Investigation of quasiparticle diffusion away from the tunneling regions of SIN X-ray sensors

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Electrons which tunnel from the normal electrode to the superconducting electrode of an SIN tunnel junction ultimately combine to form Cooper pairs. If this occurs close to the tunneling region, the phonons emitted during the combination process may enter the normal electrode and heat it. We compared 6 keV X-ray pulse data from $Al/Al_2O_3/Cu$ SIN series pairs having narrow leads with pulse data from identical SIN pairs having very wide leads. We found that quasiparticle diffusion in the wide leads was not sufficient to remove the quasiparticles from the junction region.

1. INTRODUCTION

Superconductor-insulator-normal (SIN) tunnel junctions are ultrasensitive thermometers for the electrons in the normal metal [1]. If the energy deposited in an X-ray absorber can be used to heat the electrons in the normal electrode, then the current through a voltage-biased SIN junction will change. We show in Figure 1 how the current responsivity dI/dT varies with bias voltage at different operating temperatures. The peak in dI/dT moves closer to the gap voltage Δ/e as the temperature is reduced. Hence, if we vary the temperature at fixed bias voltage below the gap voltage, we expect a maximum in pulse height at the temperature for which the peak in responsivity passes through the bias voltage.

The pulse decay time is determined by the cooling rate of the normal-metal electrons. Nahum *et al* have presented a simple thermal model of an SIN junction in which they identify two relaxation mechanisms [2]. One way that an electron can cool is to emit a phonon. Alternatively an electron can tunnel through the barrier into the superconducting electrode and thus remove its excess energy from the normal-metal electron system. This model ignored other factors which can cause heating of the electrons in the normal metal. When electrons tunnel from the normal metal into the superconductor, they become quasiparticles. These quasiparticles can recombine in the superconductor, emitting phonons with energy equal to 2Δ. These phonons could be absorbed in the normal metal, thus heating it. Another possibility is that a quasiparticle may tunnel back into the normal metal as a hole, depositing an amount of energy $E = \Delta + eV$, where V is the bias voltage. These heating processes are minimized if the quasiparticles are able to diffuse away from the junction region before they can either recombine or retunnel. In this work we have attempted to investigate these heating terms by comparing pulses from an SIN junction having wide leads with pulses from a junction having narrow leads that restrict diffusion of the quasiparticles away from the tunneling region.

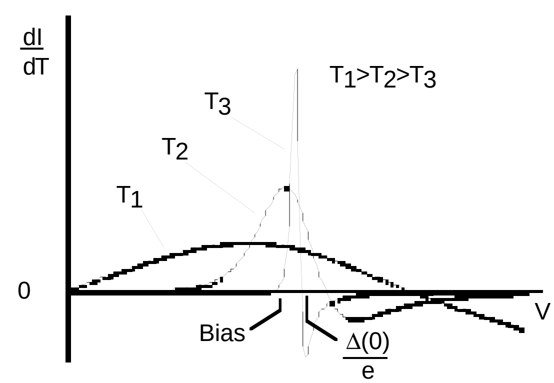

Figure 1: Current Responsivity of an SIN Junction

2. EXPERIMENTAL RESULTS

We fabricated our $Al/Al_2O_3/Cu$ SIN devices in the San Francisco State University (SFSU) Thin Film Laboratory [3]. We made series pairs of SIN junctions because both leads to each pair could be simple extensions of the superconducting base electrodes. Current-voltage characteristics were measured at SFSU and at the University of California at Berkeley (UCB). X-ray pulse data was measured in the Laboratory for Experimental Astrophysics at Lawrence Livermore National Laboratory (LLNL).

