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Backshort-Under-Grid arrays for infrared astronomy

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Abstract

We are developing a kilopixel, filled bolometer array for space infrared astronomy. The array consists of three individual components, to be merged into a single, working unit; (1) a transition edge sensor bolometer array, operating in the milliKelvin regime, (2) a quarter-wave backshort grid, and (3) superconducting quantum interference device multiplexer readout. The detector array is designed as a filled, square grid of suspended, silicon bolometers with superconducting sensors. The backshort arrays are fabricated separately and will be positioned in the cavities created behind each detector during fabrication. The grids have a unique interlocking feature machined into the walls for positioning and mechanical stability. The spacing of the backshort beneath the detector grid can be set from $\sim$30–300 μm, by independently adjusting two process parameters during fabrication. The ultimate goal is to develop a large-format array architecture with background-limited sensitivity, suitable for a wide range of wavelengths and applications, to be directly bump bonded to a multiplexer circuit. We have produced prototype two-dimensional arrays having 8×8 detector elements. We present detector design, fabrication overview, and assembly technologies.

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Keywords: Backshort-Under-Grid; Transition edge sensor; Bolometer; Large format arrays; Indium bump bonding

1. Introduction

We are developing a kilopixel bolometer array, with integrated, one quarter-wavelength backshorts, to be bump-bonded directly to a superconducting readout. As the need for large format detector arrays increases, scalable architectures, suitable for a wide range of wavelengths, must be developed. Bolometers are currently the favored type of detector for high sensitivity, low background, infrared astronomy. Several factors place constraints on the development of arrays in very large formats. Their fragility, resulting from the necessary mechanical suspension required for thermal isolation of each detector element, can be an impediment to assembly and can place constraints upon the environmental conditions under which the detectors can be used. Also, infrared bolometers require an optically reflective or absorbing element in conjunction with the sensing element, often a planar surface placed behind the detector, in order to increase detector efficiency. This feature can be difficult to integrate with the detectors, often interfering with detector electrical connections. An additional factor constraining their use is the fact that read-out of arrays has, historically, been extremely cumbersome, due to the large number of wires required for non-multiplexed signals. (i.e. each detector element required a single readout circuit with a corresponding number of wires connected to the focal plane assembly.) The recent development, by National Institute of Standards and Technology (NIST), Boulder, Co., of a large format superconducting quantum interference device (SQUID) multiplexed readout is beginning to relieve that constraint. The difficulty integrating delicate, thermally isolated detectors to their readout electronics remains an issue. Our detector system addresses the issues of

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placement of a reflective backshort and integration with multiplexing readout circuits.

2. Array design

The Backshort-Under-Grid (BUG) array is designed as a filled, square grid of suspended bolometers with transition edge sensors and SQUID multiplexer (mux) readout. The backshort array is fabricated as a separate square grid of reflective elements. The bolometer and backshort are designed with interlocking features to permit the backshorts to be inserted behind the suspended bolometers. The concept of nesting the backshort behind the detector is shown in Fig. 1. The large format BUG assembly is intended to be bump-bonded to the SQUID mux developed by NIST [1]. Indium bumps will be applied directly to the mux circuit and will mate to contact pads on the under side of the detector grid. The TES sensor's electrical connection will be accomplished by means of a Wrap Around Via (WAV), by angle deposition of metal on the sidewalls of the detector grid, to pass the connection from the top to the bottom of the grid. The precedent for the WAV is the sidewall electrode currently in use for Goddard's microshutter arrays [2].

3. Fabrication overview

The detector array is fabricated using silicon-on-insulator (SOI) starting wafers, comprised of a 1.4 μm top layer of single-crystal silicon, supported by a thick silicon wafer, with an oxide barrier in between. Sputter deposited molybdenum–gold proximity effect bilayers are patterned into TES's using plasma etch. Normal metal bars are applied, using photolithographic lift-off, patterned into

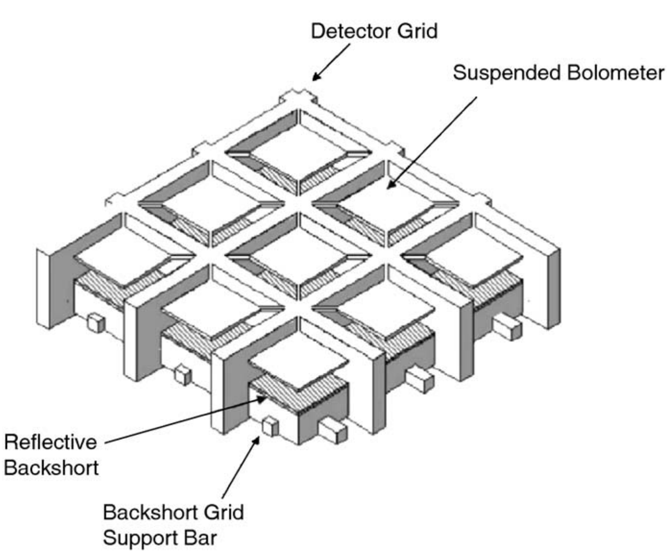

Fig. 1. Artist's concept of the backshort grid, nested in the cavities behind the bolometer grid.

