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Nuclear Instruments and Methods in Physics Research A 520 (2004) 333–335

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

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Suppression of excess noise in Transition-Edge Sensors using magnetic field and geometry[☆]

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Abstract

We report recent progress at NIST on Mo/Cu Transition-Edge Sensors (TESs). While the signal-band noise of our sensors agrees with theory, we observe excess high-frequency noise. We describe this noise and demonstrate that it can be strongly suppressed by a magnetic field perpendicular to the plane of the sensor. Both the excess noise and $\alpha = (T/R)(\mathrm{d}R/\mathrm{d}T)$ depend strongly on field so our results show that accurate comparisons between devices are only possible when the field is well known or constant. We also present results showing the noise performance of TES designs incorporating parallel and perpendicular normal metal bars, an array of normal metal islands, and in wedge-shaped devices. We demonstrate significant reduction of high-frequency noise with the perpendicular bar devices at the cost of reduced α. Both the bars and the magnetic field are useful noise reduction techniques for bolometers.

PACS: 85.25.–j; 85.25.Pb; 74.40.+k

Keywords: Microcalorimeter; Transition-edge sensor; Excess noise

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1. Introduction

Transition-Edge Sensors (TESs) are a promising technology for precise measurements of electromagnetic radiation. These sensors consist of superconducting films electrically biased in the resistive transition. The attractions of TESs include their sensitivity, speed, ease-of-fabrication, and compatibility with SQUID multiplexing technology.

The performance of TES devices is approaching but has not yet reached the predicted theoretical limits. Known sources of noise in TES sensors include Johnson noise and thermodynamic fluctuations within the thermal conductances of the devices. One factor which contributes to the discrepancy between experiment and theory is noise which cannot be explained by these two mechanisms. In this report, we demonstrate two techniques for suppressing this excess noise. The devices studied consist of Mo/Cu bilayers with transition temperatures near 70 mK.

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doi:10.1016/j.nima.2003.11.260

2. Suppression of excess noise by magnetic field

We have discovered that a magnetic field perpendicular to the plane of a TES sensor reduces device noise. As the field is increased, device noise decreases at constant operating resistance. Hence, the origin of the noise reduction is more profound than a change in operating point associated with a decrease in critical temperature. Measured device noise is shown in Fig. 1 as a function of frequency for three values of applied field. The operating point is held constant at 12 mΩ which is 75% of the normal state resistance. It can clearly be seen that fields of 130 and 210 mG significantly reduce the noise at high frequencies without changing the low frequency signal-band noise. Also shown in Fig. 1 is the predicted noise based on Johnson and phonon noise. The measured and predicted noise agree well in the signal band. However, the measured noise exceeds theory at higher frequencies with the discrepancy shrinking as the field is increased.

An additional effect of the applied field is a reduction in the transition steepness described by $\alpha = (T/R)\mathrm{d}R/\mathrm{d}T$. Values of α for the traces in Fig. 1 are 182, 39, and 34 for 0, 130, and 210 mG, respectively.

The effects of field values smaller than 1 G on both noise and transition steepness are large. These results show that accurate device comparisons, for instance between two bilayer systems, are only possible when the field is well known or constant.

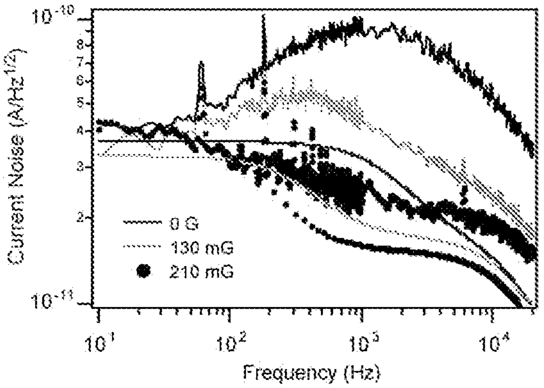

Fig. 1. Measured noise at 75% R_N in fields of 0, 130, and 210 mG. The higher field values reduce noise at high frequencies. The predicted noise is also shown.

3. Suppression of excess noise by geometry

Application of a perpendicular magnetic field is not always practical. For instance, the field may interfere with nearby SQUID multiplexer circuitry, or be screened by the ground plane of the multiplexer if the SQUIDS and detectors are integrated vertically. As a result, we have also investigated the noise properties of different TES geometries.

