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PICOSECOND RESPONSE OF THE QUASIPARTICLE CURRENT IN SUPERCONDUCTING TUNNEL JUNCTIONS

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We have investigated the response of the quasiparticle tunneling currents in superconductor-insulator-superconductor (SIS) junctions to picosecond electrical pulses.

1. INTRODUCTION

The quasiparticle tunneling current in superconductor-insulator-superconductor (SIS) junctions has been exploited in a class of ultrasensitive high-frequency devices such as mixers and video square-law detectors[1]. Previous workers have characterized the linear response of SIS junctions by using cw sources near 80 GHz[2, 3]. However, the broadband response near the threshold at $2\Delta - eV_o$ has not been studied. Here Δ is the superconducting gap parameter and V_o is the bias voltage across the junction. In this work, we have used picosecond electrical pulses to measure the broadband quasiparticle response of a Nb trilayer SIS junction. We measured the response by monitoring the DC current induced by interfering two electrical pulses at the junction, as a function of the time delay between them. The broad bandwidth of the electrical pulses was preserved by quasi-optical coupling to the SIS junction. The power in the electrical pulses was sufficiently high that they could be weakly coupled to the SIS junction via an impedance-mismatched antenna. Consequently, the resonant quasiparticle response was not significantly broadened by the radiation resistance of the antenna.

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2. EXPERIMENTAL TECHNIQUE

The picosecond electrical pulses were generated by illuminating a silicon photoconducting switch at the terminals of a 300 μm dipole antenna[4]. The silicon was ion-implanted twice at a dose of 10^{15} cm^{-2} with energies of 100 keV and 200 keV. The antenna terminals have a 5 μm gap which was DC-biased between 10 V and 20 V for the present measurements. The photoconductor was excited with a Ti:sapphire laser operating at 800 nm with 100 fs pulses and an average power of 200 mW. The use of a high repetition rate (100 MHz) laser is critical to obtain an adequate ratio of signal to noise. The emitted electrical pulses are nearly single-cycle with a center frequency of approximately 180 GHz and a 3 dB bandwidth of 80 GHz.

Figure 1 is a schematic diagram of the interferometer used in these measurements. The pulses are generated from two separate antennas. The beam from each antenna is partially collimated by a 13 mm diameter sapphire hyperhemisphere and then further collimated by a 9 cm diameter f/1 parabolic mirror. The two beams are combined into one with a 200 μm thick mylar beamsplitter. An f/3 parabolic mirror then focuses the combined beam through a 25 μm thick polypropylene window on a liquid helium cryostat which houses the SIS junction. The SIS junction was fabricated at the terminals of a Nb planar log-periodic antenna which couples the quasi-optical electrical pulses to the junction. The SIS junction

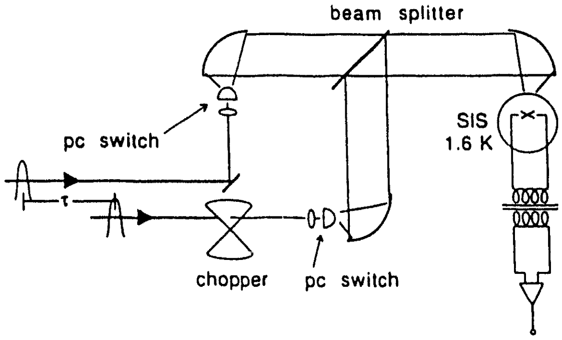

Figure 1. Schematic layout of the picosecond electrical pulse interferometer.

is a $2 \times 2\,\mu m$ $Nb/AlO_x/Nb$ trilayer with a critical current density of $5 \times 10^3\ A/cm^2$, a capacitance of 200 fF, and a normal state resistance of $14\,\Omega$. A magnetic field of about 100 G cancels the Cooper pair tunneling current and allows us to isolate the quasiparticle tunneling current.

3. RESULTS

In the first experiment, we reduced the intensity of the electrical pulses so that the induced DC current scaled linearly with RF power while still preserving an adequate ratio of signal to noise. In this regime, single photon absorption processes dominate much of the data. Figure 2a shows the average DC current induced by two electrical pulses of similar magnitude, plotted as a function of the time delay between them. The temperature of the liquid ^{4}He bath was 4.2 K. Curves with bias voltage $V_o < 2.6\,mV$ are offset for clarity. A null in the data appears at zero ps since the electrical pulse reflecting off the mylar beamsplitter undergoes a 180° phase shift. The oscillations at longer delay times result from the coherent tunneling of quasiparticles across the junction. The amplitude Fourier transforms are shown in Fig. 2b. As V_o is reduced from 2.6 mV, the resonance frequency $(2\Delta - eV_o)/\hbar$ is increased and the amplitude of low-frequency scillations is reduced while higher frequency oscillations persist. The small structure in the power spectra results from the slight frequency-dependence of the radiation pattern of the log-periodic antenna on the SIS junction.

In summary, the broadband response of the quasiparticle current in a SIS junction has been measured using picosecond electrical pulses. This work may have applications to characterizing optical interconnects between high-speed optoelectronics and superconducting circuits.

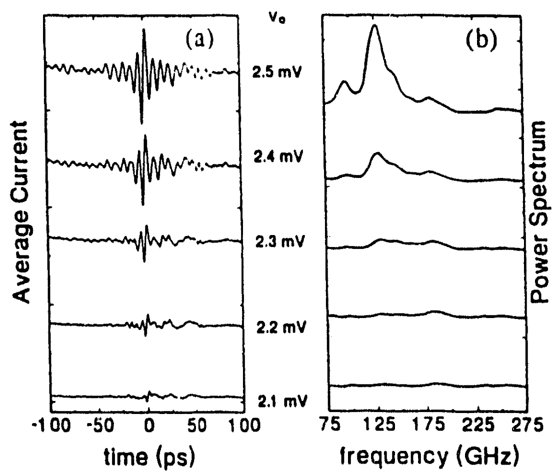

Figure 2. (a) Measured DC current induced in the junction by two incident picosecond electrical pulses which are separated by a time delay t. (b) Fourier transforms of the interference patterns.

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