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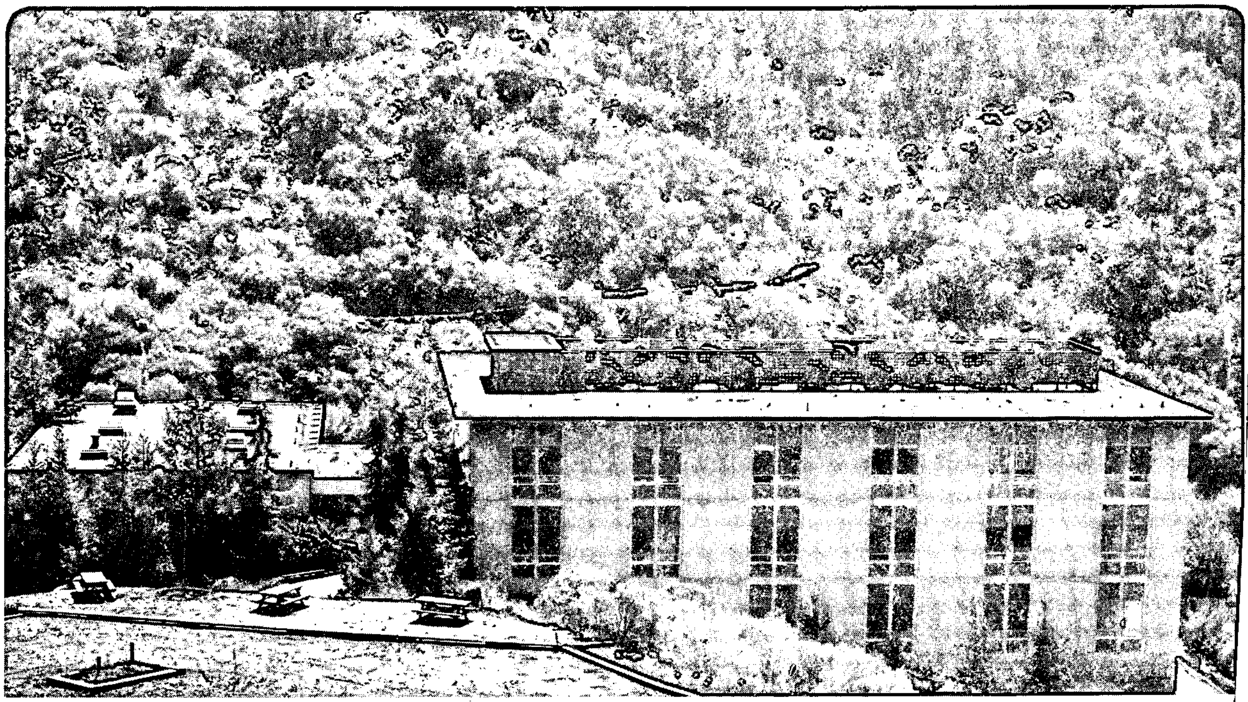

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Response of a $Nb/Al_2O_3/Nb$ Tunnel Junction to Picosecond Electrical Pulses

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Response of a Nb/Al_2O_3/Nb Tunnel Junction to Picosecond Electrical Pulses

We have resolved the time domain response of the quasiparticle current in a superconducting tunnel junction to picosecond electrical pulses propagating in free space.

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Response of a Nb/Al_2O_3/Nb Tunnel Junction to Picosecond Electrical Pulses

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The nonlinear response of 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 detectors [1]. Nevertheless, the nonlinear, and even linear, response of these junctions has not been adequately measured. While SIS junctions have been characterized using cw sources near 80 GHz [2], the broadband response near the threshold at $2\Delta - eV_{bias}$ has not been studied. Here Δ is the superconducting gap parameter and V_{bias} is the bias voltage. In this work, we have used picosecond electrical pulses to measure the broadband quasiparticle response of a Nb trilayer SIS junction in both the linear and nonlinear regimes. The use of electrical pulses is especially well suited to the nonlinear regime, in that a relatively large instantaneous voltage may be applied while the average power is kept low.

The picosecond electrical pulses used for this measurement were generated by illuminating a silicon photoconducting switch at the feed of a 300 μm dipole antenna [3]. The silicon was ion-implanted with $1.0 \times 10^{15}/cm^2$ doses of oxygen ions at both 100 keV and 200 keV. The antenna terminals have a 5μm gap which was biased as low as 10V for linear spectroscopy and up to 60V for the nonlinear measurements. To excite the photoconductor we used an unamplified Ti-Sapphire laser operating at 800nm with 100 fs pulses and an average power of 50 mW. The use of a high repetition rate (100MHz) laser is critical to obtain the high ratio of signal to noise in our data. The emitted electrical pulses are nearly a single cycle with a center frequency at approximately 180 GHz and a 3db bandwidth of 80 GHz.