Photographs of six TES X-ray detectors are shown in Figs. 2a–f. The devices shown in Figs. 2a–e are 400 μm square. The device shown in Fig. 2f is wedge-shaped with narrow and broad widths of 300 and 500 μm, respectively. The

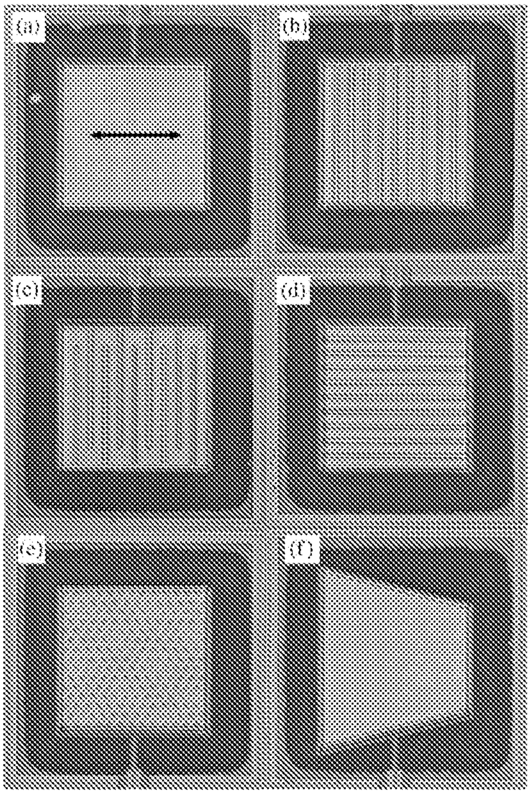

Fig. 2. (a)–(f) Photographs of TES devices. Square devices are 400 μm on a side. The path of the bias current in all the devices is indicated by the arrow in Fig. 2a.

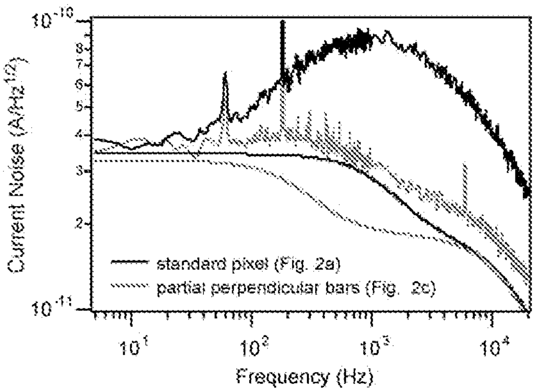

Fig. 3. Measured and predicted current noise in a standard pixel and a pixel with partial perpendicular bars. Both devices are operated in zero field and at 75% of R_N. The perpendicular bars clearly reduce the high-frequency noise.

devices in Figs. 2a–e differ due to the presence of additional Cu features on the bilayer. These features are deposited and patterned in the same step as Cu side-banks. Fig. 2a shows the 'standard' pixel which only has Cu side-banks. In Fig. 2b, Cu bars span the full-width of the detector perpendicular to the direction of current flow. In Fig. 2c, Cu bars partially span the width of the detector perpendicular to the direction of current flow. In Fig. 2d, Cu bars span the full-width of the detector parallel to the direction of current flow. In Fig. 2e, Cu islands form a triangular lattice. The Cu bars in Figs. 2b–e are 10 μm wide and 500 nm thick. The Cu islands in Fig. 2f are 5 μm in diameter and 500 nm thick.

Two of the devices in Fig. 2 show less high-frequency noise than the standard pixel of Fig. 2a. The two designs which reduce noise are the partial perpendicular bars (Fig. 2c) and the full perpendicular bars (Fig. 2b) [1,2]. Measured current noise is shown as a function of frequency in Fig. 3 for the standard pixel and for the partial perpendicular bar device. Both devices are operated in zero field and are biased at 75% of the normal state resistance. (The partial Cu bars reduce the normal state resistance of the partial perpendicular device from 16.1 to 13.9 mΩ.) While the signal-band noise of the two devices is similar, the device with bars has significantly less high-frequency noise. Also shown in Fig. 3 is the predicted noise for the two devices. The theory does not reproduce the high-frequency noise. The high-frequency discrepancy between data and theory in the standard device is close to a factor of three, but is only 50% in the device with bars. However, this reduction comes at the price of reduced α. At 75% R_N, bars reduce α from 131 to 23.

4. Discussion and conclusions

We have shown that excess high-frequency noise in TES devices can be suppressed both by a perpendicular magnetic field and by the use of normal metal bars perpendicular to the direction of current flow. We have also shown that several other geometries do not affect the noise. The effects of magnetic field are likely an important clue to the microscopic origins of the noise.

Both noise suppression techniques will reduce aliased noise power in multiplexed bolometer arrays. Both noise suppression techniques also reduce α. While this effect can be advantageous for bolometers, it can compromise the energy resolution of calorimeters. Preliminary measurements suggest that the best energy resolution is achieved near the field minimum.

References

[1] G.C. Hilton, et al. Superconducting transition-edge sensor with weak links, US patent 6239431 (filed 11/24/98).

[2] W. Bergmann Tiest, et al., TES Workshop, Boulder Co, April, 2002;
J.G. Staguhn, et al., Nucl. Instr. and Meth. A (2004), these Proceedings.