Large Format, Far-IR Photodetector Arrays for SOFIA

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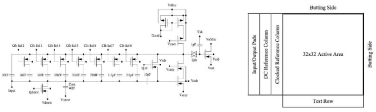
Germanium photoconductors offer excellent sensitivity in the 50-140μm spectral range. Coupled with their modest cooling requirements and their compatibility with the silicon cryo-CMOS readout technology, these detectors are the most attractive candidates for far IR astronomy in this wavelength range. Over the years we have been pursuing the advancement of this technology and our initial effort has produced a 2x16 Ge:Sb array with an NEP in the low 10^{-18} W/√ Hz range, rivaling the best far IR arrays currently available. Further work has resulted in design and fabrication of a low noise, 2-side buttable 32x32 (64x64 mosaic) CTIA readout, the first 1k-pixel Ge:Sb fully assembled focal-plane array, a new hybrid design better suited for far IR photoconductors, and the preliminary design of a 2-side buttable 64x64 (128x128 mosaic) CTIA readout. These arrays are well suited for future SOFIA instruments and with further improvements we expect to achieve sensitivity levels below 10^{-18} W/√ Hz.

SB349, CTIA READOUT MULTIPLEXER

• Key Parameters
- Format: 32x32, 2-side buttable (64x64 mosaic)
- Physical size: ≈ 28.5x28.0x0.5 mm³
- Pitch: 750μm
- Process: Custom, 2-μm cryo-CMOS
- Operating Temperature: at least as low as 1.7K
- Unit-cell design: CTIA
- Input coupling: AC (auto zero)
- No. of outputs: 8 interleaved signals + 1 reference
- Output mode: Diff., 1 ref. output & 1 clocked ref.
- Gain settings: 8 selectable
- Well capacity: ≈ 0.07x10⁶ – 25.5x10⁶ electrons
- Addressing: Nondestructive Gray code
- Reset: Row reset for unit cell & detector
- Sample & hold: Optional
- Power dissipation: < 1.0 μW per pixel, nominal
- Dynamic range: ≈ +0.6V, –0.4V
- Read noise: ≈ 250e⁻ for 106fF, 400ke⁻ well capacity

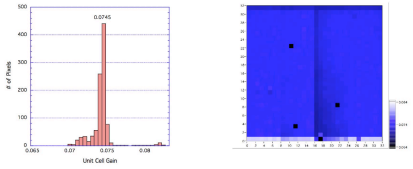


Left: Schematic of SB349 unit-cell. Right: SB340 floor plan.

• Gain Uniformity
- Except for two highest gain settings (Cfb0 and Cfb1) which have large DC offsets, readout works as designed down to at least 1.7K.
- Typical uniformity across the array is better than 97%.
- Variation from readout-to-readout is about 8%.
- Measured feedback capacitors closely match the design values.

	Cfb7	Cfb6	Cfb5	Cfb4	Cfb3	Cfb2	Cfb1	Cfb0
Unit Cell Gain	0.00654	0.0143	0.0326	0.0741	0.162	0.349	N/M	N/M
Cfb (fF), calculated	6006	2745	1206	530	242	112	N/M	N/M
Cfb (fF), design	6811	2971	1291	564	246	106	46	20

Measured unit-cell gains and capacitances for the six largest feedback capacitors. Except for the largest Cfb, the measured values closely match the design values.

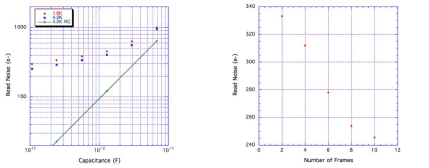


Unit-cell gain histogram and intensity plot for readout W1C1, 4.2K, Cfb4. The pixels near and over 0.08 are from row 1. The uniformity across the array is 97.9%

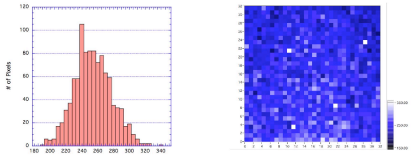
• Read Noise
- Measured as the STD of 100 successive integrations with 8 samples during a 0.5 second integration time.
- Highly uniform across the array.
- ≈250 electrons for the feedback capacitor Cfb2 (106fF, nominal) with 8 samples per 0.5sec integration time.
- Lower noise can be attained with more samples per integration.
- Very high SNR at full well even for the smallest well capacity.

	Cfb7	Cfb6	Cfb5	Cfb4	Cfb3	Cfb2	Cfb1	Cfb0
Read noise (e⁻)	952	560	406	338	292	254	N/M	N/M
Cfb (fF), measured	6006	2745	1206	530	242	112	N/M	N/M
Well capacity (e⁻)	2.25E+7	1.03E+7	4.52E+6	1.99E+6	9.06E+5	4.19E+5	–	–
S/N	23634	18393	11133	5888	3103	1650	–	–

Read noise at 4.2K for the six largest feedback capacitors (Cfb2-Cfb7) of the readout W1C1 with 8 samples per 0.5sec integration. The well capacities are for +0.6V dynamic range. S/N is the signal to noise ratio at full well.



Read noise, readout W1C1, 0.5sec integration time. Left: for the six largest feedback capacitors (Cfb2-Cfb7) at 4.2K and 1.8K, 8 samples per integration; the solid line is the baseline noise with the resets closed. Right: vs. number of frames for Cfb2 at 4.2K.



