# 2K × 2K InSb for Astronomy

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## ABSTRACT

Raytheon Vision Systems is under contract to develop 2K × 2K InSb Focal Plane Arrays (FPA) for the ORION and NEWFIRM projects teaming with NOAO, NASA, and USNO. This paper reviews the progress in the ORION, NEWFIRM, and the JWST projects, showing bare mux readout noise at 30 K of 2.4 e- and InSb dark current as low as 0.01 e-/s. Several FPAs have been fabricated to date and the ongoing improvements for the fabrication of FPAs will be discussed. The FPA and packaging designs are complete, resulting in a design that has self-aligning features for ease in FPA replacement at position of the focal plane assembly with alignment accuracy in the focus direction of ± 12 µm. The ORION/NEWFIRM modules are 2-side buttable to easily form 4K × 4K mosaics while the Phoenix modules, developed under the JWST development program, are 3-side buttable for ease in forming 4K × 2NK mosaics where N can be any integer.

This paper will include FPA QE, dark current and noise performance, FPA reliability, and module-to-module flatness capabilities.

**Keywords:** InSb SCA, ORION II, JWST, 2K × 2K module, Mosaic

## 1. INTRODUCTION

Raytheon Vision Systems (RVS) has produced high-quality InSb detector arrays specifically for astronomy applications for over 20 years. These detectors, hybridized to a silicon readout integrated circuit (ROIC) chip, form Sensor Chip Assemblies (SCAs) which have steadily increased in size and performance. The earliest arrays were just 58 × 62 elements in size compared to arrays that are up to 2048 × 2048 today, an increase of three orders of magnitude in pixel count. SCA noise has improved over this period of time from hundreds electrons to as low as 4 electrons today.[1] At the same time, detector dark has decreased from around 10 electrons/second to as low as 0.004 e-/s.[2] Manufacturing improvements have also resulted in better uniformity and fewer detector defects. This paper will show the state-of-the-art in large format InSb arrays for astronomy and present data on recent 2K × 2K arrays. RVS is currently manufacturing 2K × 2K InSb arrays for the ORION and NEWFIRM projects for the National Optical Astronomy Observatories (NOAO).

## 2. InSb MANUFACTURING CAPABILITIES

RVS is a world leader in manufacturing InSb detectors. Figure 1 shows the number of InSb SCAs fabricated each year over a recent five-year period. This high rate production, which exceeds 3,000 InSb SCAs per year, provides RVS with the manufacturing control to maintain processes and equipment within tight tolerances. The net effect is to reduce cost and improve yields for all InSb SCAs, including specialty SCAs such as those for astronomy.

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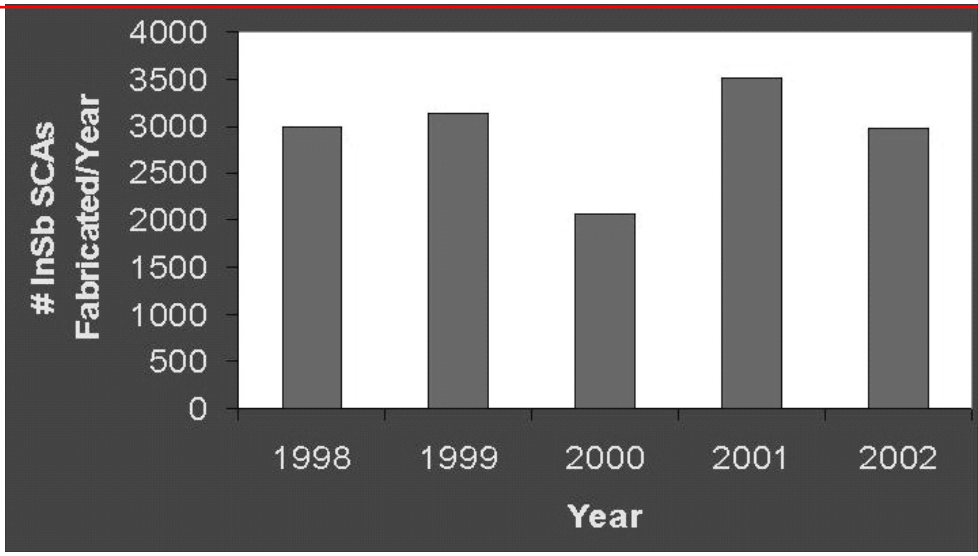


