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Development of molybdenum–gold proximity bilayers as transition edge sensors for the SPEED camera

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Abstract

Bolometers are being developed with thermistor elements using Mo/Au proximity bilayers as superconducting transition edge sensor. These bolometers will be used by the Spectral Energy Distribution camera which is being developed to study the spectral energy distribution of high redshift galaxies. The bolometers are fabricated on $11 \times 11\,\mathrm{mm}^2$ suspended 0.5 μm thick low-stress LPCVD silicon nitride films supported by 475 μm thick silicon frames. To obtain the required thermal conductivity, the films are perforated to form central disks suspended by thin legs. Here we discuss the design, fabrication process, and current test results of these bolometers.

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1. Introduction

The spectral energy distribution (SPEED) camera is a millimeter-wave instrument being developed to study the spectral energy distribution of high redshift galaxies initially using the Heinrich Hertz Telescope, later using the Large Millimeter Telescope. It will have an array of four pixels; each pixel is a Frequency Selective Bolometer (FSB) [1] stack which simultaneously senses radiation in four spectral bands in the 150–375 GHz range.

Below we describe the design, fabrication process, and current test results of the individual bolometers. In another paper [2] in these proceedings, we describe the SPEED instrument design, its design considerations and discuss the development of the FSB detector array.

2. Design

FSBs require a feed at a relatively large f number ($f/4$ or larger). The SPEED camera has a throughput of $4\,\mathrm{mm}^2\,\mathrm{sr}$. This, along with $f/4$ necessitates a detector diameter of 10 mm. The

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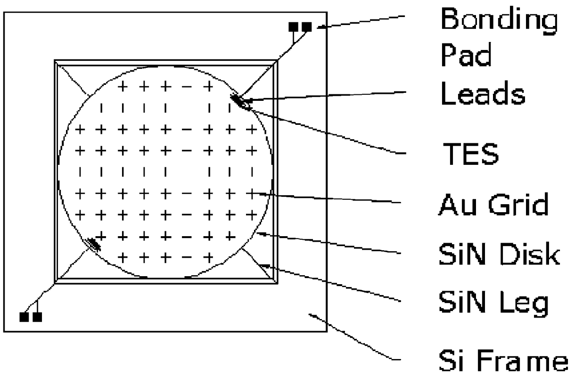

Fig. 1. Schematic of device.

detector disk is covered with a patterned absorber, and variations in incident radiation are sensed with two transition edge sensors (TES) connected in parallel. The disk is suspended by four legs, which also act as the thermal connection to the bath, and carry the superconducting leads to the TES (Fig. 1).

The detector system will be cooled to 270 mK by an ^{3}He refrigerator. The target transition temperature of the TES is 460 mK, chosen to optimize NEP.

Observing in the 150–375 GHz range from a ground-based telescope results in a significant amount of in-band radiation from foreground sources. The thermal conductance G of the bolometers needs to be large to carry off a constant power, equivalent to the sum of the electrical bias power plus optical loading. Furthermore, the bolometers must be designed with sufficient margin on G that variations in optical loading never bring the electrical bias power to zero, or the detector would become insensitive to the incoming radiation. The G values we are designing to are 0.7, 1.4, 2.5 and 3.6 nW/K in bands 1–4, respectively.

3. Fabrication

Fabrication begins with the deposition of 0.5 μm of low-stress SiN on both sides of a double-side polished ⟨1 0 0⟩ silicon wafer by LPCVD (Fig. 2a). The starting silicon substrate has a thickness of

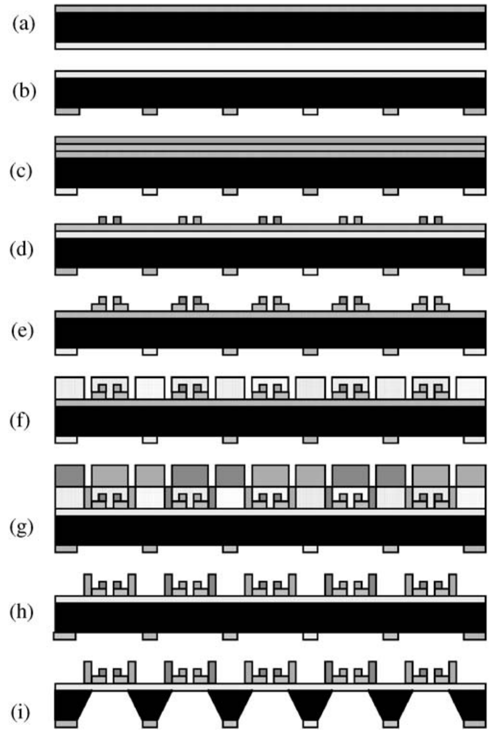

Fig. 2. Process flow diagram.

