Phonon Coupling Between SIN Tunnel Junctions for the LTD-7 proceedings

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Abstract

As part of our work developing Superconductor-Insulator-Normal Metal (SIN) tunnel junction based bolometers, we have fabricated devices with multiple distributed junctions and have investigated the coupling between junctions and devices with injection-detection experiments. The observed non-linearity in the coupling between junctions is discussed in terms of the non-equilibrium phonon distribution and propagation in our devices.

1 Introduction

Bolometers with SIN tunnel junction readouts are promising candidates for high energy resolution X-ray and phonon detectors due to the strong dependence of the thermal tunnel current on the electron temperature in the normal metal.

In order to assess and optimize our device structures and deposition parameters for producing SIN tunnel junction bolometers we have produced devices with multiple distributed junctions with common absorbers. We have studied these devices with injection-detection experiments to assess the magnitude, reproducibility and uniformity of the response of the detector sub-gap current to the increased electron temperature in the common absorber.

Here we report results showing that although the coupling between two junctions is largely mediated via substrate phonons, the presence of a normal metal absorber between the junctions will effectively suppress the coupling. We attribute these results to coupling by athermal 2Δ phonons versus localised heating and thermalisation of the signal in the absorber with subsequent thermal leakage to the substrate.

2 Device Fabrication and Measurement

For the results presented here, the devices fabricated were Nb/Al/AlO_x/Al/Pd/Au multilayers produced in a combination of a whole wafer multilayer sputter process and lift-off technique, on R-plane sapphire substrates and for one device a Si_3N_4 coated Si wafer. An initial trilayer was deposited in a turbo-pumped UHV system, the barrier layer being formed by admitting pure O_2 into the deposition system. The device was patterned using standard photolithography and reactive ion etching processes [?] and the junction region was defined by selective Nb anodisation. The Pd (250nm) /Au (500nm) normal metal absorber was deposited in a lift off process in a high vacuum sputtering system and e-beam evaporator. For most devices a final 50nm Nb layer was sputtered when depositing the absorber. For the device on the Si wafer, a 1μm thick membrane of approximately 1mm^2 area was created by wet etching a window in the Si wafer.

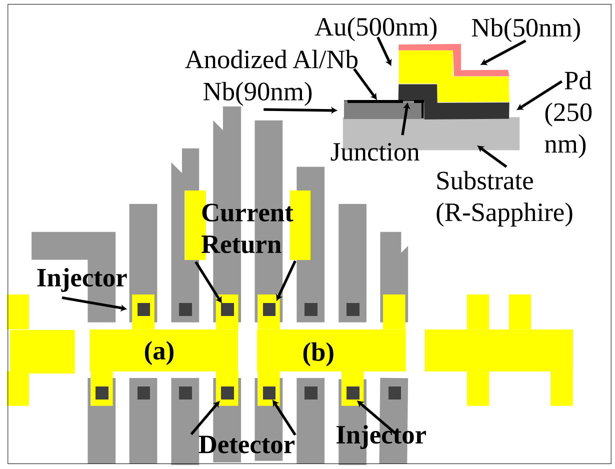

Figure 1: Device structure and plan view.

Fig. 1 shows a schematic of the final device structure with a plan view of a device with two absorbers, one with 3 junctions and an SN contact, the other with 4 junctions. Two different measurement configurations are also shown; (a) detector junction adjacent to injector junction, current return junction opposite, and (b) injector and current return adjacent, detector junction opposite.

The devices were measured in a He^3 insert at a temperature of 0.350K. Injection-detection experiments

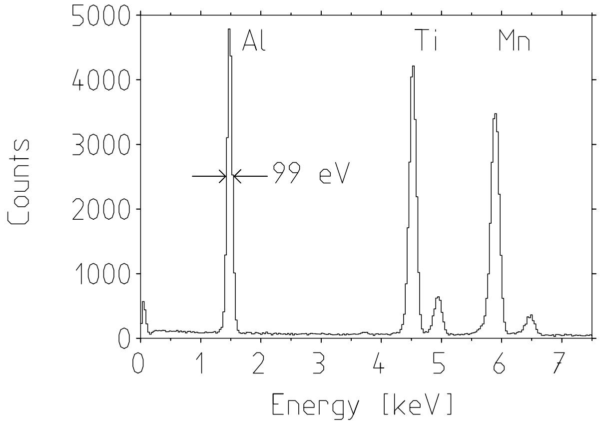

Figure 2: (a) Current-Voltage characteristic of typical device, (b) additional detector current as a result of injection current.

