985);