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Approaching the fundamental noise limit in Mo/Au TES bolometers with transverse normal metal bars

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Abstract

Recent efforts in the Transition Edge Sensor (TES) bolometer/calorimeter community have focused on developing detectors whose noise properties are near the fundamental limits. These include the in-band phonon noise, the out-of-band Johnson noise, and the 1/f noise. We have investigated the noise performance of Mo/Au-bilayer TES bolometers designed for infrared detectors. These detectors use normal metal regions for the suppression of excess noise, which are oriented either parallel to ("bars") or transverse to ("stripes") the direction of current flow. Two nearly identical detectors, one with stripes and one with bars, were fabricated at the NASA/GSFC detector development facility. Significantly lower noise is found with the normal metal regions oriented transversely. We compare the detailed noise measurement and quantitative analysis of the noise level in each device as a function of the detector resistance. Our preliminary result is that the best detector features only moderate excess noise in both the in-band region and in the out-of-band region. This noise performance is suitable for instruments with multiplexed TES arrays, such as GSFC's FIBRE and SAFIRE.

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Keywords: Bolometers; TES; Fundamental noise

1. Introduction

Attempts to find robust materials systems and fabrication methods for transition edge sensor (TES) microcalorimeters and bolometers have encountered differing amounts of noise magnitudes and functional dependences. The phonon-noise limit predicted for TES devices has been approached for certain devices and proved elusive to other designs [1]. The approaches that have been tried include a variety of materials, geometries, and fabrication techniques [2,3]. These have resulted in constraints on bias conditions, quantum efficiency of photon detection, etc. Ideally, the

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mechanisms for noise in TES bolometers will be elucidated so that, for example, an imposed geometric ordering can quell the noise sources in more of the materials, independent of deposition method, film quality, etc. A less ideal situation would be a higher degree of constraints on materials, deposition techniques, or detector geometries. In this work, we have taken a system of materials that intrinsically has a large excess noise source and identified geometric orderings that quell the noise source. It is hoped that appropriate constraints for the desired ordering can be deduced from this work to rectify excess noise problems in other materials systems and detector geometries.

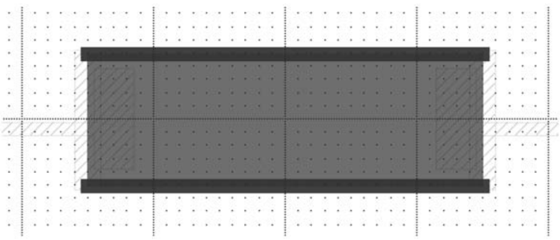

Fig. 1. Layout of the Mo/Au TES with normal metal bars (dark area) at the edges along the direction of current flow. The dots are separated by 10 μm.

2. Normal metal bar geometries

By placing normal metal regions in the active region of the superconducting detector the boundary conditions for the superconducting order parameter can be constrained. Two ideas have circulated concerning the use of normal metal regions. NIST's normal metal edge conditions [4] and SRON's normal metal regions placed over the inner regions of the bilayer [5] are used to separate superconducting and normal regions. Our group until recently has used normal metal bars at the edge of the TES that are parallel to the current flow. Fig. 1 shows the mask used for a TES with this bar geometry. The noise measurements of this device in the superconducting state, on the transition and in normal state (the normal resistance of this device is 480 mΩ) are displayed in Fig. 2. The significant excess in the out-of-band