Fig. 1. Number of InSb SCAs fabricated at RVS for 1998 through 2002. The rate has held fairly constant with a mean of over 3,000 SCAs/year. This provides a manufacturing base for custom array fabrication such as for astronomy.

As arrays have grown larger, InSb wafers—the starting material from which InSb detector arrays are fabricated—have also needed to grow larger. InSb wafers over 100 mm in diameter are now routinely processed. A photo of an InSb wafer with a 2048 × 2048 (2K × 2K) element detector array patterned on it is shown in Figure 2. The large array has 25 µm element spacing. Test structures surround the 2K × 2K array. This particular wafer is only 82 mm in diameter since a larger wafer would be more expensive and not yield any additional 2K × 2K die.

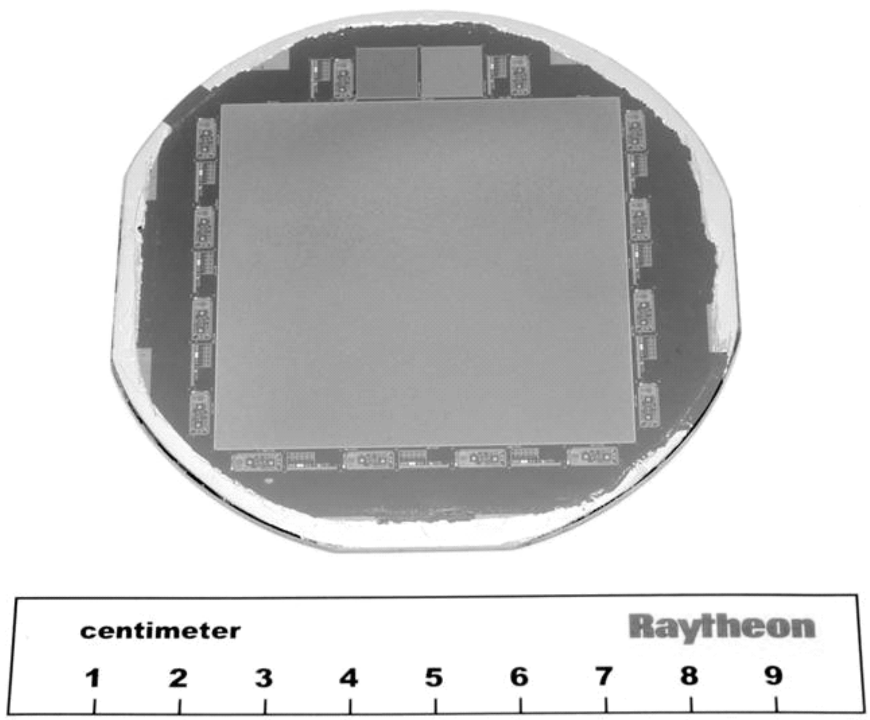


Fig. 2. Photograph of 82 mm diameter InSb wafer with a 2048 × 2048 (2K × 2K) element array patterned on it. Each detector element is 25 µm square. The small die surrounding the 2K × 2K array are various test structures.

## 3. LARGE INSB ARRAYS AND TEST DATA

The first InSb SCA to exceed one million ($1\times10^6$) pixels was the ALADDIN array first produced in 1993 and demonstrated on a telescope by NOAO in 1994. This SCA, shown in Figure 3, has 1024 × 1024 detector elements spaced on 27 µm centers. Due to the uncertain yield of large arrays at that time, ALADDIN was divided into four independent quadrants, each containing 8 output amplifiers. There are no gaps between quadrants, allowing a seamless 1K × 1K image.

