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SUPERCONDUCTING TUNNELING ON BULK NIOBIUM

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Superconducting tunneling experiments on bulk niobium-niobium oxide-lead film sandwiches indicate that the energy gap in bulk niobium is about $3.6kT_c$ which is in good agreement with the Bardeen-Cooper-Schrieffer[1] theory.

If two metals are separated by a thin dielectric (50 A), then a potential applied across them results in a current due to electron tunneling. Recent experiments by Giaever[2,3] and Nicol, Shapiro, and Smith[4] have shown that if either or both of the metals are superconducting films, then the tunneling current depends strongly upon the superconducting density-of-states functions. These experiments have provided direct measurements of superconducting energy gaps in films. Bardeen[5] has shown that the dependence of tunneling current on density of states for superconductors can be deduced if tunneling is treated as a many-particle problem.

In the present experiment, plates of commercial grade niobium were mechanically polished and then annealed at 1800°C in vacuum for about six hours. The residual gas pressure during annealing was about 10^{-5} mm Hg for some samples and about 5×10^{-7} mm Hg for others. This annealing procedure was adopted after early experiments on niobium not so treated indicated that the niobium was not superconducting at the surface.

These niobium plates were painted with collodion leaving a narrow unpainted strip at the center. Lead films were evaporated onto these substrates so that they crossed the unpainted strip at right angles, providing a region where the films were separated from the niobium only by the thin niobium oxide which had grown in air. The area of these junctions ranged from 2 mm^2 to 10 mm^2. Using an ammeter and a vacuum tube voltmeter, the tunneling current for these junctions was measured as a function of voltage.

Figure 1 shows the I vs V trace for a typical junction at 4.2°K. The niobium used for this sample was annealed in 5×10^{-7} mm Hg and was polycrystalline with crystallite sizes ranging from 0.2 mm to 1.5 mm across as evidenced by

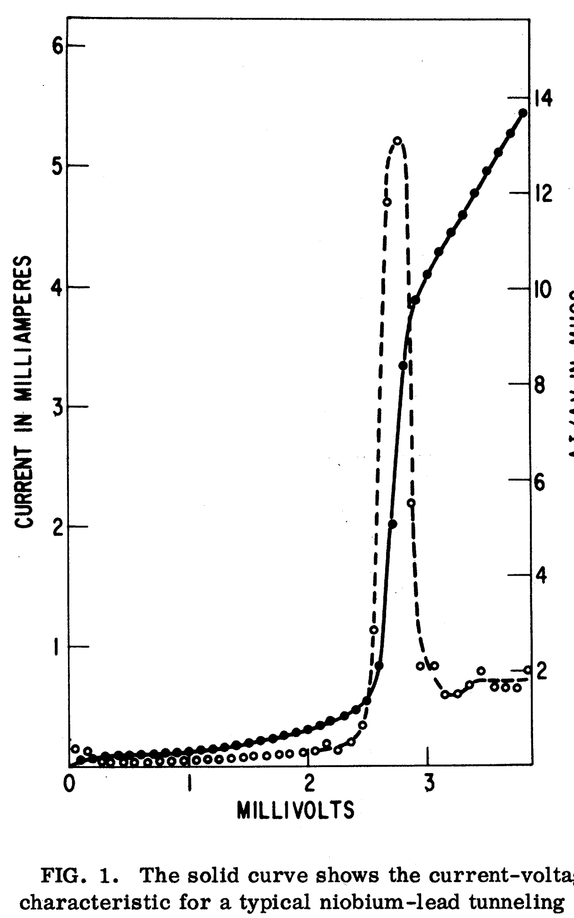

FIG. 1. The solid curve shows the current-voltage characteristic for a typical niobium-lead tunneling junction at 4.2°K. The dashed curve is the first difference ($\Delta I/\Delta V$) of the solid curve. The error in $\Delta I/\Delta V$ increases by a factor of ten over 1 ma.

the grain boundaries at the surface. In the temperature range 1.9°K to 4.2°K, no negative-resistance region was observed in this sample. This is because the energy gaps in the lead and niobium were nearly equal. There is, however, a small maximum in the slope at the origin and a large maximum at 2.75 mv. At 1.9°K the maximum at the origin was not observed and the large maximum had moved to 2.85 mv.

The position of this large maximum in the slope should be given by[2,3] $\epsilon_1+\epsilon_2$, where ϵ_1 and ϵ_2 are half the energy gaps in the two superconductors. Using previously determined values for the energy gap in lead ($2\epsilon_{\mathrm{Pb}} = 2.68$ mv $= 4.3kT_c$),[3,4] we can now determine the value of the gap in bulk niobium.

$$1.9°\mathrm{K}:\ 2\epsilon_{\mathrm{Nb}} = 3.02\ \mathrm{mv} = 3.59kT_c\ (T_c = 9.2°\mathrm{K}).$$

Richards and Tinkham[6] obtained $2\epsilon = 2.8kT_c$ for niobium from far-infrared reflection measurements. They pointed out, however, that it was possible that the surface layer of their sample did not have the value of the energy gap characteristic of bulk niobium.

The I vs V characteristics for several junctions displayed some indications that the energy gap was not the same for all parts of the junction. Almost all samples had a small minimum in the slope of the I vs V curve about 0.2 to 0.3 mv above the second maximum. In one sample this minimum became a small negative resistance region (0.11 mv broad at 3.0 mv) when cooled to 1.9°K. Figure 2 shows the data for another junction (annealed in 10^{-5} mm Hg) which has a small negative-resistance region corresponding to a very small energy gap for part of the junction.

Since these peculiarities were either absent or much less pronounced for niobium plates prepared in the better vacuum, the conclusion that they are due to anisotropies in the energy gap is not justified. Instead we tentatively conclude that they are probably caused by the poor quality of the niobium plate.

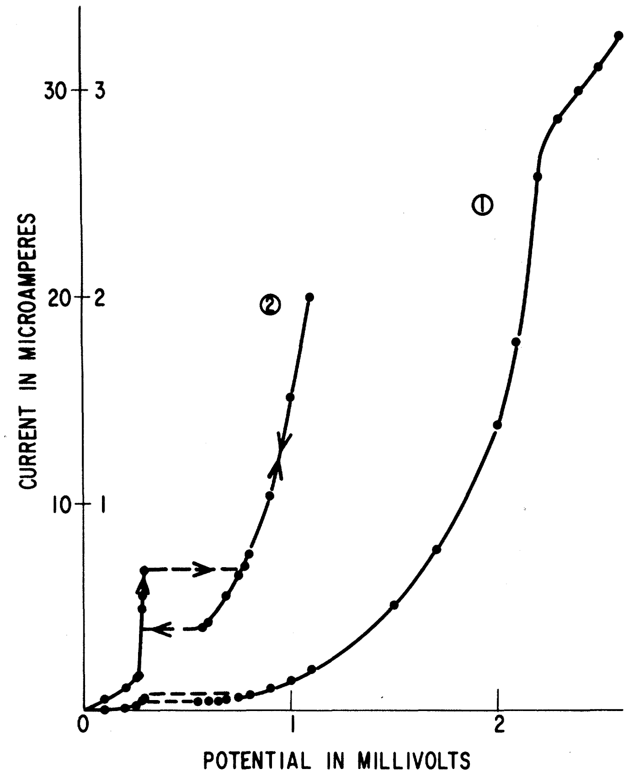

FIG. 2. The current-voltage relationship for the most atypical junction studied. Curve 2 shows the data of curve 1 plotted to an expanded current scale.

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