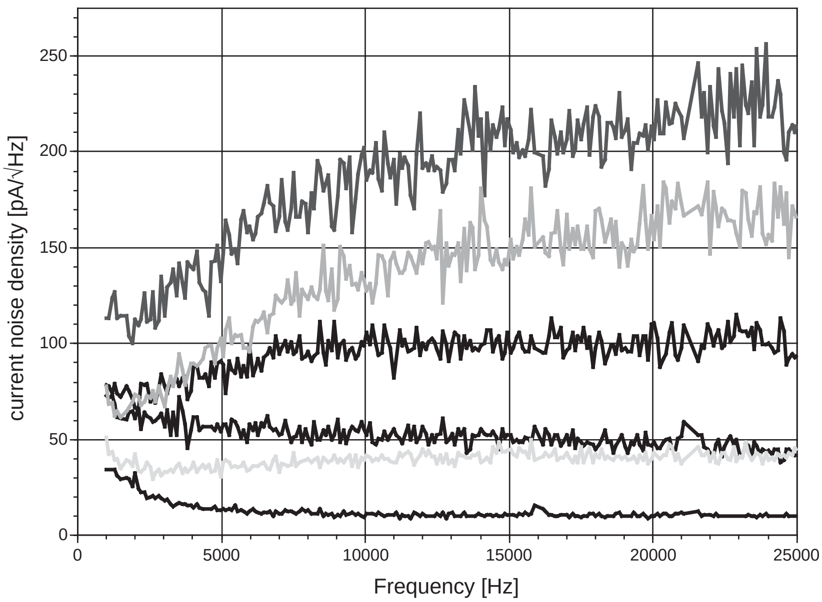

Fig. 2. Measured current noise density of the bar device shown in Fig. 1. The solid lines are measurements on the transition, the darkness corresponds to a quasi-logarithmic magnitude of the bias current through the detector with TES resistance ranging from ~5 mΩ (dark) to ~300 mΩ (light gray). The light dashed line corresponds to the superconducting state, the dark dashed line shows the noise in the normal state.

($>$4.5 kHz) noise in the data taken on the transition is evident. Fig. 3 shows the normal metal mask of our modified "zebra". The device [6] was fabricated on the same wafer, but the normal metal bars are perpendicular to the current flow direction. A drawback of a conventional zebra detector, where the normal stripes span the width of the film, is the creation of parasitic normal resistance when biased low on the transition. Our modified zebra pattern has attempted to utilize the boundary conditions imposed on the interior of the superconducting region of the detector without creating regions of parasitic normal resistance. Fig. 4 shows the noise measurements for this device in the superconducting state, on the transition, and in the normal state (420 mΩ). A significant reduction in excess noise, particularly out-of-band noise, is observed. This indicates that the normal metal bar geometry confines regions driven normal by the bias current, and makes them sufficiently spaced to prevent interaction; hence it is an efficient method for excess noise reduction. The device shown in Fig. 4 had a 400 Ω/square Bi film for broadband submillimeter absorption added, which did not result in the increase out-of-band excess noise. Fig. 5 shows the theoretical noise which was calculated by using the following parameters: $T_{base} = 300$ mK, $T_c = 445$ mK, $R_{shunt} = 3.7$ mΩ, $R_{stray} = 3.7$ mΩ, stray inductance $L_{stray} = 55$ nH, $I_{SQUID\_noise} = 6\ \mathrm{pA}/\sqrt{\mathrm{Hz}}$, and perfect electrothermal feedback on transition with an electrical time constant yielding a bandwidth of 6.0 kHz [7]. The excess in the measured noise of the zebra device approaches a factor of two over the fundamental noise level only at the high resistance part of the transition where the fundamental noise of the TES is lowest.

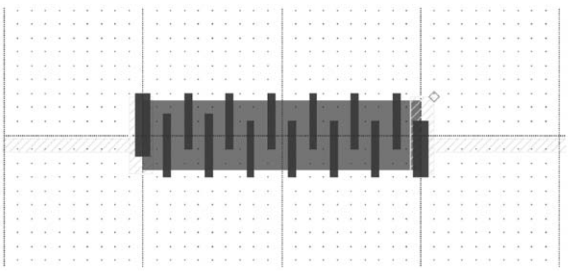

Fig. 3. Layout of the MoAu TES with normal metal bars (dark area) perpendicular to the current flow. The dots are separated by 10 μm.

3. Conclusion and outlook

Our measurements strongly suggest that relative unconstrained motion of superconducting and normal regions creates a broadband noise source

