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Characterization and reduction of noise in Mo/Au transition edge sensors

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Abstract

We measured noise in a variety of Mo/Au transition-edge sensor (TES) X-ray calorimeters. We investigated the relationship between the noise, bias, and the superconducting phase transition in the TESs. Our square TES calorimeters have achieved very good energy resolutions (2.4 eV at 1.5 keV) but their resolutions have been limited by broadband white excess noise generated by the TES when it is biased in the phase transition. We have recently fabricated Mo/Cu TESs with interdigitated normal metal bars deposited on top of the bilayer. The new TES calorimeters have demonstrated little or no excess noise in the phase transition. These results point the way to development of TES calorimeters with higher energy resolution.

Keywords: Transition edge sensor; Reduced excess noise; Calorimeter; Molydenum; Gold; Bilayer

1. Introduction

Our transition edge sensors consist of a Mo/Au bilayer. Through the proximity effect, the bilayer acts as one superconducting film with a critical temperature determined by the thicknesses of the two layers. Our transition-edge sensors (TESs) are designed such that the superconducting to normal state phase transition is at approximately 100 mK and the phase transition is several mK wide.

Our standard TESs are square with a resistance of about 10 mΩ. We bias the TES in the phase transition and measure the current with a DC SQUID. Absorption of an X-ray generates a pulse. The amplitude of the pulse is proportional to the energy of the X-ray. The energy resolution of our TES calorimeters is limited by noise in the TESs.

Ideally, the broadband electronic noise generated by the TES in the phase transition should be equal to Johnson noise. However, the broadband noise generated by our standard TESs when in the superconducting phase transition is significantly larger. The magnitude of the excess noise depends on the TES resistance and is several times larger than Johnson noise. The excess broadband noise

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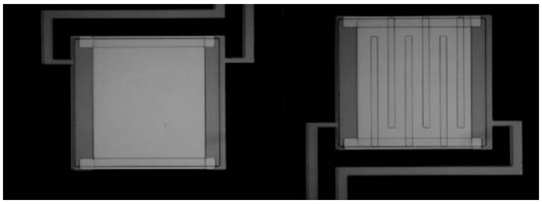

Fig. 1. Ordinary Mo/Au TES and a similar TES with stripes. These are 140 μm on a side. The stripes are spaced every 15 μm.

dominates the noise in frequencies larger than the thermal bandwidth of the TES [1].

In this paper, we compare excess broadband noise found in our standard TESs to reduced noise observed in TESs with interweaving gold bars deposited on top. Both types of TESs are illustrated in Fig. 1. The bars are perpendicular to the direction of current flow in the TES. The normal metal bars proximitize the bilayer beneath them, forcing the supercurrent to meander through the bilayer between the bars. However, the striped devices differ from an ordinary meander-shaped TES in that the normal state resistance and thermal conductance across the striped TES is approximately the same as for a single square bilayer.

2. Excess noise in ordinary TESs

The picture in Fig. 1 shows a typical square Mo/Au TES. We have fabricated and tested many such square TESs of sizes ranging from 125 to 600 μm—some with metal banks on the edges as shown, others with the Mo layer at the edges undercut beneath the gold layer to form normal metal edges.

These TESs demonstrated significant broadband excess noise when biased at low resistances. Data from typical noise measurements of one such TES are plotted in Fig 2. The excess noise is typically 4 times Johnson noise in the middle of the transition and is 20 times Johnson noise at low resistances.

3. TESs with stripes

Recently, we tested a 500 μm TES with interdigitated gold stripes spaced every 30 μm. We

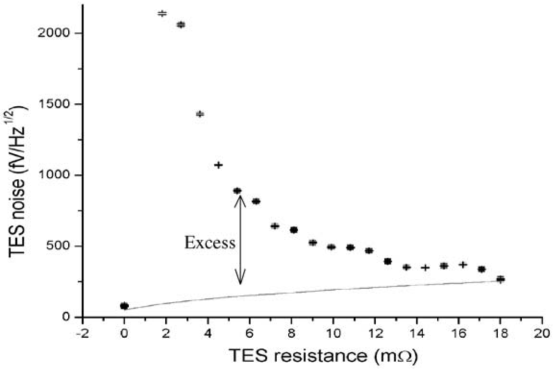

Fig. 2. Excess noise in ordinary square TES compared to the calculated Johnson noise of the TES and shunt resistor.

