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A bolometer array for the spectral energy distribution (SPEED) camera

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Abstract

The Spectral Energy Distribution (SPEED) Camera is being developed to study the spectral energy distributions of high redshift galaxies. Its initial use will be on the Heinrich Hertz Telescope and eventually on the Large Millimeter Telescope. SPEED requires a small cryogenic detector array of 2×2 pixels with each pixel having four frequency bands in the 150–375 GHz range. Here we describe the development of the detector array of these high-efficiency Frequency Selective Bolometers (FSB). The FSB design provides the multi-pixel, multi-spectral band capability required for SPEED in a compact stackable array. The SPEED bolometers will use proximity effect superconducting transition edge sensors as their temperature-sensing element, allowing for higher levels of electronic multiplexing in future applications.

Keywords: Bolometer; Millimeter; Telescope

1. Introduction

Detections of high redshift galaxies have generated great interest in high-efficiency survey array cameras for use at millimeter and submillimeter wavelengths [1–4]. While some of these large format cameras have multi-frequency capability, they generally can only be operated at one frequency band at a time. Below we describe the detector array for the SPEED camera, an instrument designed to do simultaneous, spatially coincident, multi-pixel, multi-frequency photometric observations. The SPEED camera achieves these capabilities because it will use FSBs [5] as the basic detector element.

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A camera such as SPEED has many applications, from measurements of the Sunyaev-Zel'dovich Effect to the determination of photometric redshifts of protogalaxies, identification and imaging of cold dust in galaxies, and characterization of cold solar system objects such as comets and asteroids. High sensitivity and simultaneous spatial and color information will make this small format camera ideal for the study of many classes of discrete objects.

Below we describe the SPEED instrument design, its design considerations and discuss the development of the FSB detector array. In another paper [6] in these proceedings, we describe the fabrication and testing of the SPEED FSBs.

2. Instrument design

The SPEED camera is designed as a small format (four pixel) multi-frequency instrument designed to observe in atmospheric windows available from ground-based millimeter telescopes; the camera is a prototype for a larger spatial coverage and broader bandwidth balloon-borne camera, the Explorer of Diffuse Galactic Emission (EDGE) [7]. Larger format cameras are usually constrained to single band operation at one time, but some can be reconfigured to observe at different wavelengths. Although this is not disadvantageous if detection is the objective, single band operation is inefficient when attempting to do multi-band photometry on previously targeted objects.

The entire SPEED array of FSBs is housed in a cryogenic dewar with a ^{3}He refrigerator designed to operate at 270 mK. The dewar also contains the cryogenic portion of the telescope coupling optics. Because FSBs only efficiently absorb in-band radiation and have high transmission out of band, SPEED can be designed to operate at all of its frequencies simultaneously (see Table 1 for the SPEED bands, expected loading from the atmosphere and telescope, and bolometer characteristics).

Table 1
SPEED characteristics and expected performance

Band	Center (GHz)	Loading (pW)	G[a] (nW/K)	BLIP[b] $(\mathrm{aW}/\sqrt{\mathrm{Hz}})$	NEP[c] $(\mathrm{aW}/\sqrt{\mathrm{Hz}})$[d]
1	148	17	0.7	92	112
2	216	35	1.7	128	157
3	260	63	2.5	182	219
4	303	92	3.6	233	276

[a] Thermal Conductance.
[b] Background-Limited Performance.
[c] Noise Equivalent Power.
[d] $\mathrm{aW} = 10^{-18}$ W.

3. Frequency selective bolometers

A SPEED camera spatial pixel will be built as a stack of FSB detectors. An FSB is a bolometer with a resonant absorber that is paired with a resonant backshort to form an interference filter. The two filter elements are capacitive meshes of electrically conductive crosses on a grid. The bolometer element crosses have finite conductance to absorb radiation and the backshort crosses have very high conductance to enhance the absorption of the bolometer element. Because they transmit out-of-band radiation, they can be cascaded in a common light pipe to produce a compact multi-frequency photometer. (see Fig. 1). The shortest wavelength detector is at the front of the stack and successively longer wavelengths are placed after that. After the last individual detector in a stack, an absorber is inserted to avoid reflections back up the tube. A detailed description of the fabrication and some preliminary tests of individual FSB elements is found in these proceedings [6].

We have chosen to implement the temperature sensing element of the FSBs using superconducting Transition Edge Sensors (TES) because they are very sensitive and it is now convenient to readout large numbers of detectors inside a cryostat by using a Superconducting Quantum Interference Device (SQUID) multiplexer. While the multiplexing capability is not extremely important for SPEEDs 16 element configuration, more complex instrument configurations such as the EDGE instrument would need substantial multiplexing for a practical instrument. Each

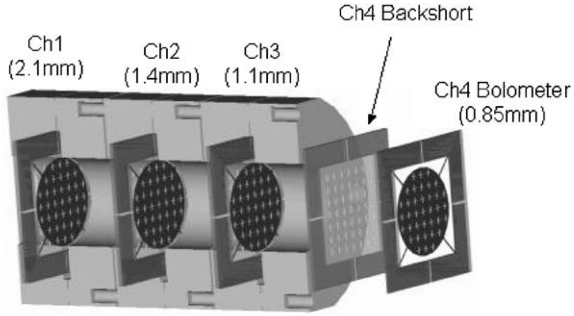

Fig. 1. Schematic of the SPEED detector array assembly for one spatial pixel.

FSB bolometer element has two TES sensors near the edge of the free-standing suspended square Silicon Nitride (SiN) 0.5 μm membrane approximately 1.1 cm on a side. The TES sensors are bilayer proximity effect devices fabricated of molybdenum and gold with a transition temperature adjusted to 460 mK. The entire membrane is thermally isolated and electrically connected by four 30 μm wide legs, two of which have pairs of 8 μm electrical leads of superconducting Ti/Al/Ti.

4. Detector array

Once individual FSBs for each band of interest are fabricated and tested, the FSBs may be stacked. Careful alignment of the bolometer and backshort layers is required to achieve the calculated performance. The square FSBs are placed in a circular mount that allows us to simply slide the completed detectors into a circular light pipe. Provision for electrical leads is provided to bias and readout the detectors. Four of these light pipes are then joined to make a compact four pixel arrangement.

TES sensors do not approach saturation gracefully, but cease to function when the optical loading exceeds the design threshold. Therefore, the SPEED detectors are designed to be able to withstand about four times as much loading as we expect. While FSBs transmit most of the out-of-band radiation, the out-of-band power absorbed can be significant when bright atmospheric water lines are near the frequency of interest. For this reason, it is important to limit the bandwidth of incident radiation in a ground-based application and SPEED incorporates additional notch filters (not shown in Fig. 1) to reject emission from atmospheric oxygen and water lines at 120, 185, 325 and 380 GHz.

The two TESs on each bolometer are read out in parallel, so only a single SQUID is needed for each detector. All 16 bolometers will be read out using a SQUID array and time-based SQUID multiplexer developed at NIST [8].

5. Conclusion

The SPEED camera extends the concept of focal plane arrays beyond the spatial domain into the region of simultaneous spatial and color information. We anticipate that this camera will be the first use of an FSB array in a scientific instrument. Careful control of residual out-of-band absorption and addition of blocking filters should allow SPEED to efficiently observe compact sources of millimeter radiation with little detector crosstalk. Detector, cryostat, optics, and electronics fabrication are now underway.

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