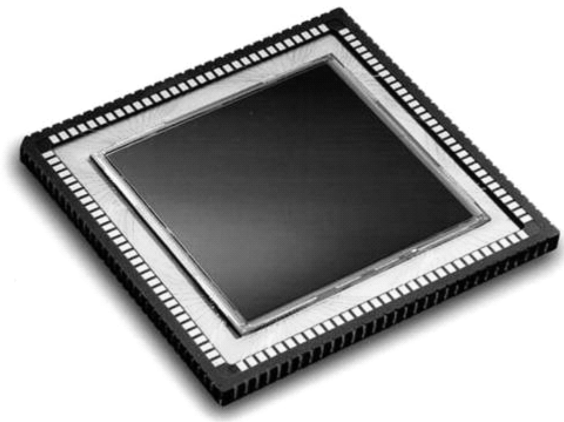

Fig. 3. ALADDIN InSb SCA with 1024 × 1024 detector elements on 27 µm spacing. The SCA is mounted in a 124-pin leadless chip carrier (LCC).

The next step in the development of larger astronomy SCAs was the 2048 × 2048 (2K × 2K) ORION InSb SCA shown in Figure 4. The detector element spacing is 25 µm making this array, at over 51 mm, the largest infrared array manufactured to date. The SCA has 64 outputs, allowing up to a 10 Hz frame rate. When mounted on a module, the ORION focal plane includes electrical cables, current sources for all the outputs, a temperature sensor, and noise-reducing capacitors. Light baffles are built into the module to reduce stray light.

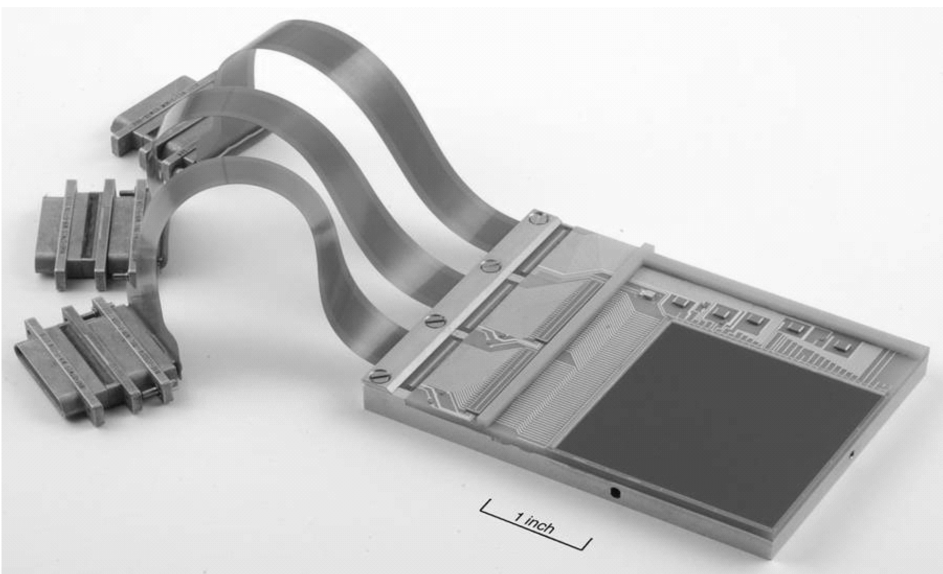


Fig. 4. An ORION 2048 × 2048 (2K × 2K) InSb SCA mounted on a module. A temperature sensor and noise-reduction capacitors are also mounted on the module. Two of the connecting cables carry the 64 output lines; the third cable is for clocks and biases. Current sources for all 64 outputs, shown just to the left of the light-baffle bar, are included. The module is 2-side buttable.