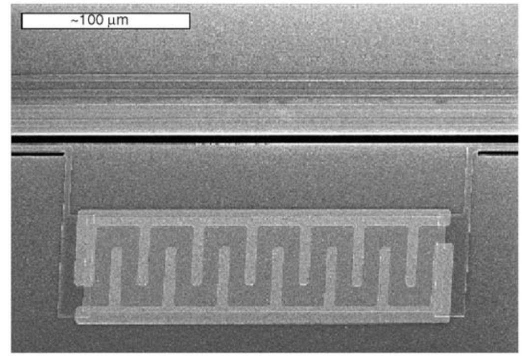

Fig. 2. SEM image of a Mo–Au TES with normal-metal zebra stripes. The sensor is 200 μm in length.

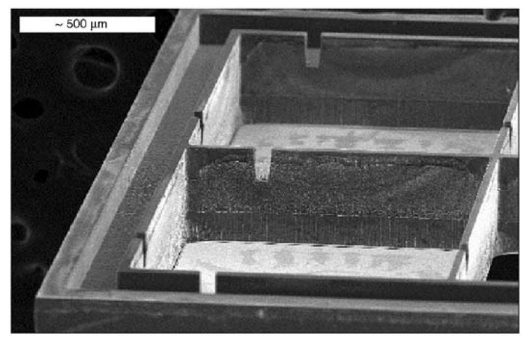

Fig. 3. SEM image of the back, support side of a 2 × 2 array of TES detectors. Note the notches in the grid walls, and moat surrounding the array, intended to receive the backshort.

"zebra" stripes, or iterdigitated fingers (Fig. 2), shown to mitigate frequency-dependent excess noise [3,4].

The silicon grid, which supports the detector array is etched from the back side of the SOI starting wafer using deep reactive ion etching (Fig. 3). The grid walls shown are 40 μm wide and 380 μm tall. The unique notch feature, which will intersect with the backshort grid is clearly seen in the image and is described elsewhere [5].

For integration with the multiplexer, we have developed an indium bump bonding capability using a method of single-sided bumps. Indium bumps are formed using thick, lift-off photolithography. The bumps are 10 μm in height (Fig. 4). We have measured bond strength of 0.33 g/bump. The indium bumps will be deposited on the SQUID circuit and will interface with the base of the grid seen in Fig. 3.

The remaining element of the detector design, backshort arrays, are fabricated of silicon wafers using deep reactive ion etch. The top side is etched first, delineating the blocks of silicon which will become the backshorts. The etch stops at a depth determined by the desired resting place of the grid within the notch in the detector back wall. Then, the wafer is etched through the reverse side forming the intersecting grid of support bars.

We have fabricated, and are testing, 8 × 8 arrays, requiring no bump bonding. Next we will demonstrate bump bonding of arrays in preparation for integrating

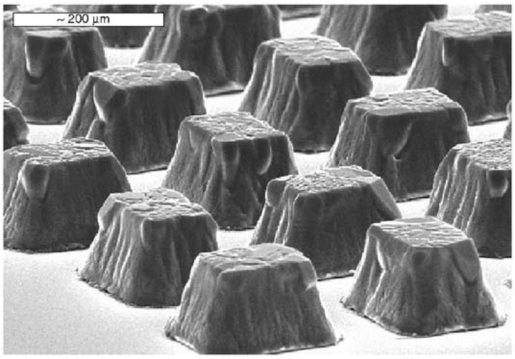

Fig. 4. SEM image of 10 μm tall indium bumps, closely spaced on a bonding pull-test chip.

large-format arrays with NIST multiplexers in the future. The TES elements have demonstrated extremely low noise, the specifics of which are presented elsewhere [4].

4. Conclusions

We have developed a detector design that will enable large-format IR bolometer arrays to be indium bump bonded to a planar SQUID multiplexer. We have established deep reactive ion etch techniques that allow three-dimensional features in square grid sidewalls. We have developed in-house bump-bonding capabilities and demonstrated pull strength of 0.33 grams per bump. Test results on suspended bolometers show extremely low-noise, TES behavior and thermal properties are in the expected range for the detectors as designed.

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