The broadband response of the SIS device is inferred by measuring the dc current induced by interfering two electrical pulses at the junction, as a function of the time delay between them. Figure 1 is a schematic diagram of the interferometer that was used to perform these measurements [4].

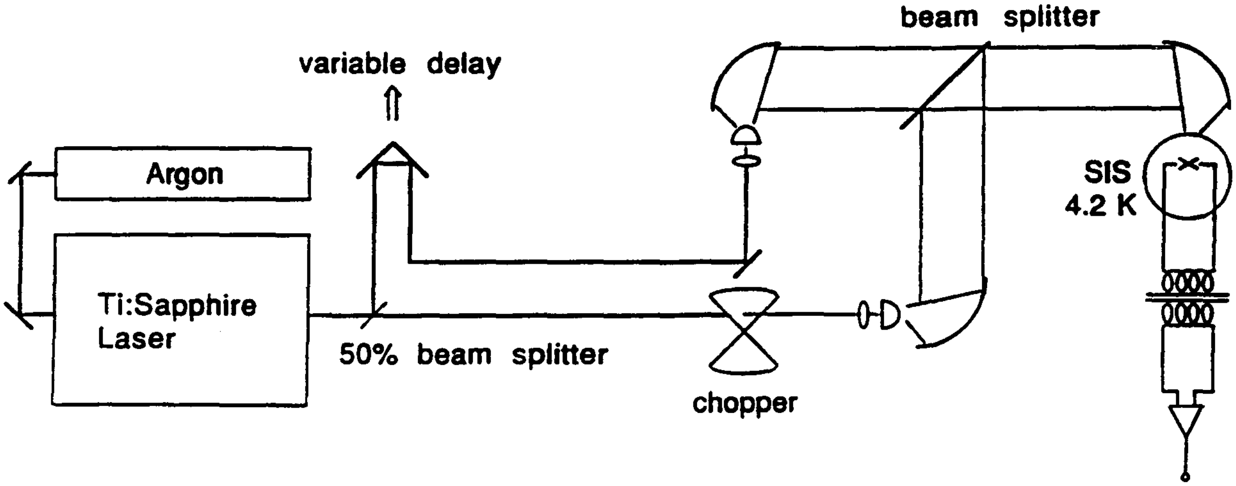

Figure 1. Schematic layout of the picosecond electrical pulse interferometer.

The pulses are generated from two separate antennas. The beam from each antenna is partially collimated by a 13mm diameter sapphire hyperhemisphere and then further collimated by a 3.5 inch diameter f/1 parabolic mirror. The two beams are combined into one with a 200μm thick mylar beamsplitter. To focus the recombined beam onto the SIS junction an f/3 parabolic mirror first directs the pulses onto the polypropylene window of a 4.2K cryostat which houses the junction. The beam which enters through the window is then focused onto the SIS junction with a TPX lens and a quartz hyperhemisphere.

The SIS junction was fabricated at the terminals of a log-periodic planar antenna, which couples the free space electrical pulses to the junction. The SIS junction is a 2μm x 2μm $Nb/Al_2O_3/Nb$ trilayer with a critical current density of 3.5 kA/cm^2 , capacitance of 200 fF, and normal state resistance of 14 Ω. A magnetic field of about 100 gauss cancels the Cooper pair tunneling current and allows us to isolate the quasiparticle tunneling current.

The SIS junction can be modeled as a superposition of voltage tunable two level systems [5]. The BCS theory [6] predicts that when the junction is biased at a voltage V_{bias}, the system will have strong resonant absorption when $hf_0 = 2\Delta - eV_{bias}$. Deviations from the predicted width of the resonance can arise from inhomogeneous broadening mechanisms such as a distribution of energy gap values along the SIS junction. According to the theory developed by Tucker, the response of the SIS junction to an arbitrary voltage pulse in the time domain can be calculated from the measured dc I-V characteristic [6]. The broadening of the resonance is manifested by the width of the current onset at $2\Delta / e$ in the current-voltage (I-V) characteristic. In response to a voltage pulse, the current is expected to oscillate near the frequency $(2\Delta - eV_{bias}) / h$ and to decay with a lifetime related to the broadening of the dc I-V curve. For our SIS junction, $2\Delta = 2.75$ meV and the measured width of the threshold in the dc I-V curve corresponds to a decay time of 10 ps.

Figure 2a shows the signal generated by two electrical pulses incident on the junction as a function of the time delay between them, for $V_{bias} = 2.0$ mV. The bias voltage on the antennas was adjusted so that the pulse intensity was the same in both arms of the interferometer. The laser excitation of one of the antennas was chopped at 1 kHz. Low noise electronics are necessary for measuring the linear quasiparticle response to small electrical pulses. The signal was coupled through a 300K transformer to a low noise FET amplifier with a spot noise referred to the SIS junction of $0.2nV/\sqrt{Hz}$ at 1 kHz.

