TRANSITION-EDGE SUPERCONDUCTING ANTENNA-COUPLED BOLOMETER

Cynthia L. Hunt[1], Andrew E. Lange, Anastasios Vayonakis, Jonas Zmuidzinas
California Institute of Technology, Pasadena, CA 91125, USA

James J. Bock, Peter K. Day, Alexey Goldin, Henry G. LeDuc,
Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, USA

ABSTRACT

We are developing a single pixel antenna coupled bolometric detector. Our device consists of a dual slot microstrip antenna coupled to an Al/Ti/Au voltage-biased transition edge superconducting bolometer (TES). The coupling architecture involves propagating the signal along superconducting microstrip lines and terminating the lines at a normal metal resistor on a thermally isolated island where the TES is also located. The device, which is inherently polarization sensitive, is optimized for 140GHz band measurements. Dark testing of the bolometer element showed a noise equivalent power of 2.0×10^{-17} W/√Hz with a thermal conductance G ~5.5×10^{-11} W/K. The device shows an optical time constant of 1.1 ms, and gives a figure of merit NEP $\sqrt{\tau} = 6.6\times 10^{-19}$ W·s. The fastest time constant measured is 437μs. The NEP is consistent with the value expected from thermal noise, Johnson noise, and amplifier noise. This device shows negligible excess noise down to frequencies as low as 1 Hz.

INTRODUCTION

The temperature anisotropy of the cosmic microwave background (CMB) is now being probed to unprecedented accuracy and sky coverage by MAP, and will be definitively mapped by Planck after its launch in 2007. The polarization of the CMB, particularly the curl-polarization, may be used to probe the energy scale of the inflationary epoch. Detection and mapping of CMB curl polarization requires a large advance in the format of millimeter-wave bolometer arrays. SAMBA (Superconducting Antenna-coupled Multi-frequency Bolometric Array) is being developed to address these needs for the next generation of sub-millimeter astronomical detectors. SAMBA consists of a focal plane populated with microstrip antennae, whose signals are coherently added and sent to transition edge superconducting bolometers (TES) via microstrip lines. SAMBA eliminates the need for the feedhorns and IR filters normally currently used on current CMB observational instruments, such as Plank and Boomerang. The SAMBA architecture allows for a high density of pixels in the focal plane with minimal sub-Kelvin mass[1]. As a precursor to a full monolithic high-density antenna array, we are developing a single band antenna-coupled bolometric detector.

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[1] *Contact Information for Cynthia L. Hunt: email: cynthiah@its.caltech.edu, phone(626)395-2016*

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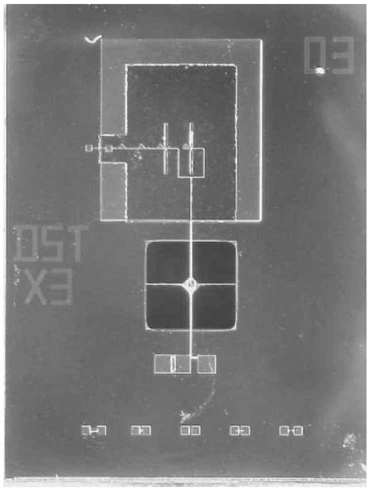

Figure 1: A fully fabricated single element device studied in this paper. This device is optimized for 140GHz radiation.

The single element device presented in this paper consists of a dual slot microstrip antenna, which is cut into a superconducting niobium ground plane, coupled to a TES (Figure 1). The electric field from the microstrip antenna is propagated along planar transmission lines. These microstrip lines consist of a niobium superconducting lead separated from the ground plane by 2000Å of SiO dielectric. The electric fields from each antenna are passively added and terminated at a thin film Au resistor located on a thermally isolated silicon nitride island. On the same island, an Al/Ti/Au TES film responds to the temperature rise of the resistor, and the signal is read out with a low impedance superconducting quantum interference device (SQUID) current amplifier. We use a standard circuit for the operation and readout of a TES[2]. One advantage of this device is that the microstrip line can be quite long with small losses. Vayonakis et al. report 1% loss per wavelength in the dielectric at temperatures below 1.5 K[3]. This allows the TES bolometers to be placed out of the optically exposed focal plane. In addition, microstrip filters can be inserted between the antennae and the bolometer to define several bands[4].

RESULTS

Bias curves at several temperatures were taken to determine the relationship between power and temperature. From this, we determine a thermal conductance G = 55 pW/K. Devices that have not been etched and released show a transition of 414 mK, while released devices tend to transition around 360 mK. The change in the transition temperature may be a result of changes to the film upon final processing, or due to stray optical power in the dewar which would result in a lower apparent transition temperature.