The ORION module was designed to be 2-side buttable, allowing for easy construction of 4K × 4K focal planes as shown in Figure 5. The focal plane in this figure consists of one InSb SCA and three modules with bare readouts attached. Gaps of less than 1.5mm between the active areas of the modules have been demonstrated. A fully populated 4-SCA focal plane will be constructed for NOAO's NEWFIRM project.

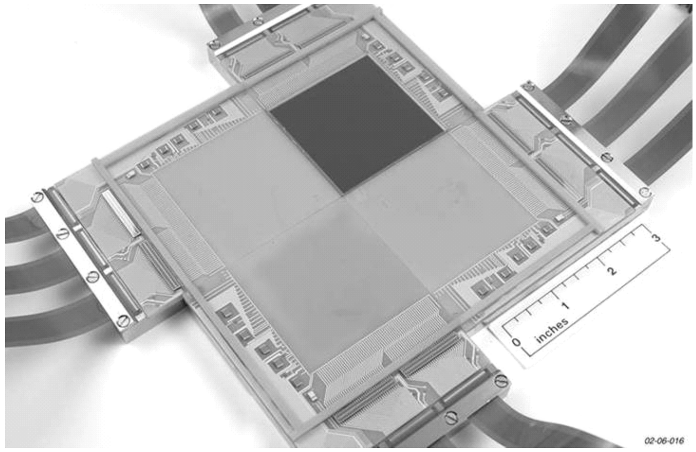


Fig. 5. A demonstration focal plane with four ORION modules. One module contains an InSb SCA while the others have bare readouts. This focal plane demonstrates the ability of the 2-sided buttable modules to create a 4K × 4K focal plane.

A challenge for large focal planes is maintaining optical focus over such a large area. This is especially critical in instruments with fast optics and a shallow depth of focus. The most critical step to maintaining focus is maintaining the flatness of the detector surface. The flatness of a detector array on an ORION module has been measured both warm and cold by NOAO. Figure 6 shows interferograms of an InSb detector on an ORION 2K × 2K InSb module taken with the module at room temperature and again at 80 Kelvin. There is very little change in shape as the module is cooled due to the lack of thermal expansion stresses in the module. In addition, the detectors are extremely flat: < 3 µm peak-to-valley over the 350 × 350 pixel area imaged in the interferogram.

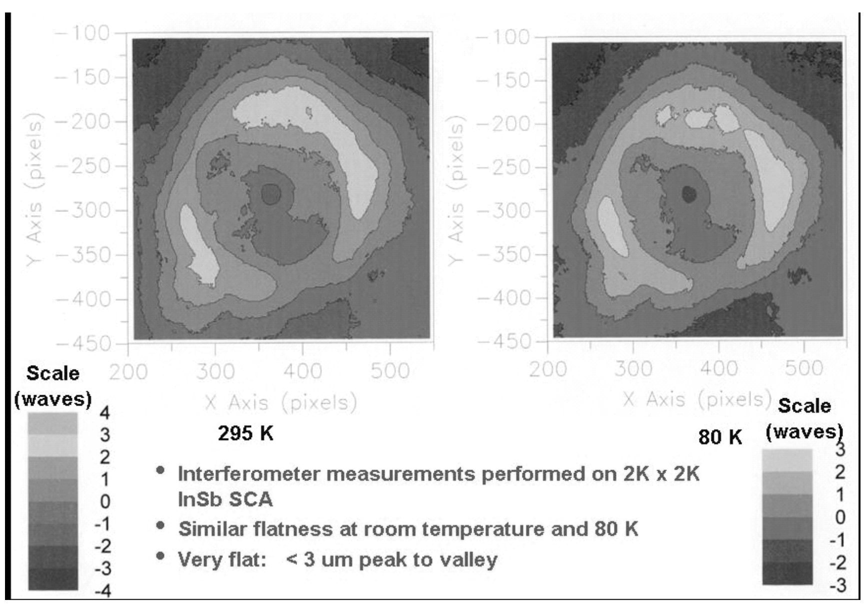

Fig. 6. Interferograms of the top surface of the detector on an ORION 2K × 2K module. The picture on the left shows the flatness at 295 K while the flatness at 80 K is shown on the right. The scales (in waves) for the interferograms are included on each side. The detectors are extremely flat over this area and there is almost no change in shape with temperature.

