Background-limited bolometers for far-IR/submm spectroscopy

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Abstract

We built and measured the electrical properties of membrane-isolation transition-edge sensors (TESs) suitable for background-limited far-IR/submm spectroscopy. Each TES consists of a Mo/Au bilayer patterned onto a suspended, thermally isolated absorber that is connected to the substrate through four Si_xN_y beams deposited by low pressure chemical vapor deposition (LPCVD). We fabricated TESs with straight and meander support beams. The dimensions of the meander (straight) support beams are 700 µm (700 µm) long by 0.25 µm (0.5 µm) thick by 0.35 µm (0.5 µm) wide. The meander-beam TES has an NEP that is 6 $x20^{-20}$ $W/Hz^{1/2}$. We measured the natural time response τ of a noise thermometry device and show that effective response time of a TES can be below 100 ms. These values for the NEP and τ for the meander-beam TES meet the requirements for the Background-Limited farIR/Submillimeter Spectrograph (BLISS), a proposed NASA instrument.

Introduction

* Probing the far-IR/submm is critical to understanding the history of star and galaxy formation and black hole growth.
* Half total luminosity of universe emerges in far-IR/submm, but difficult to observe thus far.
* Missing elements: cryogenic telescopes with big apertures and large arrays of sensitive detectors.

Background-limited Infrared-Submillimeter Spectragraph (BLISS) [1] is a proposed spectrometer for SPICA [2] and SAFIR with orders of magnitude better sensitivity than the current state-of-the art (see FIG. 1):

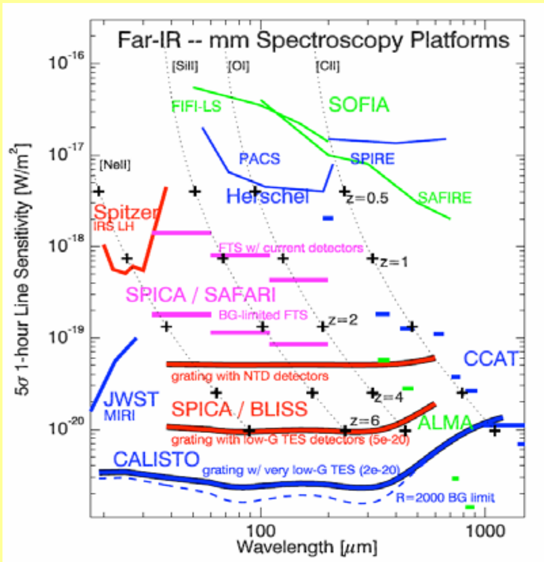

FIG. 1: Spectral sensitivity of BLISS-SPICA. Assumes background noise is from zodiacal and cirrus background fluctuations. Calculation of bottom red curve (BLISS) assumes 25 % instrument and 75 % aperture efficiency, single polarization and chopping. Solid blue curve shows CALISTO performance. Pink curves show a BLISS fourier-transform spectrometer. BLISS is not limited by background from telescope and atmosphere like Herschel and SOFIA.

Detector Requirements

* BLISS demands direct detectors with large formats and NEP= 4 x 10^{-20} $W/Hz^{1/2}$ [1].
* BLISS detectors must have a response time of less than 100 ms.

1D & 2D arrays of low-NEP TESs

* BLISS requires direct detectors with an NEP that is 50 times lower than state-of-the art.
* NEP = $\sqrt{4 k_b T^2 G}$. G is thermal conductance. T is temperature [3].
* State-of-the-art cryocoolers for BLISS limit T to about 60 mK. Therefore, G must be SMALL.
* What we did: fabricated membrane-isolated transition-edge sensors (TESs) with long, thin support beams (low G) (see FIG 2. [4]):

(a) (b)

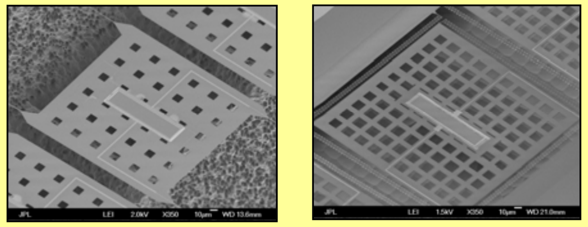

FIG. 2: (a) TESs with straight, suspended Si_xN_y support beams. The beam dimensions are 700 µm long by 0.5 µm thick by 0.5 µm wide. (Note: the beams extend beyond the edge of the micrograph.) The thermistors are Mo/Au bilayer films deposited onto a perforated, rectangular Si_xN_y absorbers. The final release of the Si_xN_y structure is performed using a XeF_2 etcher which causes the Si underneath the Si_xN_y support structure to appear pitted. (b) TESs with meander suspended Si_xN_y support beams. The beam dimensions are 700 µm long by 0.25 µm thick by 0.35 µm wide. This pixel geometry is suitable for a close-packed 2D array.