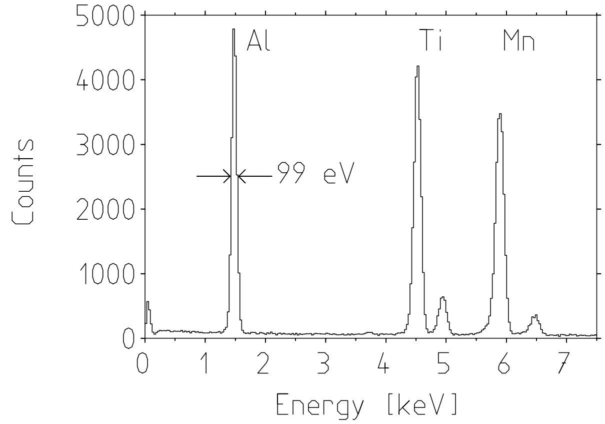

Figure 3: Additional detected current (at a detector bias of 0.5mV) as a function of injected current for (a) configuration in fig. 1a, (b) configuration in fig. 1b, and (c) device on membrane.

were performed by measuring the I-V characteristic of one junction with and without a second junction biased at the injector current. The current return for both detector and injector was through a third contact, which was either another junction or a SN contact. Since the common electrode in this configuration is a normal metal, the measured bias across the detector junction exhibits an offset proportional to the injector current and related to the relative geometry of the injector, detector and other current volatge contacts to the absorber. To eliminate this extra factor, a thin Nb layer was deposited on top of the normal metal. This effectively equalized the potential across the absorber and removed the geometrical factors, although the interactions between the injected ('hot') electrons and this SN interface do have to be considered.

3 Results

Fig. 2 shows a typical I-V characteristic of one junction along with the difference in detector junction current due to an injected current through a neighbouring junction. Data were taken for injector currents corresponding to junction bias in the range $eV = 0 - 4\Delta$.

Depending on the measurement configuration, two types of response were observed for sapphire substrate devices; (Fig. 3a) essentially no response – measurement configuration as in fig. 1a, (Fig. 3b) and a step in the response at a bias in the injector of approximately $eV = \Delta$ – configuration as in fig. 1b. Increasing the distance between the detector junction and second junction did not result in a significant difference in the repsonse, indicating that a simple distance argument does not explain these results. Furthermore measurements between the two electrically isolated absorbers demonstrated coupling between the two devices, thus implying coupling via substrate phonons. For the device on a membrane the response was independent of configuration and qualitatively different (Fig. 3c)

4 Discussion

There are two particular points to be explained in these results, firstly the form of the response with a sharp step at an injector bias of $eV = 1\Delta$ and secondly the geometrical effect where coupling is not observed across the absorber.

A simple explanation of the step feature would be that it was scaling with injected current or power, however this would not explain the essentially constant response for injector biases in the range $eV = 1\Delta - 4\Delta$.

When the injector junction is biased at the energy gap, the current flow introduces a large population of quasiparticles of one character into the superconductor, well in excess of the thermal population. This combined with a relatively short mean free path in the Nb will result in a large local concentration of recombination phonons. For higher biases, the higher energy phonons produced will be down converted to 2Δ and sub 2Δ energy phonons.

Phonons which enter the normal metal will rapidly inelastically scatter to create a hot electron since in this temperature regime the majority of the heat capacity of the metal is electronic. Although the hot electron will have a relatively long lifetime against inelastic scattering, the distance between inelastic scattering events is short as the elastic mean free path is of order nm. Thus a phonon is thermalised within a relatively small region of the normal metal – a simple calculation based on a Drude model would inidcate a length scale of order 10μm.

At the detector junction, 2Δ phonons will be absorbed in the normal metal adjacent to the junction, creating a local hot spot, which will give rise to the observed increase in detector current. However if there is a substantial volume of normal metal between the phonon source and detector, the athermal phonons will be absrobed and thermalised without being detected. For this reason we observe the geometrical effects in the sapphire substrate devices.

The coupling between the two separate absorbers indicates that at least a significant component of the coupling is via the substrate. Indeed even where there is a possibility of coupling via the electrons this is not significant as the mean free path in the normal metal for an electron is very small, so that even though the inelastic scattering time will be large, the range of a hot electron will be short (a simple model assuming a mean free path of 10nm and an inelastic scattering rate calculated from [XX lifted out of Neils Pt II project] would give a range of order 10μm). Additionally, the presence of the superconducting layer on top of the absorber will tend to confine electrons of energies within Δ of the fermi surface as Andreev reflection will be the dominant sctttering process at the interface.

5 Figures

Sometimes you will need to play around with the figure placement. The \begin{ figure} ... \end{ figure} commands might need to be placed considerably before or after the figure reference \ref{ fig1} . This is done in this file, for example, to avoid having Fig. 1 appear before the abstract.

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6 Submission of Papers

The proceedings will be printed in Garching during the conference, starting at 8:00 on Monday morning. Thus late submissions cannot be included. You must bring your **camera-ready** paper with you to registration on Sunday, 27 July. (We will not have any facilities for printing .ps files – BRING THE PRINTED VERSION!) Registration will be open from 2 PM until 8 PM in the Hilton hotel. The earlier you can bring your paper during that period, the better, as it would help us to distribute the workload of assembling the proceedings.

If there is any danger that you might arrive too late, you can send your paper to the conference secretary at MPI [1] to make a reference to arrive by Friday morning, 25 July, at the latest. We cannot receive mail at the Hilton! If another colleague is travelling via a different flight, you might both bring a copy of your paper, in case one flight is delayed.

7 Rules for Proceedings

In order to be printed in the proceedings, your paper must obey the following rules:

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8 Citations

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9 Conclusions

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Acknowledgements

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References

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[2] second reference or footnote