One of the reasons for selecting InSb for infrared instruments is its broad spectral response. InSb has nearly 100% internal quantum efficiency (QE) from 0.4 µm to 5 µm, with a rolloff in efficiency only near the cutoff wavelength of 5.5 µm. The only limiting factor in QE over this large spectral range is the reflection of incident light at the InSb surface. This is minimized with anti-reflection (AR) coatings. QE measurements of large-format InSb SCAs have been obtained by both Fowler at NOAO and McMurty at the University of Rochester.[1] The results of these measurements are shown in Figure 7. The NOAO SCA had a broad-band single-layer AR coating while the one at the University of Rochester had a seven-layer coating designed to boost QE in the visible portion of the spectrum without losing QE in the rest of the infrared spectrum. The data plotted in Figure 7 confirm the high, spectrally uniform QE that is expected for the combination of InSb detectors and the AR coating applied.

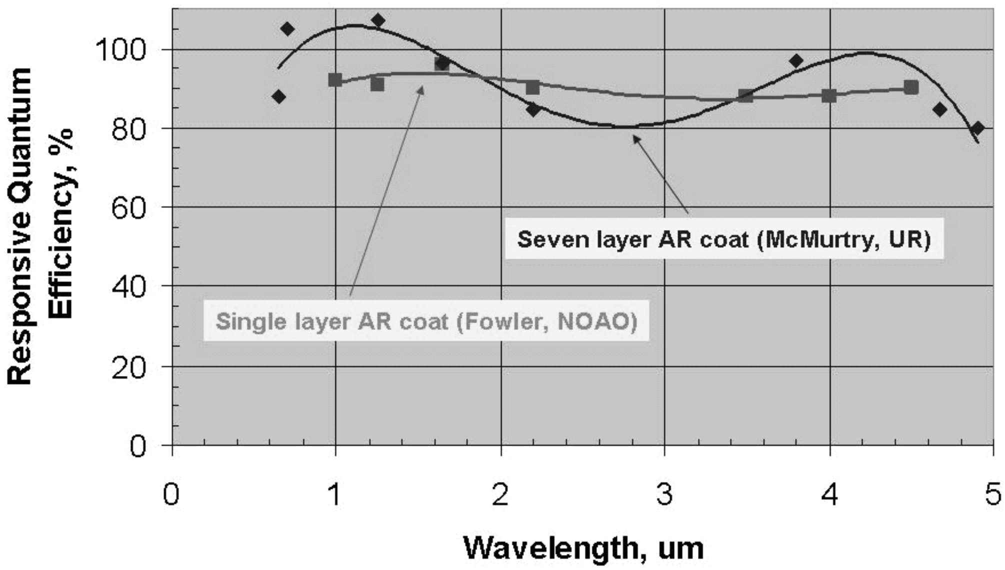


Fig. 7. QE of large-area InSb SCAs as a function of wavelength. The data obtained by Fowler at NOAO is from a 1K × 1K ALADDIN SCA with a single-layer, broad-band AR coating. The data from McMurtry at the University of Rochester is from a 2K × 2K Phoenix SCA with a seven-layer AR coating designed to enhance visible response and maintain high QE in the infrared as well. The smooth curves are polynomial fits to each data set.

Besides the ORION SCA, another 2K × 2K array that has been fabricated and tested is the Phoenix SCA. Although the detector array is identical to ORION (25 µm pixels), the readout is optimized for lower frames rates and lower power dissipation. With only 4 outputs, the full frame read time is typically 10 seconds. The smaller number of outputs allows a smaller module package that is 3-side buttable, as shown in Figure 8.

