DDF annual report

Title of Investigation:

Integrated Refrigerator/Bolometer Array

Principal Investigator:

Robert F. Silverberg (Code 665)

Other In-house Members of Team:

Dominic Benford (Code 665), Harvey Moseley (Code 665), Tina Chen (Code 665), Fred Finkbeiner (Code 662), and Jay Chervenak (Code 553)

Other External Collaborators:

Joel Ullom, Nathan Miller, Dan Schmidt, and William Duncan (National Institute of Standards and Technology, Boulder)

Initiation Year:

FY 2005

Aggregate Amount of Funding Authorized in FY 2005 and Earlier Years:

$62,000

Funding Authorized for FY 2005:

$82,000

Actual or Expected Expenditure of FY 2005 Funding:

In-house: $57,000; Contracts: $20,000 for supplies and equipment; Grants: $5,000 to Joel Ullom (National Institute of Standards and Technology, Boulder)

Status of Investigation at End of FY 2005:

Single prototype detector fabrication

Expected Completion Date:

September 2006

Purpose of Investigation:

Cryogenic (low temperature) bolometric (total energy) detectors are ultra-sensitive thermometers. When cooled to very low temperatures near absolute zero, they are capable of rapidly detecting temperature changes of less than a millionth of a degree. This high sensitivity makes them nearly ideal for measuring the heat from distant astronomical objects.The goal of this investigation is to develop a small prototype array of bolometric detectors, which are equipped with integrated electron-tunneling refrigerators that would allow the array to be cooled to temperatures below ~200 mK from a 300 mK bath. Up to now, the mass, complexity, and power required to achieve these lower temperatures have been an obstacle to space-borne missions in the millimeter and sub-millimeter wavelength range

Recently, a group at the National Institute of Standards and Technology in Boulder, Colorado (NIST/Boulder), has succeeded in developing a practical solid-state refrigerator, which uses the electron tunneling in a superconductor-insulator-Normal metal-Insulator-Superconductor (NIS) sandwich layer (Clark et al., 2004) as well as thin-film technology and photolithographic processes for their manufacture. The operation of this refrigerator is illustrated in Figure 1. These compact refrigerators are capable of cooling a small sample from an ~300 mK bath temperature to the 130 mK range—allowing significant improvement in detector performance with low power, no moving parts, and small mass. Even under typical loads of ~10 pW that might be experienced in ground-based operations, temperatures of ~150 mK have been demonstrated. The NIST achievement opens the possibility of directly integrating these solid-state refrigerators with low-temperature detectors using superconducting transition edge sensors (TES) to provide higher-sensitivity detectors for space-borne instruments in a smaller, low mass, low-power system where only the detector unit itself needs to be cooled to the very lowest temperatures.

Accomplishments to Date:

A unit cell adaptable for a small array of integrated transition edge sensors (TES) bolometers/NIS refrigerators has been designed. The prototype design is suitable for operation on a ground-based telescope at wavelengths of ~3 mm. Several variations of the NIS refrigerator have been incorporated into a mask set for production of a number of prototype devices. One of the prototype devices will be selected to produce a small array of the devices in the second year of the DDF effort. A schematic layout of the unit cell is shown Figure 2.

The device's layout is modeled after a detector being built at the Goddard Space Flight Center (GSFC) for use at 3 mm wavelength on the 100 m Robert C. Byrd Green Bank Telescope (GBT) operated by the National Radio Astronomy Observatory in Green Bank, West Virginia.

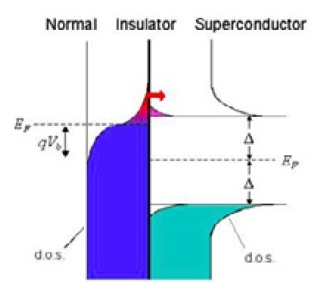

Figure 1. Band diagram for a normal-insulator-normal junction. When the junction is biased as shown in this figure, hot electrons in the normal metal can tunnel into the superconductor, forming quasiparticles. This allows the normal metal to cool.

