MASTER

EXPERIMENTAL DETERMINATION OF THE QUASIPARTICLE DISTRIBUTION
FUNCTION IN NON-EQUILIBRIUM SUPERCONDUCTORS

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Prepared for

15th International Conference on
Low Temperature Physics (LT-15)

Grenoble, France

August 23-29, 1978

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EXPERIMENTAL DETERMINATION OF THE QUASIPARTICLE DISTRIBUTION
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ABSTRACT

Results are presented on a technique to determine the distribution function $f(E)$ in the non-equilibrium state of a superconductor. This technique is used to show for the first time a more highly peaked $f(E)$ near the gap for tunnel injection at low voltages.

On présente les résultats concernant une technique de détermination de la fonction de distribution $f(E)$ pour un superconducteur hors d'équilibre. Cette technique a été appliquée pour démontrer pour la première fois un déplacement de $f(E)$ vers les faibles énergies dans le cas de l'effet tunnel à des potentiels faibles.

INTRODUCTION

In any non-equilibrium state of a superconductor it is extremely important to know the quasiparticle distribution function $f(E)$. This depends in a complicated way on the nature of the perturbation from equilibrium, the interaction with phonons and the rate at which phonons escape the system. For a given experiment, it is very difficult to predict $f(E)$ from basic principles. Therefore a technique to measure $f(E)$ would be an important contribution to our understanding of these non-equilibrium systems. In this paper, we present such a technique.

A particularly interesting non-equilibrium distribution is the μ^* distribution¹ which is more highly peaked at low energies than the corresponding thermal distribution. It has been shown that more highly

*Work performed under the auspices of the U. S. Department of Energy.

peaked distributions generally lead to instabilities as the strength of the perturbation is increased.^{1,2} It has been suggested that such a distribution can be achieved by one of the following conditions: (1) a quasiparticle-lattice scattering rate much greater than the quasiparticle recombination rate¹; (2) high phonon trapping³; and (3) tunnel injection at the gap energy.^{4,5} We show experimental evidence confirming such a distribution, which is obtained by tunnel injection.

TECHNIQUE

The technique to measure $f(E)$ was suggested by Chang and Scalapino⁶ and uses the current-voltage characteristics of a tunnel junction. We introduce two important modifications: (1) the use of an aluminum-lead detector, and (2) gaussian smearing of the density of states in each superconductor. Quasiparticles are frozen out in the lead, due to its large gap, Δ_{Pb} , and we study the aluminum which has a much smaller gap Δ_{Al} . As a result the current for voltages less than $\Delta_{Pb} - \Delta_{Al}$ is simply related to $f(E)$ in the aluminum. Unfortunately tunnel characteristics are never as sharp as predicted by BCS. We therefore assume that there is a gaussian distribution of energy gaps in each film.⁷ The fit to experimental curves is very sensitive to the parameters; however Δ_{Pb} ($= 1368 \mu V$) and the gaussian half widths σ_{Pb} ($= 2.4\%$) and σ_{Al} ($= 5\%$) are fixed for all calculations in this paper, and Δ_{Al} is fixed by the structure of each experimental curve. Using the measured junction resistance and temperature, the calculations are compared to experiments in thermal equilibrium with no adjustable parameters (see Fig. 1).

RESULTS

Tunnel injection is used to obtain the non-equilibrium state in spite of difficulties associated with the inhomogeneous state.⁵ To

overcome these, we bias the aluminum-aluminum injector junction at the top of the vertical rising portion of its characteristic. At this point, and for larger voltages, V , the injection rate and energy gaps are homogeneous throughout the films.

Examples of the detector IV characteristics for two different voltages on the injector junction are shown in Fig. 2. Also shown for comparison, are the IV curves in thermal equilibrium which most closely match. For $V < \Delta_{\text{pb}} - \Delta_{\text{Al}}$, the curves reflect the differences in $f(E)$ between a non-equilibrium state caused by injection and thermal equilibrium. It is clear that injection at $V \sim 2\Delta$ gives a more peaked distribution than thermal (as expected since the quasiparticles are injected near the gap), and injection at $V \sim 8\Delta$ gives a less peaked distribution than thermal. The latter result indicates that the quasiparticle-lattice scattering rate is not sufficiently greater than recombination rate in our aluminum films to cause a more peaked distribution, and low voltage injection is necessary.

For lower injection voltage, the more peaked distribution can be compared with a μ^* model. Using the same fixed parameters as before, and determining Δ_{Al} from the structure of the experimental curve with injection at $V \sim 2$, we calculate the best fit by varying T and μ^* . The values of μ^* ($= 45 \mu\text{V}$) and T ($= 0.565 \text{ K}$) are in good agreement with the μ^* model for the appropriate gap reduction, but indicate significant heating above the bath temperature $\sim 0.4 \text{ K}$. This agreement indicates a good approximation to a μ^* distribution.

COMMENTS

Based on this result, we feel justified in our previous comparison⁵ of gap reduction with the μ^* model. We should also point out a possible

difficulty in observing the instability at the first order transition in such a system. As the non-equilibrium gap becomes small, it may be impossible to have the injection voltage sufficiently near the gap edge, to obtain a more highly peaked $f(E)$ necessary for the instability. We plan to investigate this more completely.

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FIGURES CAPTIONS

Figure 1. Comparison of experimental (Δ) and calculated (Δ) IV curves in thermal equilibrium.

Figure 2. Experimental IV curves in thermal equilibrium (Δ) and with tunnel injection ($\bullet$) at a voltage V_g . The bottom curves are compared with calculation (Δ and o).