To test the relationship between superconducting electrode geometry and quasiparticle diffusion length, we produced two series pairs of $(90\mu m)^2$ junctions on the same chip. One pair has long narrow leads (1660 μm long x 10 μm wide) while the other pair has large leads (1740 μm x 2740 μm). If superconducting electrode geometry is important, we expect the narrow leads to confine quasiparticles more effectively near the junctions. This should cause the narrow lead device to self heat to a higher temperature than the wide lead device. As a result, as the bath temperature is changed, the variation of pulse height and decay time in the narrow lead pair should not have the same functional forms observed in the wide lead pair.

We tested these sensors in an adiabatic demagnetization refrigerator at LLNL. We thermally grounded the chip by using silver-filled epoxy to attach one end of a 24 gauge copper wire to the chip and the other end to the copper sample stage. We irradiated the junction pairs with Mn Kα and Kβ X-rays from an ^{55}Fe source. We voltage biased each junction pair and measured the current pulses with a 200-SQUID series array manufactured by HYPRES, Inc., operated in an open-loop mode.

At a temperature of 100 mK we found the optimum bias voltages to be 275 μV and 300 μV for the narrow and wide lead devices, respectively. At these voltages we measured the pulse height and decay time as we varied the temperature between 80 mK and 400 mK.

Figure 2 is a plot of pulse height *vs* temperature for each junction pair. In both cases as the temperature decreases the pulse height increases but does not have a

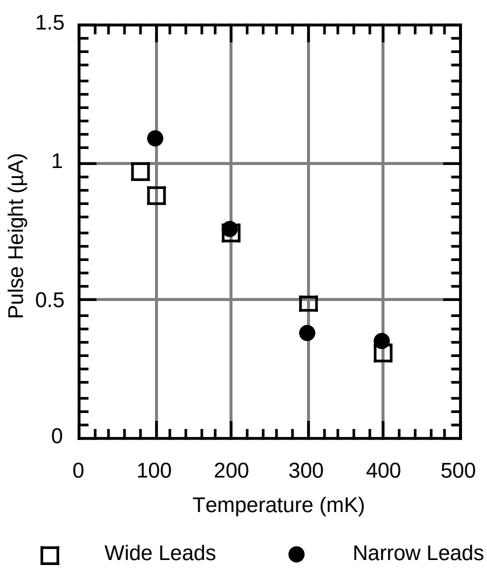

Figure 2: Pulse Height vs. Temperature

peak. The pulse heights are very similar for the narrow lead and wide lead devices. Figure 3 is a plot of 80%-to-(1/e)×80% pulse decay times *vs* temperature for each junction pair. The decay times are nearly identical.

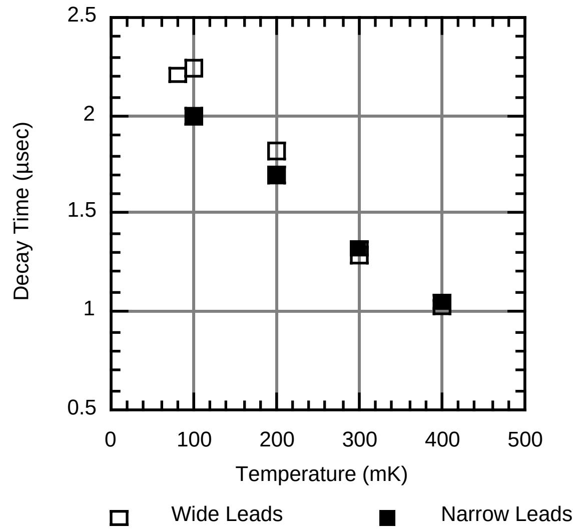

Figure 3: Decay Time as a Function of Temperature

3. CONCLUSIONS

We did not observe any difference in the temperature dependence of pulse height and pulse decay time between the narrow lead and wide lead devices. This suggests that the quasiparticle diffusion length is much less than the junction dimensions so that the quasiparticles which have tunneled remain in the junction region until they recombine or retunnel. We are now working on experiments to determine whether quasiparticle diffusion is limited by impurities or grain boundaries in the film or by scattering off the top and bottom interfaces of the film.

4. ACKNOWLEDGMENTS

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