475 μm. Holes the size of the desired free standing area of the SiN membranes are initially etched using reactive ion etch (RIE) in the nitride on the back side of the wafer (Fig. 2b). This is done by photolithographically patterning a photoresist (PR) etch mask and etching the exposed nitride.

In an ultra-high vacuum deposition system, the Mo/Au bilayers are thermally deposited by electron beam evaporation at a base pressure of 1×10^{-10} Torr (Fig. 2c). A 50 nm thick molybdenum (Mo) layer is deposited first at a rate of 0.5 nm/s on the SiN wafer front at a temperature of 500°C. Under these conditions, Mo films show low tensile film stress and sharp superconducting transitions at about 800 mK. A 50 nm gold (Au) layer is deposited next at a rate of 0.1 nm/s at temperatures between 10°C and 20°C.

The Mo/Au bilayer structure is defined on the SiN membrane using photolithographic techniques aligning to the back of the wafer. The Au is patterned with PR and dry etched in a vacuum chamber by argon ion milling (Fig. 2d).

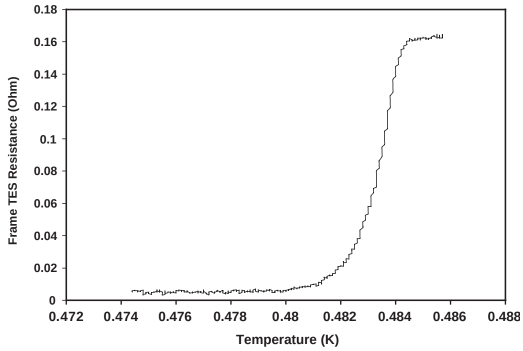

Fig. 3. R(T) Curve of typical transition.

Monolithic Mo leads are then formed at the same time and alongside the Mo layer of the TES (Fig. 2e) using wet chemical etch (HNO_3:H_2SO_4:-DIW). The Ti/Al/Ti leads are then produced in a series of masking (Fig. 2f), deposition (Fig. 2g), and lift-off (Fig. 2h) steps. For lift-off, we use Futurrex PR which produces overhang structures of 3 μm and removes in RR-4. Similarly, the bonding pads are fabricated.

The wafer fronts are protected and backs are etched in an anisotropic KOH chemical etch to form free standing SiN membranes (Fig. 2i).

Perforations are made in the membranes to control the G of the device by photolithographically patterning a PR etch mask etching the nitride with RIE, and removing the PR in an oxygen plasma.

4. Results

A typical transition curve for the TES is shown in Fig. 3. We reliably get sharp transitions, between 410 and 490 mK, with $\alpha \sim 500$. Note that these TES have no normal metal bars.

We have measured the G of the SiN legs plus Mo/Ti/Al/Ti leads to be well approximated by $4.6\,\mathrm{nW/K}\ (T/K)^{2.9}$, at the current leg and lead dimensions. We suspect that this is strongly dominated by the leads, but have not yet conclusively demonstrated this. This measurement indicates that it will be straightforward to achieve the design G by scaling the widths of the legs and leads.

Our measurements of the parameters that affect the dynamics, such as the heat capacity, the non-ohmic TES behavior ($d \ln R/d \ln I$), and a possible "hanging heat capacity" model for the SiN disk, are ongoing. The measurements are qualitatively as expected, and we continue developing the detailed model fits. This detailed analysis is required to interpret our noise measurements, but it is clear that they have the correct qualitative behavior.

5. Conclusion

We have designed, fabricated and tested several iterations of detectors for the SPEED camera. These detectors have thermistor elements using Mo/Au proximity bilayers as superconducting transition edge sensors. We have been able to obtain reliably sharp transitions. We are continuing to take measurements of the devices and developing the detailed model fits.

To date, we have only tested the detectors in the 'dark'. The next step in our developmental effort will be to incorporate absorbers so that we can better characterize these devices.

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