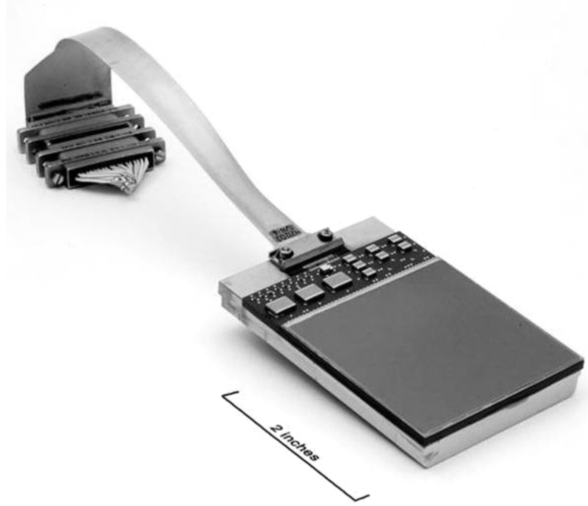


Fig. 8. The Phoenix 2048 × 2048 (2K × 2K) InSb module. The InSb SCA occupies the majority of the module surface. A temperature sensor, current-source resistors, and noise-reduction capacitors are located on the upper-left of the module.

Performance of InSb detectors on Phoenix modules has been outstanding. QE measurements by the University of Rochester (UR), previously shown in Figure 7, demonstrate high QE on 2K × 2K InSb, between 80% and 95% from visible to 5 µm radiation. UR has also measured low noise on a Phoenix InSb module as shown in Figure 9. The noise, measured using 100-second integrations, is reported using Fowler sampling from Fowler-1 up to Fowler-8. The noise, which includes readout, detector, and test set noise sources, decreases as the square root of the number of Fowler samples, as expected from an uncorrelated white noise source. At Fowler-8, the total noise is 4 electrons.