* Studied electrical properties of longest beam device to determine G and NEP (see FIGS. 3 and 4 for details).
* Measured (I-V) characteristics of 1D & 2D devices as function of T.

(a) (b)

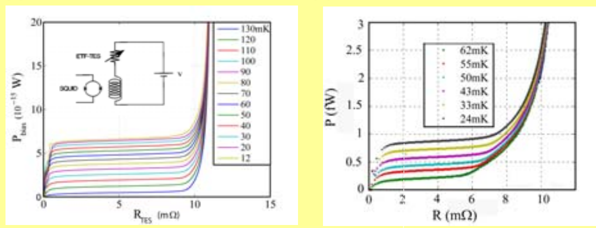

FIG. 3: (a) Bias power vs. TES resistance for several substrate temperatures for straight beam device. (b) Bias power for meander beam device. These curves allow us to determine T_c and G and, thus, the NEP.

(a) (b)

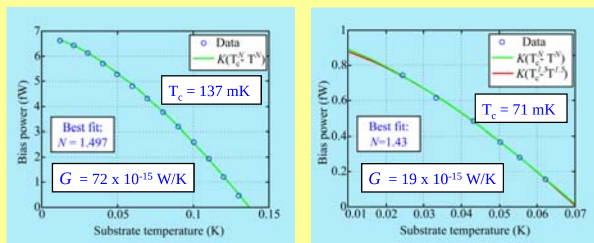

FIG. 4: (a) Bias power vs. T for straight beam device. (b) Bias power vs. T for meander beam device. These curves imply an NEP equal to 1.9 x 10^{-19} $W/Hz^{1/2}$ and 6.1 x 10^{-20} $W/Hz^{1/2}$ for the straight and meander beam devices, respectively.

Time Response of TES

* We wanted to know how the response time τ depends on temperature T.
* Performed noise thermometry measurements on support beams identical to those in FIG. 1(b) but with an "open" absorber.
* What is this measurement? Put two resistors on Si_xN_y membrane: one measures T through its Johnson noise and the other is a heater. We apply power P to heater, measure T and determine response time τ (see FIG. 5).

(a) (b)

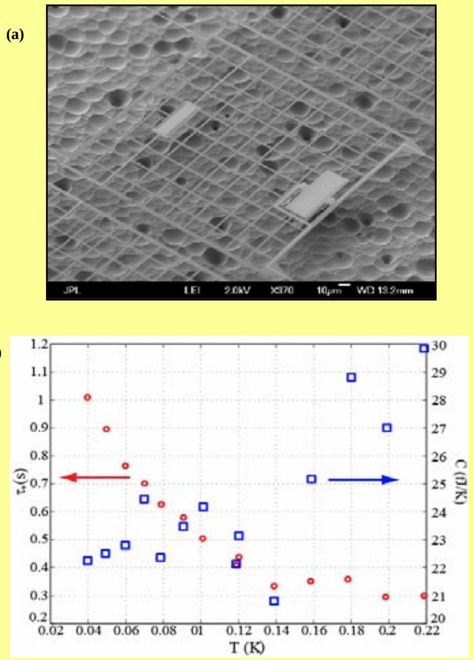

FIG. 5: (a) Micrograph of suspended Si_xN_y membrane with Au thin film heater and Johnson noise thermometer. Support beam dimensions are 1000 µm long by 0.5 µm wide by 0.25 µm thick. The membrane is 75 % open. The pitting underneath the membrane is caused by the dry release process. (b) "Natural" time response τ and heat capacity C of device versus substrate temperature T. With electrothermal feedback, the "effective" response time should drop by a factor of 10 or more, making the response time fast enough for BLISS.

Conclusion

These noise thermometry and TESs measurements show that membrane-isolated TESs can be sensitive enough for background-limited far-IR/submm direct-detection spectroscopy. These detectors are inherently scalable to large arrays formats and an NEP of 4 x 10^{-20} $W/Hz^{1/2}$ at 60mK is attainable.

References

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