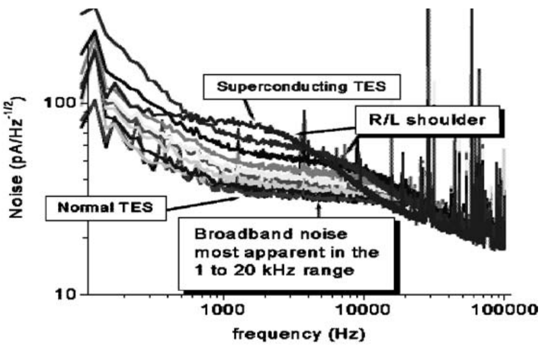

Fig. 3. Recent measurements of noise in Striped 500 μm TES.

plotted the measured noise in Fig. 3. In these data, the broadband current noise in the phase transition lies in between the noise of the normal state and superconducting state, as would be expected if there were little excess noise. The broadband noise dominates frequencies between 1 and 20 kHz. The R/L shoulder (at several kHz) varies with the resistance of the TES. Phonon noise and pick up dominated the noise at lower frequencies.

We subtracted out approximately 30 pA/Hz$^{1/2}$ of noise generated by the readout electronics. (This amount electronic noise is typical of our four-channel two-stage SQUID electronics, which is still under development.) We referred the remaining noise-to-voltage fluctuations at the TES. These data are plotted in Fig. 4. The measured noise corresponded to the calculated Johnson noise of our TES (0–10 mΩ at 105 mK) plus shunt resistor.

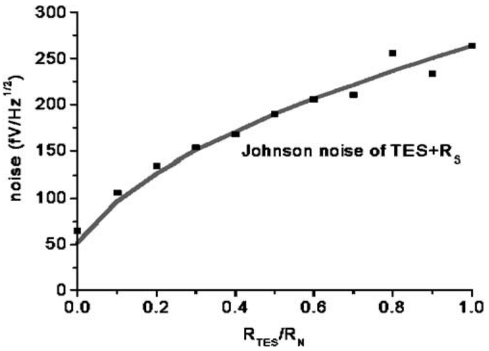

Fig. 4. Little or no broadband noise in TES with stripes. The broadband noise (measured at 3 kHz) equals the expected Johnson noise from the TES and shunt resistor.

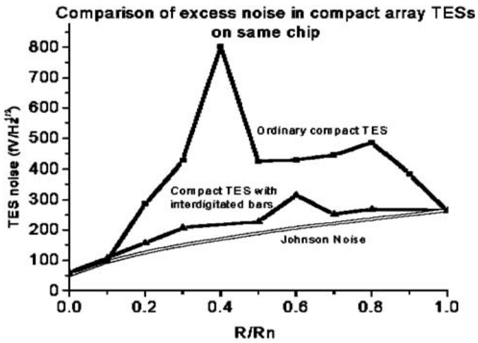

Fig. 5. Direct comparison between a TES with stripes to one without. The two TESs were fabricated on the same chip.

4. Direct comparison

On a single chip, we fabricated two compact arrays of TESs with Bi/Cu absorbers. The TESs are similar to the ones pictured in Fig. 1. They differed from each other only in that TESs of one of the arrays had interdigitated stripes. The other array consisted of ordinary TESs (Fig. 5).

We measured noise throughout the transition of a TES from each array. The ordinary TES was atypical of our square TESs: it demonstrated the largest excess noise in the middle of the transition and had low excess noise at low resistances. Nevertheless, the striped TES demonstrated significantly lower noise than did the ordinary TES.

5. Conclusions

We demonstrated that excess noise in our Mo/Au TESs is dramatically reduced by the addition of interdigitated gold bars on top of the TES. The new TESs can be biased lower in the phase transition without greatly increasing the excess noise. Biasing lower in the phase transition allows us to more fully take advantage of the dynamic range of the TES. The greater dynamic range allows us to design calorimeters with smaller heat capacities. We anticipate designing our calorimeters to take advantage of the lower noise and the larger usable dynamic range of the new TESs to achieve improved energy resolution in the near future.

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