Nonequilibrium Superconductivity, Phonons, and Kapitza Boundaries

Edited by
Kenneth E. Gray
US Department of Energy
Argonne National Laboratory
Argonne, Illinois

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THE EFFECT OF MICROWAVES ON TUNNEL JUNCTIONS

Ivan K. Schuller

Solid State Science Division
Argonne National Laboratory
Argonne, IL 60439 USA

E. D. Dahlberg

Physics Department
University of Minnesota
Minneapolis, MN 55455

INTRODUCTION

Interest in the effects of microwave radiation incident on tunnel junctions first arose nearly twenty years ago in the early 1960's. Even though research, both theoretical and experimental, has been extensive in this area, it has not been exhaustive. Recent renewed interest has been motivated by theoretical predictions and experimental observations relating to redistribution of quasiparticles and their relationship to the "gap enhancement" phenomenon. In the present paper we will describe the effect of microwaves on tunnel junctions excluding specifically "gap enhancement," which will be described in Chapter 7 by J. E. Mooij.

Microwaves incident on a superconductor-superconductor tunnel junction have the effect of opening up new tunneling channels which manifest themselves as additional structure in the I-V characteristics and their derivatives. The evolution of this structure as a function of frequency and microwave power has been theoretically calculated and is in good agreement with experimental observations. Other effects include microwave induced Josephson steps and microwave steps related to subharmonic gap structures in tunnel junctions. It is interesting to note that a number of similar effects are present in Esaki tunnel diodes where structures are observed at characteristic phonon frequencies due to phonon assisted tunneling.

In the next section we will describe the theory of photon assisted tunneling. We present the experimental techniques in Section 3 and the experimental results relating to photon assisted tunneling in Section 4. Section 5 is dedicated to the effect of microwaves on phonon structures and in the final section our conclusions are summarized.

2. THEORY OF PHOTON ASSISTED TUNNELING

The original theory for photon assisted tunneling which we will follow was originally developed by Tien and Gordon (1963). Independently, Cohen, Falicov and Phillips (1962) found a similar result using manybody techniques. An electric field perpendicular to a tunnel junction has the effect of setting up a time varying potential difference

$$V_{rf} \cos\omega t \tag{1}$$

between the two films A and B. If the potential in film A is used as a reference, the effect of the electric field is to add an electrostatic potential to the electrons in film B. The quasiparticle wave function in film B in the absence of microwaves can be written as

$$\Psi(x,y,z,t) = f(x,y,z)e^{-iEt/\hbar} \tag{2}$$

The new hamiltonian in the presence of microwaves is

$$H = H_o + eV_{rf}\cos\omega t \tag{3}$$

where H_o is the unperturbed hamiltonian. Since the spatial part of Ψ is not changed by the perturbation, the new wave function is given by

$$\Phi(x,y,z,t) = \Psi(x,y,z,t)\left\{\sum_{n=-\infty}^{\infty} B_n e^{in\omega t}\right\} \tag{4}$$

After substituting Eq. (4) into the time dependent Schrödinger equation one finds that the coefficients B_n obey Bessel function recursion relations so that

$$\Phi(x,y,z,t) = f(x,y,z) \sum_{n=-\infty}^{\infty} J_n(\alpha)\, e^{-it(E+n\hbar\omega)/\hbar} \tag{5}$$

with

$$\alpha = eV_{rf}/\hbar\omega \tag{6}$$