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Characterization of TES bolometers used in 2-dimensional Backshort-Under-Grid (BUG) arrays for far-infrared astronomy

J.G. Staguhn[a,b,*], C.A. Allen[a], D.J. Benford[a], J.A. Chervenak[a], D.T. Chuss[a], T.M. Miller[a,c], S.H. Moseley[a], E.J. Wollack[a]

[a]NASA/GSFC, Greenbelt, MD 20771, USA
[b]SSAI, 10210 Greenbelt Rd., Lanham, MD 20706, USA
[c]QSS, 4500 Forbes Blvd., Lanham, MD 20706, USA

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Abstract

We have produced a laboratory demonstration of our new Backshort-Under-Grid (BUG) bolometer array architecture in a monolithic, 2-dimensional, 8×8 format. The detector array is designed as a square grid of suspended, 1 μm thick silicon bolometers with superconducting molybdium/gold bilayer TESs. These detectors use an additional layer of gold bars deposited on top of the bilayer, oriented transverse to the direction of the current flow, for the suppression of excess noise. This detector design has earlier been shown to provide near fundamental noise limited device performance. We present results from performance measurements of witness devices. In particular we demonstrate that the inband excess noise level of the TES detectors is less than 20% above the thermodynamic phonon noise limit and not significantly higher out of band at frequencies that cannot be attenuated by the Nyquist filter. Our 8×8 BUG arrays will be used in the near future for astronomical observations in several (sub-)millimeter instruments.

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Keywords: Bolometers; Transition edge sensor; Superconductor; Fundamental noise

1. Introduction

Our group at the NASA/Goddard Space Flight Center has an ongoing program to develop the key technologies needed to produce large-format, close-packed, high-sensitivity, bolometer arrays suitable for use from the far-infrared to millimeter wavelengths. As part of this development effort, we are producing a laboratory demonstration of the new Backshort-Under-Grid (BUG) bolometer array architecture in a monolithic, 2-dimensional, 8×8 format. These arrays utilize molybdium/gold bilayer transition-edge sensors (TES) as sensing elements of the "Zebra" design which was introduced in Ref. [1]. This detector design provides near fundamental noise limited device performance. The array architecture allows scalability to 32×32 pixel arrays that can be bump bonded to the 32 channel NIST multiplexers used in the SCUBA-2 instrument [2,3]. We will demonstrate the 8×8 array in ground-based instruments to better understand the capabilities and suitability of this array design for future space-based photometers, spectrometers, and polarimeters.

2. Device performance

We have tested witness samples of the BUG devices. The quantitative results presented here were obtained from testing a pixel from a suspended witness 2×2 pixel array. The architecture and fabrication of the devices is presented in Ref. [4]. Fig. 1 shows two bug pixels with integrated TES sensors. The TES sensor is clearly visible top center on the right pixel. Fig. 2 shows a representative I–V curve for a BUG device. Fig. 3 shows the electrical power dissipated in the device that is necessary to heat a suspended pixel of a 2×2 array from the base temperature to the transition temperature T_c versus base temperature plus the associated

*Corresponding author. Tel.: +1 301 286 7840; fax: +1 301 286 1617.
E-mail address: johannes.staguhn@gsfc.nasa.gov (J.G. Staguhn).

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Fig. 1. Photograph showing two pixels of the 8×8 Bolometer-Under-Grid (BUG) array. The TES sensor with its meandering Zebra normal metal layer is clearly visible top center on the right pixel.

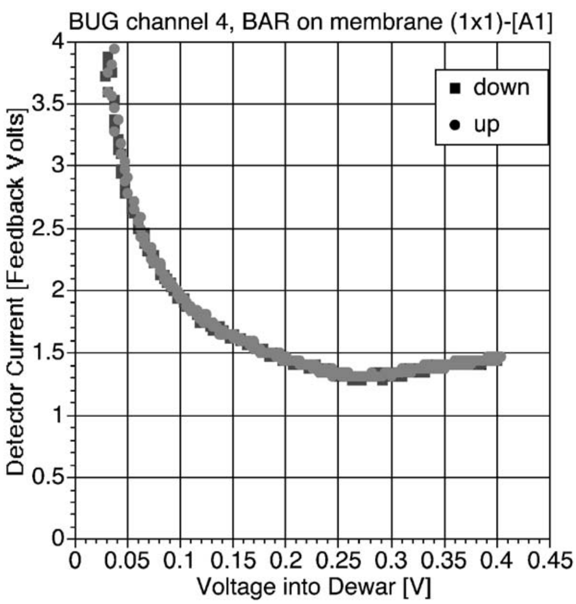

Fig. 2. A representative I–V curve of a TES on a BUG pixel, using a bias ramp driving the device from the normal state into the transition (labeled "down") and back into the normal state (labeled "up").

