

PHONON EMISSION BY QUASIPARTICLE DECAY
IN SUPERCONDUCTING TUNNEL JUNCTIONS

H. KINDER *, K. LASZMANN ‡ and W. EISENMENGER *

III. Physikalisches Institut der Universität Göttingen, Germany

Received 10 March 1970

Improved measurements on phonon emission and detection by tunnel junctions show qualitative agreement with a numerical evaluation of Tewordt's theory on quasiparticle lifetime.

Phonon generation and detection by superconducting tunnelling junctions (Sn - I - Sn) has been reported in ref. [1]. We now present similar measurements under improved experimental conditions.

The signal to noise ratio was increased using substantially higher phonon intensity by the preparation of very low impedance junctions (typically $R_{\infty} = 2 \text{ m}\Omega$) and reducing the geometrical loss by the use of a shorter sapphire crystal (3 mm thick, C-oriented). The detector characteristic was linearized by a negative feedback loop regulating the bias. A modulation technique suppressed direct electromagnetic feedthrough and yielded the first derivative of the detector signal with respect to the generator current.

Thus the results allowed quantitative comparison with numerical calculations based on the theory of Tewordt [2] for $T = 0$. The theoretical decay probability (in BCS limit) for a quasiparticle of given energy under emission of a phonon of energy Ω was normalized by the total decay rate and folded with the quasiparticle distribution injected by tunnelling (in BCS limit). The resulting theoretical phonon spectrum due to first step decay (the second step contribution is small) is plotted in fig. 1 for several values of generator voltage U .

The "monochromatic" peak at $\Omega = 2\Delta$ due to recombination is not shown. It rises proportional to the generator current and has one half of the area of the corresponding decay spectrum. The most outstanding feature of the spectrum is the cutoff at $\Omega = eU - 2\Delta$.

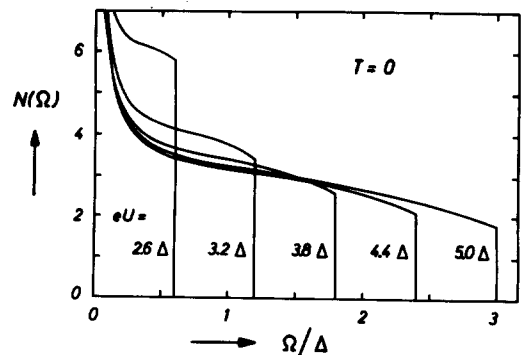


Fig. 1. Theoretical phonon spectrum due to quasiparticle decay for various junction voltages. $N(\Omega)$ the phonon number per energy Δ and per time is in units of $\Delta/(e^2R_{\infty})$.

To obtain directly the theoretical prediction for the measured dependence of the detector signal on the generator current we assumed that the detector responds fully to the monochromatic peak at $\Omega = 2\Delta$, but only to those decay phonons with $\Omega \geq 2\Delta$. This part of the spectrum was integrated over Ω and then differentiated with respect to the generator current.

The result valid for $T = 0$ is plotted together with an experimental curve at $T = 1.1^\circ\text{K}$ in fig. 2. The scaling factor is adjusted to the plateau above the 4Δ step. The experimentally observed step at 4Δ turns out to be less than expected theoretically.

The increase beginning at 6Δ indicates an enhanced phonon yield. This can be explained assuming reabsorption of phonons of $\Omega \geq 2\Delta$ within the generator films by pair breaking and subsequent decay of the secondary quasiparticles under emission of new phonons. The corresponding

* Present address: Institut für Festkörper- und Neutronenphysik, Kernforschungsanlage Jülich, Germany.

‡ Present address: I. Physikalisches Institut, Universität Stuttgart, Germany.

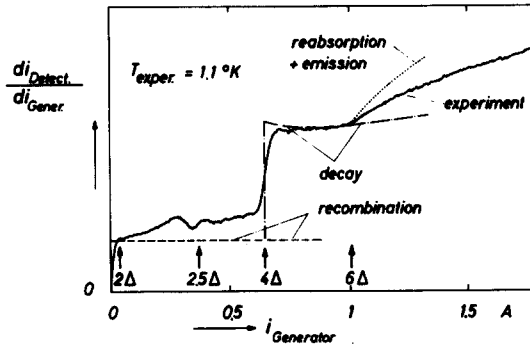


Fig. 2. Modulation of the detector signal dI_D/dI_G (arb. units) versus generator current I_G .

foldings, though more complicated, were done numerically using the same scaling factor as before. The resulting theoretical enhancement of the detector signal is indicated by the dotted line in fig. 2.

The qualitative agreement with experiment is rather good confirming that most of the phonons undergo the reabsorption process. The quantitative disagreement however has about the same ratio as is observed at the 4Δ step suggesting an identical, yet unknown loss. Measurements at

higher temperatures show a still increased loss indicating that the effect of finite temperature should be included in the calculation.

Additional structure is seen around 2.5Δ (see arrow in fig. 2). A much larger but similar structure was observed using a generator junction of still lower impedance. In this connection the small decrease of the generator gap due to the high quasiparticle injection may be of importance.

We gratefully acknowledge the encouragement by Prof. E. Meyer and financial support by the Deutsche Forschungsgemeinschaft and by the Akademie der Wissenschaften Göttingen. One of us (H. K.) is indebted to Dr. F. Hozfeld, Miss U. Rogge and Miss B. Darsow of the Institut für Festkörper- und Neutronenphysik, Kernforschungsanlage Jülich for the numerical data processing.

References

1. W. Eisenmenger and A. H. Dayem, Phys. Rev. Letters 18 (1967) 125;
W. Eisenmenger, Tunneling phenomena in solids, eds. E. Burstein and S. Lundqvist (Plenum Press, New York, 1969).
2. L. Tewordt, Phys. Rev. 127 (1962) 371;
L. Tewordt, Phys. Rev. 128 (1962) 12.

* * * * *