To take time constant measurements, we need to deposit heat into our TES. We used a LED coupled to the TES via optical fiber, which heats the TES island directly. The LED was driven with a pulse generator and the TES response was measured on an oscilloscope. The fastest time constant measured was 437µs, as shown in Figure 2. This is the effective time constant reduced by electrothermal feedback in the voltage biased TES[5].

We have measured the current noise of this device for a wide range of frequencies. Figure 3 shows the noise current of the device operated at a bath temperature of 282 mK, a bias voltage of 0.38 µV, and a measured effective time constant of 1.4ms. Within the thermal bandwidth of the TES the noise equivalent power is ~2.0×10^{-17} W/√Hz which is in good agreement with noise theory plotted as[6]:

$$
\begin{aligned}
\mathrm{NEP}^2 &= NEP_{ph}^{\ 2} + NEP_{Jn}^{\ 2} + NEP_{sq}^{\ 2} \\
NEP_{ph}^{\ 2} &= \gamma 4 k_B T^2 G \left(\frac{1}{1+\omega^2\tau^2} \right) \\
NEP_{Jn}^{\ 2} &= \frac{4 k_B T}{R_{TES} |S|^2} \left(\frac{\tau}{\tau_0} \right)^2 \left(\frac{1+\omega^2\tau_0^{\ 2}}{1+\omega^2\tau^2} \right) \\
NEP_{sq}^{\ 2} &= i_n^{\ 2}(SQUID) \cdot |S|^2
\end{aligned}
\qquad (1)
$$

where γ is a factor on the order unity, S is the responsivity of the device, τ is the effective time constant, and τ_0=C/G. The terms describe the thermal fluctuation noise, Johnson noise, and amplifier noise respectively. Above 200 Hz, however, the measured noise current is about 20% above the expected phonon noise. The small excess could result from systematic errors in estimating the G and transition temperature.

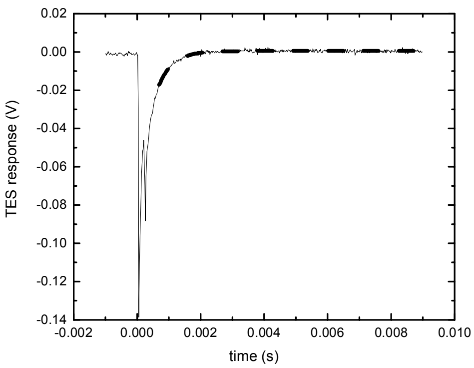

Figure 2: The fastest response of TES to a pulse from an LED coupled directly via optical fiber. Data taken at 282 mK and 3 µV bias. The exponential fit to the response is shown as the bold dashed line and indicates and effective time constant of 437 µs.

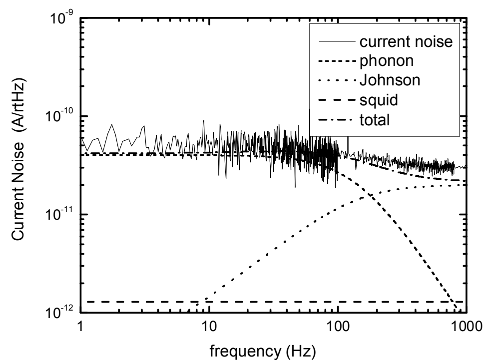

Figure 3: Measured current noise from the single element TES, biased at 0.379 µA. Spectra taken at different frequency bands were combined for better coverage of the range of frequencies.

REFERENCES

1. Please see Posters 3-46 and 3-28 and talk 5-02 at this conference for more information on the SAMBA instrument.

2. Lee AT, Richards PL, et al, *A superconducting bolometer with strong electrothermal feedback,* Appl. Phys. Lett. **69** (12), 1801-1803

3. Vayonakis A, et al, *The millimeter-wave properties of superconducting microstrip lines*, Low Temperature Detectors, AIP Conference Proceedings from LTD-9 2002, 539-542

4. Goldin A, et al, *SAMBA: Superconducting Antenna-coupled, Multi-frequency, Bolometric Array,* Low Temperature Detectors, AIP Conference Proceedings from LTD-9 2002, 251-254

5. Irwin, KD, *An application of electrothermal feedback for high resolution cryogenic particle detection*, Appl. Phys. Lett. **66** (15), 1998-2000

6. Lee SF, Gildemeister JM, et al, *Voltage-biased superconducting transition-edge bolometer with strong electrothermal feedback operated at 370mK*, Appl. Optics, **37** (16), 3391-3397