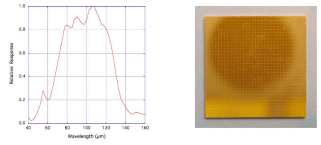
Read noise histogram and intensity plots: readout W1C1, Cfb2, 4.2K, 8 samples per 0.5sec integration.

GERMANIUM DETECTOR

• Material and Processing
- Ge:Sb (boule 831-7.2) grown at Lawrence Berkeley National Laboratory.
- First two arrays were pixelized with 90μm-deep grooves.
- Later arrays were pixelized during the ion-implantation of electrical contacts and subsequent metallization.
- Low dark current and very good quantum efficiency.

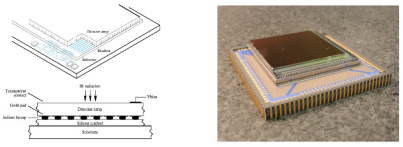
Material: Ge:Sb, LBNL 831-7.2	Format: 32x32
Spectral range: ≈50-140 μm	Pixel size: 0.7x0.7x1 mm³
Dark current*: 0.67 fA (4200 e⁻/sec)	Pixel pitch: 0.75 mm
Responsivity*: 32 A/W	Pixel grooves: 90 μm deep
Gn*: 0.37	Illumination: Longitudinal through ITO contact
Detective QE*: 0.41	

*Above: Ge:Sb characteristics. *Past performance at 2.6K, 300mV, 107.5μm.*
Right: Typical spectral response of Ge:Sb and 32x32 Ge:Sb array on the pixelized side.

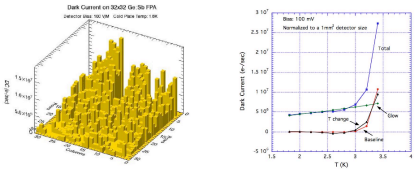


INTEGRATED FOCAL-PLANE ARRAY

• Standard-Hybrid Architecture
- Detector and readout are bump bonded face-to-face in intimate contact.
- Successfully assembled a 32x32 FPA using this architecture.
- FPA responded to IR radiation.
- Tests showed minor fluctuations in detector temperature when readout was clocked but more seriously:
- readout glow generated excess dark current which would degrade detector performance.
- To eliminate readout glow, layered-hybrid architecture was developed.

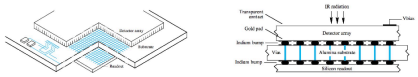


Standard-hybrid Ge:Sb FPA. Left: conceptual diagram. Right: fully packaged in a 124-pin leadless chip carrier.

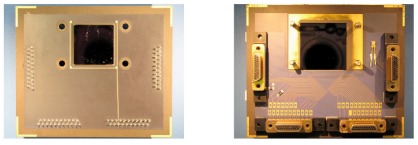


Dark current of standard-hybrid Ge:Sb FPA. Left: the gradient across the array showing higher dark current in the back where the readout power lines are located. Right: contributions of different mechanisms. The excess dark current generated by readout glow makes this architecture unsuitable for far IR photodetectors.

• Layered-Hybrid Architecture
- Detector and readout are not in intimate contact but separated by an intervening substrate.
- Substrate is designed to block the readout glow, provide a more efficient and uniform cooling mechanism, and mitigate the effect of thermal mismatch between the detector and the readout.
- Successfully assembled a 32x32 FPA using this architecture.
- FPA survived at least a dozen cool-down cycles.
- Full test will be performed in the near future.



Conceptual diagram of the layered-hybrid FPA. A substrate is placed between the detector and readout to block readout glow, provide uniform cooling across the array, and reduce mechanical stress caused by thermal mismatch between the detector and readout.



Fully assembled layered-hybrid Ge:Sb FPA. Left: detector side. Right: readout side.

SUMMARY

• Readout
- SB349, 32x32 CTIA unit-cell, operable down to at least 1.7K.
- Buttable on two side to form a 64x64 array.
- Especially designed for photodetectors such as germanium.
- Selectable well capacity to match different background levels.
- High uniformity: > 97%.
- Low power dissipation: < 1μW per pixel.
- Low read noise: ≈ 250e⁻ for 106fF, 400ke⁻ well capacity.

• Detector
- Ge:Sb (50-140μm) or Ge:Ga (50-120μm).
- Low dark current.
- QE ≈37% for 1mm-thick detector, higher for thicker detectors.

• Integrated Focal-Plane Array
- Layered-hybrid structure more suitable for far IR photodetectors.
- Intervening substrate between the detector and readout is designed to block readout glow, provide uniform cooling, and reduce mechanical stress caused by thermal mismatch between the detector and readout.
- 1st Ge:Sb FPA is fully assembled and survived several thermal cycles.
- 2nd FPA, with modifications and improvements is being assembled. Full test of the FPA will follow.

• Expected Performance
- Operating temperature ≈2.5K
- NEP (noise equivalent power) is readout noise limited.
- Nominal NEP in the low 10^{-18} W/√ Hz.
- NEP <10^{-18} W/√ Hz is achievable with further readout optimization and/or thicker detector.

• Future Plans
- Complete characterization of the layered-hybrid FPA.
- Development of a 64x64 FPA.
- Development of germanium BIB.