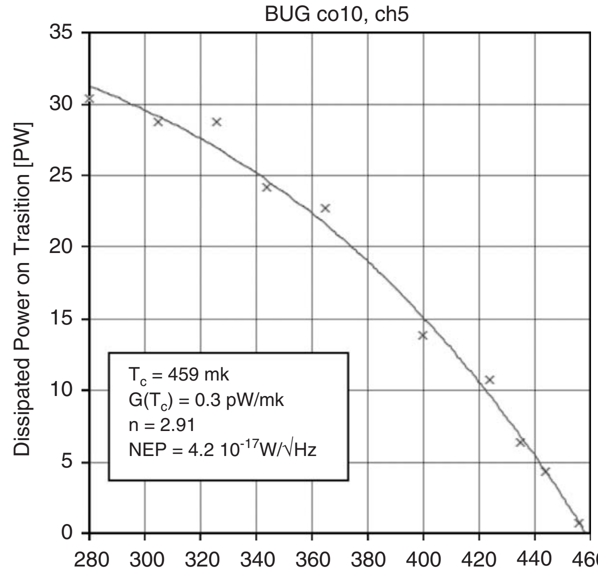

Fig. 3. Plot showing the required dissipated power to drive a suspended pixel of a 2×2 array from the base temperature to the transition temperature T_c versus base temperature with associated fit to the data. The derived device parameters are included in the figure. The fitted index n corresponds to the power law with which the thermal conductivity scales with the base temperature.

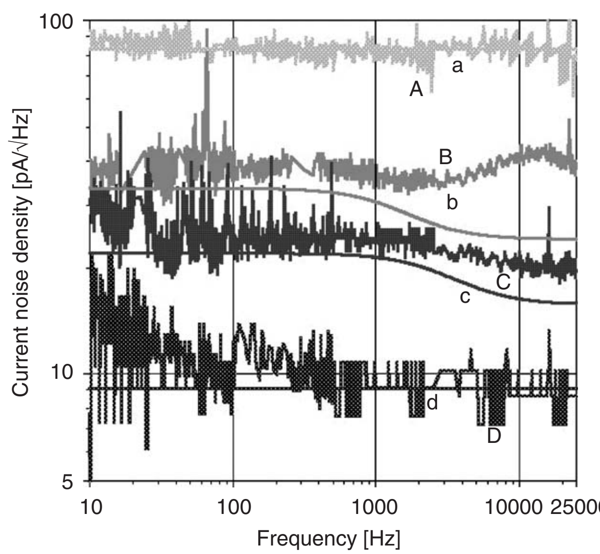

Fig. 4. Current noise density of a BUG device in its superconducting state dashed light gray (A), on the transition (solid light gray shows device on the transition at 40 mΩ (B) and solid darker gray at 90 mΩ (C)) and in its normal state at 445 mΩ (D). Superimposed with the same line style is the expected thermodynamic noise for the device (a–d) assuming a TES circuit stray resistance of 0.4 mΩ and a detector speed of 1.5 kHz on the transition at 40 mΩ and a detector speed of 3.0 kHz on the transition at 90 mΩ. The phonon noise roll-off is clearly visible in both noise spectra on the transition.

fit which yields the thermal conductivity of the device. The device parameters derived from the fit are included in the figure. The phonon noise equivalent power (NEP) of the device is $4.2 \times 10^{-17}\,\mathrm{WHz}^{-1/2}$. The TES has an electro thermal feedback time constant τ_{etf} of about 50 μs (corresponding to $f_{\mathrm{TES}}{\sim}3.5$ kHz) which is expected to increase lower into the transition as the TES approaches the superconducting state. The TES circuit contains a Nyquist inductor which is chosen such that the detector integrates for a full readout cycle of the multiplexer (typically the frame rate is set to several tens of kHz). Fig. 4 shows the measured noise spectrum of this device in its superconducting state, on the transition (two bias points are shown), and in its normal state. Superimposed is the expected thermodynamic noise for the device, using the known values for the SQUID noise, and the shunt resistor. The Nyquist L/R roll off was removed in the plot in order to highlight the intrinsic device performance. Both superconducting and normal state of the TES were measured with the device unbiased. The values for the TES resistances on the transition were determined from the measured I–V curve, and independently verified by the slope of the L/R roll-off. The normal state resistance of this device is $445\,\mathrm{m\Omega}$. Only the change in the time constant of the TES in the transition (which is theoretically difficult to determine) and the value of the stray resistance in the superconducting state were free parameters in the calculation of the expected noise spectra shown in the plot. The value for the TES circuit stray resistance chosen for the plot is $0.4\,\mathrm{m\Omega}$, the value for the detector speed is 1.5 kHz on the transition at $40\,\mathrm{m\Omega}$ and 3.0 kHz on the transition at $90\,\mathrm{m\Omega}$. The phonon noise roll-off is clearly visible in both noise spectra on the transition. The in-band noise of the device on both measured bias points in the transition was less than 20% above the fundamental phonon noise limit. Only at the higher frequencies above the detector speed the excess noise on the low bias point exceeds this value significantly at high frequencies above $\simeq 10\,\mathrm{kHz}$. However this frequency is more than a factor of six above the device speed and therefore can be in part attenuated by the Nyquist filter (the L/R roll-off is not displayed in Fig. 4).

3. Conclusion

We have built a planar array using TES bolometers with an in-band noise level of less than 20% above the thermodynamic phonon noise limit. With a transition temperature $T_c = 460\,\mathrm{mK}$ and a phonon NEP of $4 \times 10^{-17}\,\mathrm{WHz^{-1/2}}$ these arrays will be suitable for background limited performance for a number of planned ground based (sub-)millimeter wavelength astronomical instruments, using conventional ^{3}He coolers.

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