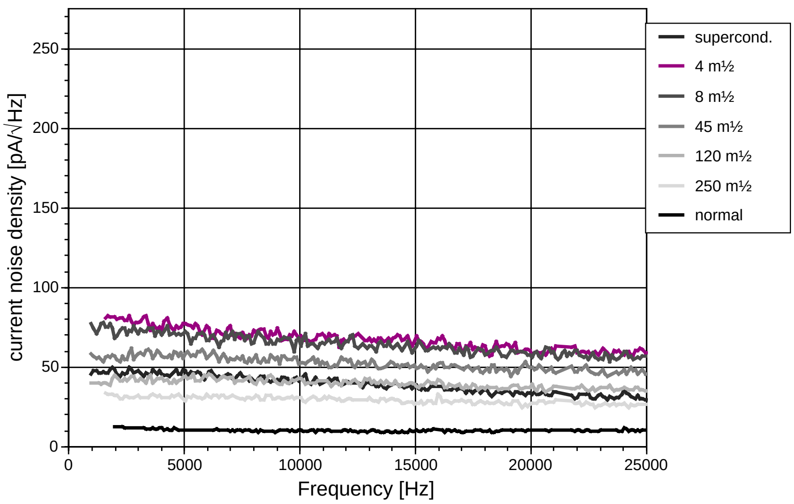

Fig. 4. Measured current noise density of the "Zebra" device shown in Fig. 3.

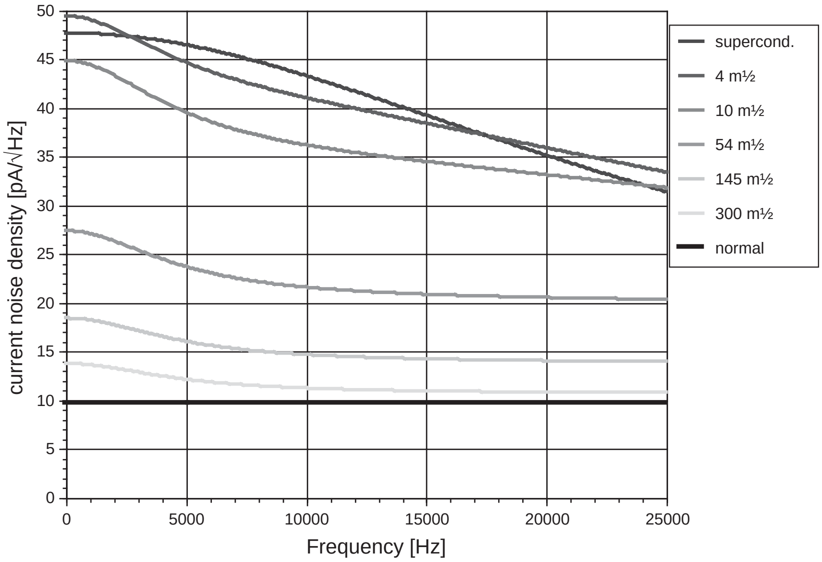

Fig. 5. Theoretical noise of the device shown in Fig. 3. The parameters used for the calculations can be found in the text.

that appears as out-of-band excess noise in TES detectors. Geometric ordering of the normal regions within the superconductor by means of normal metal bars perpendicular to the current direction results in a significant improvement of the noise performance of our Mo/Au TES devices. We are currently improving our model of the tested devices [7] and calculating the noise without the assumption of perfect electrothermal feedback on the transition close to the superconducting state. The excess noise model for the modified ''zebra'' device will include a hanging heat capacity of the low T_c Mo leads ($C_{Mo}/C_{TES} \sim 0.2$). The superconducting boundary condition at the edge of this device may also create some excess noise.

References

[1] J.A. Chervenak, et al., Absorber-coupled superconducting transition edge sensors for submillimeter imaging, in: J. Wolf (Ed.), Proceedings Far-IR, Sub-mm & mm Detector Technology Workshop, NASA/CP-211408, 2003, in press. http://sofia-usra.arc.nasa.gov/det_workshop/papers/manuscriptb.html

[2] H.F.C. Hoevers, et al., Appl. Phys. Lett. 77 (26) (2000) 4422.

[3] J.M. Gildemeister, A.T. Lee, P.L. Richards, Appl. Opt. 40 (34) (2001) 6229.

[4] G. Hilton, et al., IEEE Appl. Supercond. 11 (1) (2001) 739.

[5] W.M. Bergmann Tiest, et al., Proc. of LTD-9, Madison, WI, American Institute of Physics Conference Proceedings, vol. 605, 2002, p. 199.

[6] C.A. Allen, et al., Y24, Nucl. Instr. and Meth. A, (2004) these proceedings.

[7] D.J. Benford, et al., T02, Nucl. Instr. and Meth. A, (2004) these proceedings.