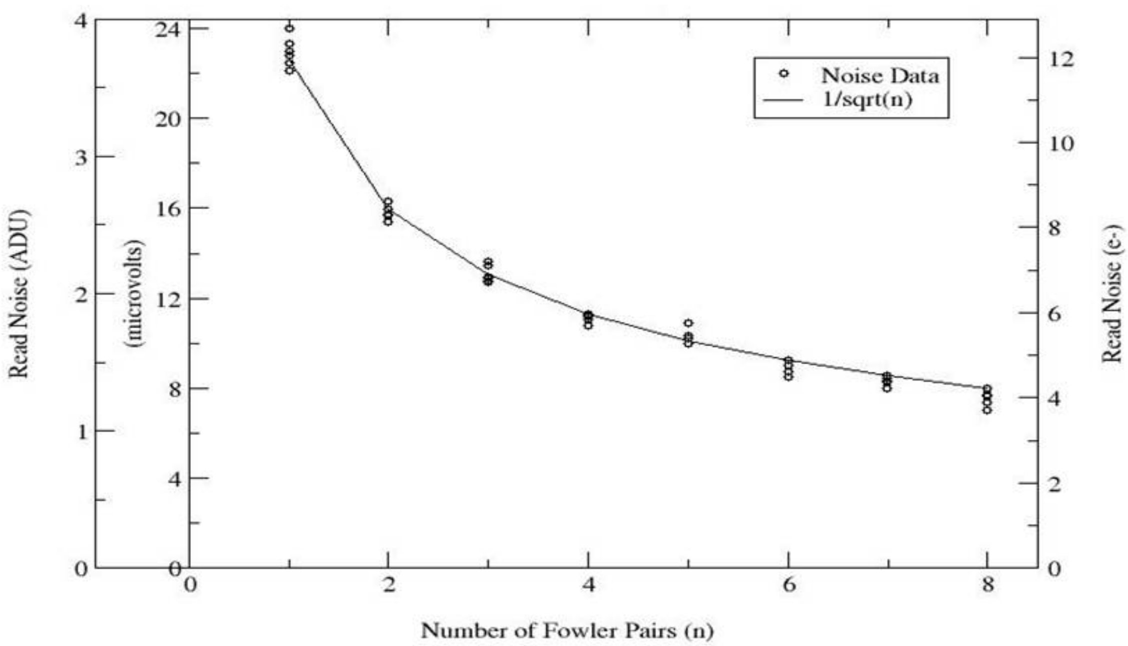


Fig. 9. Noise measured by University of Rochester on a Phoenix 2K × 2K InSb module using 100-second integrations.[1] The total noise—including readout, detector, and test set noise contributions—is shown as a function of the number of Fowler sample pairs. The noise follows the square root (number of Fowler pairs) relation predicted for uncorrelated white noise with 4 electrons noise measured for Fowler-8. The module temperature was 30 Kelvin.

InSb has been shown to have low dark current in large format arrays. The "world record" for low dark current in infrared arrays has been claimed by ESO in measuring 0.004 electrons/second on a 1K × 1K ALADDIN InSb SCA.[2] Similarly good dark current results have been obtained by the University of Rochester measuring a Phoenix 2K × 2K InSb module.[1] Figure 10 shows the "sample-up-the-ramp" technique use to make dark current measurements. The array was read out once every 11 seconds for over 2,200 seconds to obtain these data.

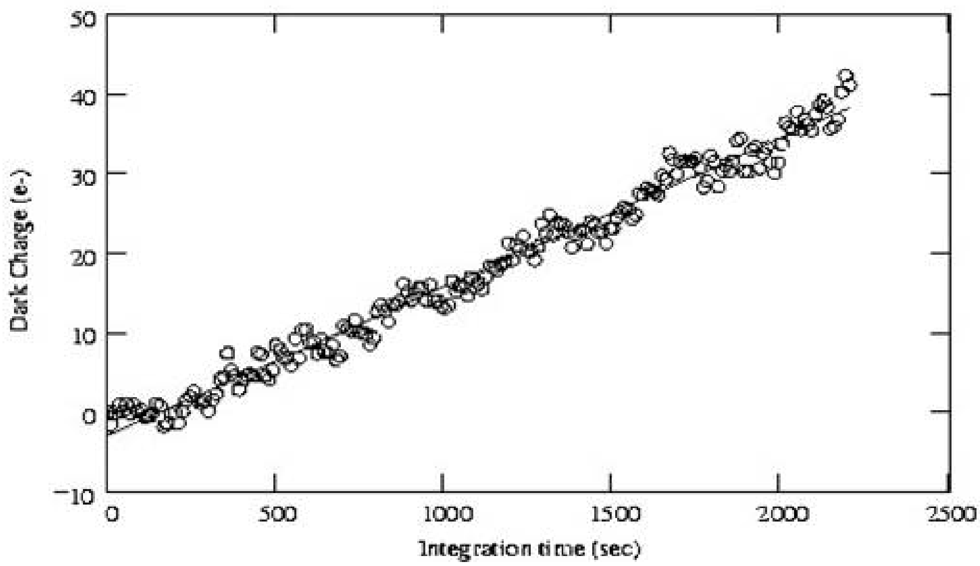


Fig. 10. Graph depicts “sample-up-the-ramp” technique for dark current measurements.

Repeating this measurement at many temperatures and plotting log (dark current) as a function of inverse temperature results in an Arrhenius plot as shown in Figure 11. The dark current drops exponentially with inverse temperature from the upper end of the temperature range (about 55 K) to 33 K at which point it decreases at a slower rate, finally settling out at 0.01 electrons/second at 30 K.

