A SIMPLE QUALITATIVE DETERMINATION OF JOSEPHSON TUNNEL JUNCTION PARAMETERS NEAR THE TRANSITION TEMPERATURE

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A SIMPLE QUALITATIVE DETERMINATION OF JOSEPHSON TUNNEL JUNCTION PARAMETERS NEAR THE TRANSITION TEMPERATURE †

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Résumé.- Il est montré qu'on peut estimer soit la capacité soit l'amplitude du "cosϕ" d'une petite jonction Josephson en analysant la caractéristique courant-tension près de la température de transition supraconductrice. La méthode s'appuie sur l'observation empirique que la tension d'une jonction de petite surface saute d'une valeur finie à zéro lorsque la fréquence Josephson devient voisine de la fréquence plasma.

Abstract.- The junction capacitance may be determined and the cosϕ-amplitude may be estimated from the switching characteristics seen in the IV curve near the critical temperature. The method relies on the empirical observation that a small area tunnel junction returns from finite to zero voltage when the Josephson frequency is about equal to the plasma frequency.

Within the framework of the shunted junction model (SJM) four Josephson junction parameters are of interest : (1) the critical current I_c,(2) the normal state resistance R, (3) the capacitance C, and (4) the cosϕ-amplitude ε.The parameters I_c and R are readily determined from the dc IV curve. For the capacitance, C, essentially two methods exist : (i) a measurement of the geometrical resonance frequency from the position of the cavity induced step /1/ in the IV curve, and (ii) a determination of the McCumber parameter /2/ $\beta(\propto C)$ using measured values of the hysteresis parameter /2/α. Both methods have drawbacks; the former requires knowledge of the temperature and frequency dependent penetration depth, and the latter /3/ depends on the value of ε. With respect to the cosϕ-amplitude, ε, it is generally argued /4/ that the IV curve itself does not provide such information. Here we describe how additional information may be obtained using empirical methods deduced from experiments on superconducting tunnel junctions where C and ε have been independently determined from more sophisticated microwave measurements /5/.

For a tunnel junction close to the transition temperature, T_c, the IV curve may typically appear as shown in the inset of figure 1. Thus at these temperatures the IV curve is very similar to that of the SJM. Accordingly, the detailed shape is determined by the magnitude /2,3/ of the dimensionless parameter $\beta = 2eR^2I_cC/\hbar$, which for an ideal tunnel junction may be written as $\beta = (\pi\ \Delta(T)RC/\hbar)$ $\tanh\ (\Delta(T)/2kT)$, where $2\Delta(T)$ is the energy gap.

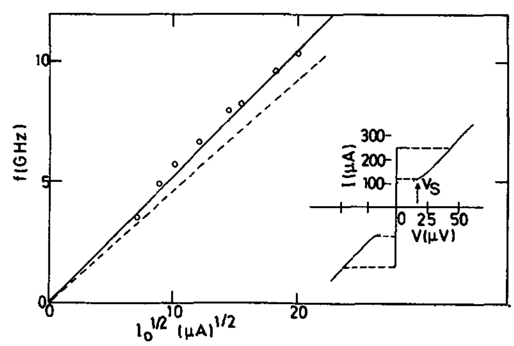

Fig. 1 : The switching frequency (circles and full line) and the maximum plasma frequency (dashed line) as functions of $I_o^{\frac{1}{2}}$. The inset shows an IV curve : Sn-Snoxide-Sn junction, 20A/cm2 at T = 0, 0.1x0.2 mm^2, T/T_c = 0.98, T_c = 3.815 K.

Assuming R and C to be temperature independent it is observed that β will vary from zero at $T = T_c$ to a larger value at $T\simeq 0$. A typical feature of an IV-curve with hysteresis is the switching back to zero voltage at a finite voltage, V_s (c.f. figure 1). The dynamics of the switching is not understood in detail although it has been argued /6/ that the process involves an excitation of an internal resonance by the Josephson ac voltage, i.e., the plasma resonance or a geometrical resonance /6/.

The switching frequency $f_s = 2eV_s/h$ versus $I_c^{1/2}$ is shown in figure 1. The data points are

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obtained by varying the temperature in a range where energy gap structure does not disturb the SJM behaviour of the IV curve ($1 > T/T_c > 0.97$). Figure 1 shows that it is possible to fit a straight line through the origin to the data points. The maximum plasma frequency, $f_o = (2eI_c/\hbar C)^{\frac{1}{2}}/2\pi$, is also shown in the figure (the dashed line). The plasma frequency was independently determined from plasma resonance experiments /5/. The conclusion drawn from figure 1 is that the junction switches back to zero voltage at a voltage V_s given by $V_s = k\, h\, f_o/2e$, where k is a constant of order unity. For the data in figure 1, k = 1.13; in other junctions we have found k = 0.94 and k = 0.85.

The present empirical observation is of similar nature as the observation of Fulton and Dynes /6/ who from analog computations found that when $\langle V \rangle$ becomes less than $h\, f_o/2e$ the uniform mode of the phase, $\phi(x,t)$, becomes unstable to spatial fluctuations.

In order to obtain an estimate of the cosϕ-amplitude, ε, we use the known relation /3/ between the McCumber parameter, β, and the hysteresis parameter, α. To a good approximation $\beta = \left[4(1+\varepsilon/3)/\pi\alpha\right]^2$. A plot of β vs. α is shown in figure 2 for different values of $|\varepsilon| < 1$. Experimentally, α may be determined from the dc IV curve. With an IV curve as shown in figure 1 we obtain an upper limit for α using the value of the bias current, I_{SW}, corresponding to the switching from finite to zero voltage : $\alpha_{SW} = I_{SW}/I_c$.

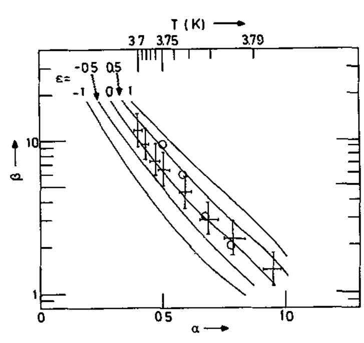

Fig. 2 : β vs. α diagram. Crosses are derived from the dc IV curve as explained in the text. Circles are measured by plasma resonance experiments. Full curves are theoretical curves for ε = -1, -0.5, 0, 0.5, and 1. Upper scale : The temperature corresponding to the data points.

Another estimate is obtained by extrapolating to V=0 (the dotted curve in figure 1), $\alpha_{ext} = I_{ext}/I_c$. The two α-values define the horizontal bars shown in figure 2 obtained on the same junction at temperatures in the interval $0.97 \leq T/T_c \leq 1.0$. At each temperature the value of β may be determined using the value of capacitance derived from the switching voltage. Since $\beta \propto C$ the uncertainty in β is ±30 % as indicated by the vertical bars. The experimental points indicates that the cosϕ amplitude is positive although the magnitude, cannot be determined. The temperature dependence of ε has, however, been accurately measured for this junction /5/ and the result is also shown in figure 2 (circles) using the upper horizontal temperature axis. We can state that the simple estimate of ε based on dc characteristics of the junction is consistent with the more elaborate methods.

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