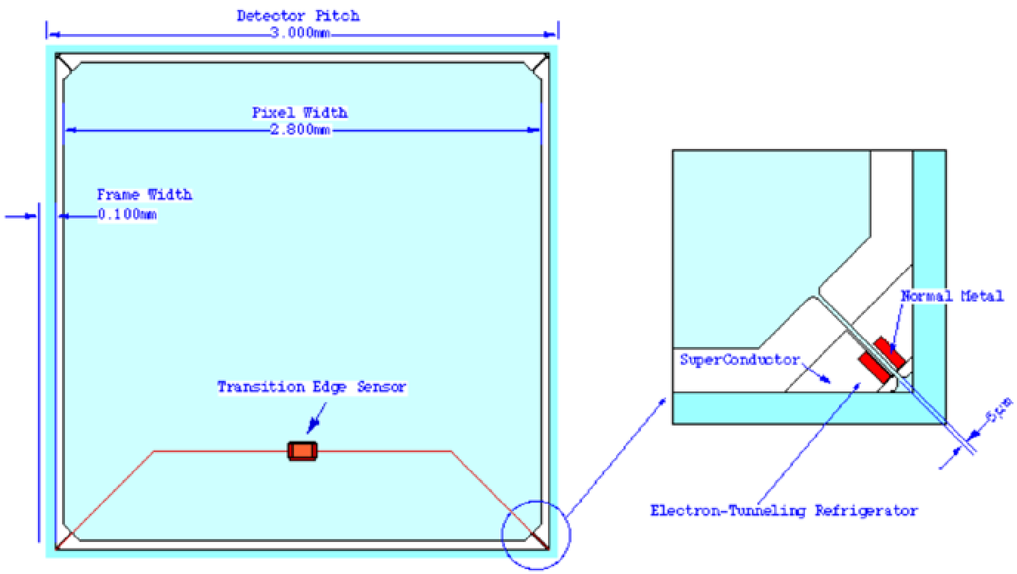

Figure 2. Schematic layout of the unit cell adaptable for an array of integrated TES bolometer/NIS refrigerator cooled detectors. The center area is a thin layer (~1 µm) of Silicon suspended by four legs that thermally isolate the detector from the thermal bath. The blowup of the leg area shown at the right of the figure shows the construction of the NIS refrigerator and its integration into the detector design.

The detector we are building for this DDF is modified from its original design to include NIS coolers at the base of each suspension leg of the absorbing portion of the detector. In addition, the TES detector operating temperature is designed to be lower to take advantage of the cooling from the NIS refrigerator. The lower operating temperature means that the detector can achieve higher sensitivity.

To take advantage of the experience developed at NIST/Boulder in NIS refrigerator technology, our NIST collaborators are assisting us with the design and fabrication of the NIS refrigerator portion of the devices. We will fabricate the TES, the bolometer structure, and test the prototype device at GSFC.

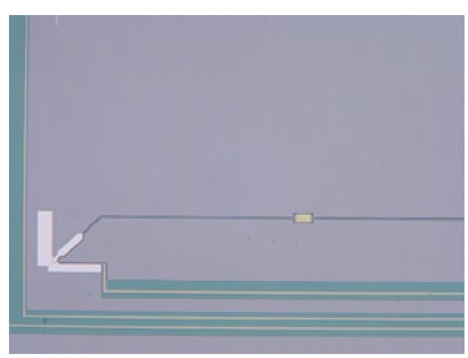

Figure 3. Enlarged photomicrograph of the corner of one of the devices during fabrication. The TES bolometric detector is the small rectangle near the center of the figure while the large structure near the left corner is the NIS cooler. The cooled portion of the refrigerator is on the diagonal while the vertical and horizontal portions are where waste heat is deposited and returned to the thermal bath at ~300 mK. This photograph was taken before the detector membrane is released from the silicon wafer.

Figure 3 shows a photomicrograph of one of the prototype devices during fabrication. At this stage, the TES detector has been fabricated on the silicon wafer and the wafer has been processed at NIST/Boulder to put down then the refrigerator. Preliminary testing of these first devices is scheduled to begin shortly.

Publications and Conference Presentations:

Silverberg, R., Benford, D., Chen, T., Chervenak, J, Finkbeiner, Miller, N., Schmidt, D., Duncan, W., and Ullom, J., "Integrated Electron-tunneling Refrigerator and TES Bolometer for Millimeter Wave Astronomy," *Nuclear Instruments and Methods in Physics Research, A,* to be published in 2006.

We also presented at the 11th International Low Temperature Detector Conference in Tokyo, Japan, in July 2005. The presentation had the same title as the publication referenced in the previous paragraph.

Planned Future Work:

The prototype devices are nearing completion. They will be tested for thermal performance and stability. After we have tested the prototype devices, we will select the best configuration for incorporation into a close-packed array design. The array configuration requires consideration of crosstalk (both thermal and electrical) as well as routing of electrical wiring for multiplexing the readout of all the detectors in the array.

Key Points Summary:

Project's innovative features: This is the first attempt to combine NIS refrigerators directly with a bolometric detector. Arrays of these integrated detectors would offer the possibility of low-mass, low-power, high-reliability instrumentation for millimeter and submillimeter astronomy from ground-based, high altitude or space-borne platforms.

Potential payoff to Goddard/NASA: If the success criteria are met, significant improvement in detector performance is possible. Compact, low-mass, low-power arrays of detectors would open the way for more advanced and lower-cost instruments for NASA's future missions.

The criteria for success: The main criterion for success will be to demonstrate cooling power, temperature stability, and increased sensitivity using the integrated NIS refrigerator/TES bolometer. In addition, the uniformity from device to device will determine how well the devices can be arrayed.

Technical risk factors that might have, or that in fact have, prevented achieving success: No technical obstacles have been encountered yet. Processes used are standard photolithographic techniques. The required tolerances are well within normally achievable parameters for both bolometer and refrigerator fabrication.

References:

Clark, A., M., Williams, A., Ruggiero, S. T., van den Berg, M. L., and Ullom, J. N., “Practical electron-tunneling refrigerator,” *Appl. Physics Lett.,* **84**, (4), 625, 2004.