Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Materials & Molecular Research Division

Presented at the XVIIth International Conference
on Low Temperature, Karlsruhe, Germany,
August 15-22, 1984

RESONANT ACTIVATION OF A JOSEPHSON JUNCTION

M.H. Devoret, J.M. Martinis, D. Esteve,
and J. Clarke

August 1984

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

RESONANT ACTIVATION OF A JOSEPHSON JUNCTION

Michel H. Devoret,* John M. Martinis, Daniel Esteve,* and John Clarke

Department of Physics, University of California
Materials and Molecular Research Division, Lawrence Berkeley Laboratory
Berkeley, California 97420
*Permanent address: C.E.N. Saclay, GIF, France

The lifetime of the zero voltage state of a current-biased Josephson junction is reduced by the application of a weak microwave perturbation at a frequency near the plasma frequency of the junction. We call this process "resonant activation". The experimental data are in good agreement with numerical simulations.

A Josephson tunnel junction with critical current I_o biased at a constant current I can be modeled as a particle moving in the one-dimensional potential(1) $U(\delta) = U_o(s\delta - \cos\delta)$. Here, $U_o = I_o\Phi_o/2\pi$, $s = I/I_o$, $\Phi_o = h/2e$, and δ, the phase difference across the junction, represents the position of the particle. In the zero voltage state with $s < 1$, the frequency of oscillation of the particle at the bottom of the well is the plasma frequency $\omega_p = \omega_{po}(1 - s^2)^{1/4}$, where $\omega_{po} = (2\pi I_o/C\Phi_o)^{1/2}$. We define $Q = \omega_p RC$, where the shunt resistance, R, and capacitance, C, may contain contributions from the external circuitry in addition to their intrinsic values. In the thermal limit $k_BT >> \hbar\omega_p$, the particle escapes from the well at a rate(2)

$$\tau^{-1} = (\omega_p/2\pi)\exp(-\Delta U/k_BT), \tag{1}$$

where(3)

$$\Delta U = (4\sqrt{2}/3)U_o(1 - s)^{3/2}. \tag{2}$$

In this paper, we report the effect on τ^{-1} of a weak microwave current, representing a small perturbation on the dynamics of the particle in the presence of thermal noise, that tilts the washboard sinusoidally. When the microwave frequency in close to ω_p, we expect τ^{-1} to be enhanced: We call this process "resonant activation".

Our experiments were performed on high quality 10 × 10 μm^2 Nb-NbOx-PbIn tunnel junctions. Each junction was attached to an attenuating mount that was connected to the room temperature electronics via two heavily-filtered coaxial lines. A microwave current could be applied via a separate coaxial line. We measured the microwave-induced changes in τ induced by applying a 10 kHz square-wave modulated bias current to the junction and measuring the time that elapsed between the leading edge of the pulse and the transition from the zero voltage state. The inset in Fig. 1 shows the expected exponential distribution of switching events (in the absence of microwaves) from which we obtain τ. Figure 1 shows the variation in $\ell n[\tau(P)/\tau(0)]$ for a particular set of parameters when the microwave frequency is swept from 4 to 7 GHz, where P is the microwave power. We observe a dip in $\tau(P)$ when the microwave frequency is near ω_p.

We have performed a numerical simulation of the Brownian motion of the particle in the potential $U(\delta)$ in the presence of a weak, oscillating force. Our best fit to the data is shown in Fig. 1. We note that both the experimental data and the simulations depart significantly from a Lorentzian curve as a result of the anharmonic properties of the Josephson oscillator. The fit to the data yields $\omega_p/2\pi$ = 6.3 GHz and Q = 13, from which we deduce C = 6.8 pF and R = 48 Ω. The value of the capacitance is consistent with our estimates of the self-capacitance of the junction. On the other hand, the value of the resistance is several orders of magnitude lower than the junction resistance at low voltages, and is completely dominated by the shunting impedance of the external circuitry.

Apart from its inherent interest, the new phenomenon of resonant activation provides an in situ measurement of the junction parameters as modified by the complex impedance loading the junction. This information is very useful in experiments to investigate macroscopic quantum tunneling(4).

M.H.D. and D.E. thank the Commissiariat à l'Energie Atomique for partial support. This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

REFERENCES

(1) W. C. Stewart, Appl. Phys. Lett. 22 (1968) 277; D. E. McCumber, J. Appl. Phys. 39 (1968) 3133.

(2) V. Ambegoakar and B. I. Halperin, Phys. Rev. Lett. 22 (1969) 1364.

(3) T. A. Fulton and L. N. Dunkleberger, Phys. Rev. B 9 (1974) 4760.

(4) A. O. Caldeira and A. J. Leggett, Ann. Phys. (N.Y.) 149 (1983) 374.

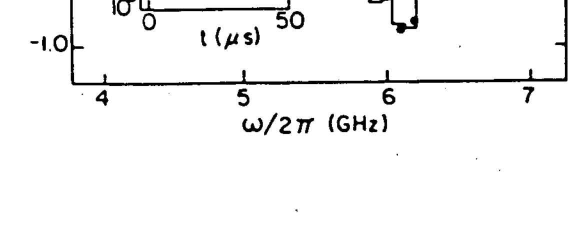

Fig. 1 Variation of escape time with mirowave frequency. Circles are experimental data for a junction at 4.2K with I_o = 4.64 μA, I = 3.07 μA and τ(0) = 8.4 μs, line is numerical simulation. Inset shows exponential distribution of switching events in the absence of microwaves.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720