Large InSb arrays are quite robust in terms of thermal cycling. Both 1K × 1K and 2K × 2K arrays have been subjected to high cooldown/warmup rates (>> 10 K/minute) without damage. Smaller InSb SCAs have been subjected to over 2,000 thermal cycles without degradation and, because of the InSb material is a thin film on the SCA, a similar level of reliability is expected for 2K × 2K SCAs.

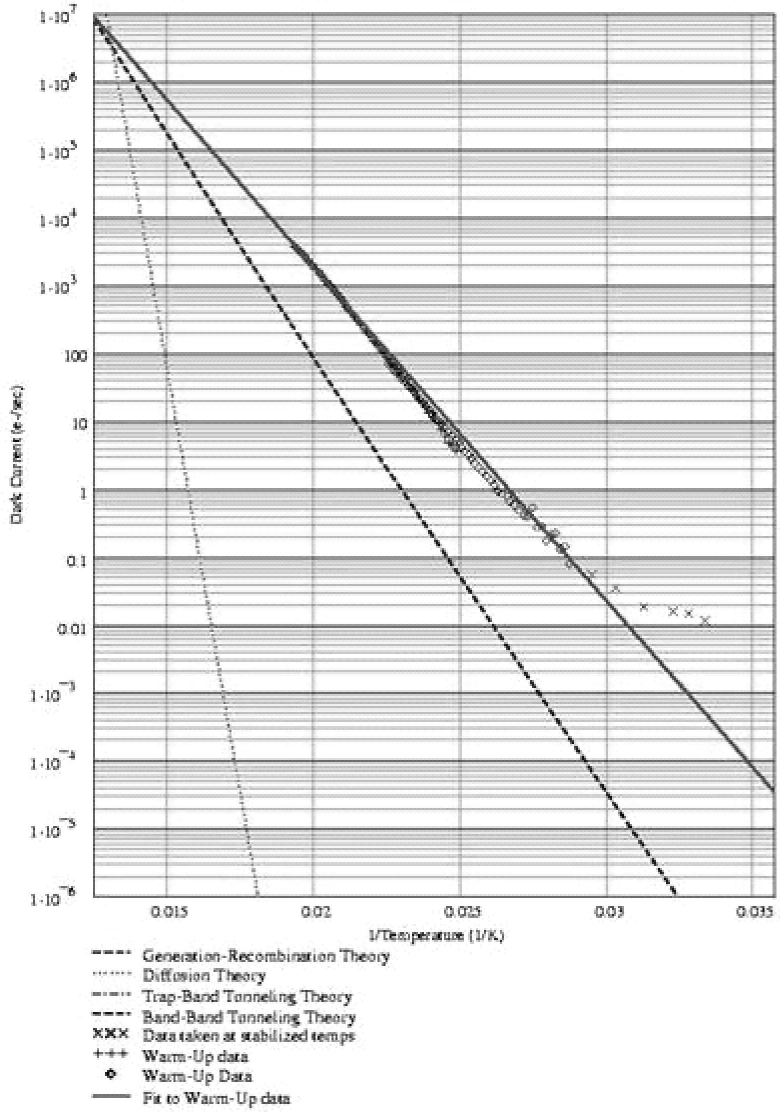


Fig. 11. Arrhenius plot of dark current as a function of inverse temperature for a 2K × 2K InSb array obtained by the University of Rochester.[1] The measured dark current follows a straight line on this semi-log plot down to 33 K and then flattens out to 0.01 electrons/second at 30 K. Data were obtained both during warming up and cooling down the detectors.

## 4. SUMMARY AND CONCLUSIONS

InSb, which is the highest performing detector material in the 0.6 to 5.2 µm range, is now available in array formats up to 2K × 2K. The high performance is due to the maturity of the technology and high-rate, continuous production of InSb arrays. Array formats of 3K × 3K and even 4K × 4K are possible with the larger InSb substrates currently available.

## 5. ACKNOWLEDGEMENTS

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