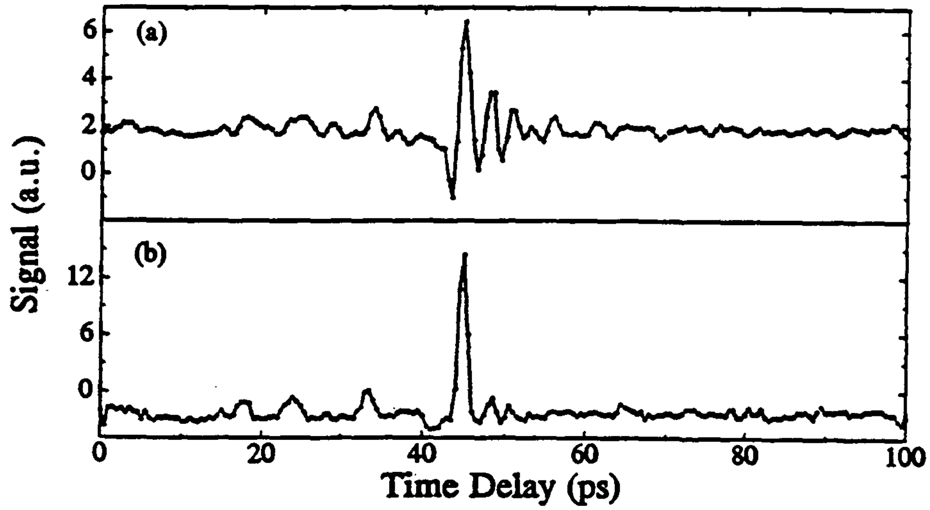

Figure 2. (a) One photon cross-correlation in the SIS junction at $V_{bias} = 2.0$ mV. (b) Two photon cross-correlation at $V_{bias} = 1.0$ mV.

At V_{bias}=2mV the SIS junction has a strong absorption at 180 GHz which is the center frequency of our driving pulse. The peak pulse intensity was kept low so that the SIS junction responded linearly. The coherent oscillation of the quasiparticle current shown in Fig. 2a decays in 10 ps and is consistent with the broadening of the dc I-V curve and correlation time of the incident pulses. We suspect that the asymmetry in the cross-correlation may be due to some small misalignment of the interferometer which may be aggravated by the polarization sensitivity of the log-periodic antenna. Previous cross-correlation measurements with a 1.5 K composite bolometer which has no polarization sensitivity in place of the SIS junction showed that the electrical pulses coupled from the two different arms of the interferometer are nearly identical.

Figure 2b shows the result of a measurement similar to Fig. 2a, except that V_{bias} = 1.0 mV. Two absorption mechanisms contribute to the response of the SIS junction for this value of $(2\Delta - eV_{bias}) / h$. Either one 360 GHz photon or two 180 GHz photons can be absorbed. We expect the two-photon absorption will dominate since the 360 GHz component of the electrical pulse measured with the bolometer was negligible. Signatures of a two-photon absorption process which appear in Fig. 2b are the rectification of the interference pattern and the peak to off-peak ratio of 8:1 [7]. Also, the response of the junction to a single electrical pulse scales as the electric field amplitude to the fourth power, as is expected for a two photon process.

In conclusion, we have applied the technique of picosecond electrical pulse generation to study the time-domain response of a SIS tunnel junction in the linear and nonlinear regimes. The successful measurement of the two-photon absorption process in an SIS junction demonstrates the application of picosecond electrical pulses to time-resolved non-linear spectroscopy. Future experiments will include other nonlinear techniques, such as spectral hole burning, which may allow us to probe the mechanism which broadens the dc I-V curve of the SIS junction.

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References:

[1] P. L. Richards and Q. Hu, Proc. IEEE 60, 1233, (1989).

[2] Q. Hu, C. A. Mears, P. L. Richards and F. L. Lloyd, Phys. Rev. Lett. 64, 2945 (1990); A. H. Worsham, N. G. Ugras, D. Winkler, D. E. Prober, N. R. Erickson, P. F. Goldsmith, Phys. Rev. Lett. 67, 3034 (1991).

[3] M. van Exter, D. Grischkowsky, IEEE Trans. MTT 38, 1684 (1990).

[4] S.E. Ralph, D. Grischkowsky, App. Phys. Lett. 60, 1070 (1992); B.I.Greene, J.F. Federici, D.R. Dykaar, R.R. Jones, P.H. Bucksbaum, App. Phys. Lett 59, 893 (1991).

[5] Q. Hu, C.A. Mears, P.L. Richards, F.L. Lloyd, Phys. Rev. B 42, 10250 (1990).

[6] J. R. Tucker, M.J. Feldman, Rev. Mod. Phys. 57, 1055 (1985).

[7] J.-C. M. Diels, J. J. Fontaine, I. C. McMichael, F. Simoni, Applied Optics 24, 1270 (1985).