Germanium Detectors

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18 July 2022

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This material is based upon work supported by the National Aeronautics and Space Administration under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Aeronautics and Space Administration .

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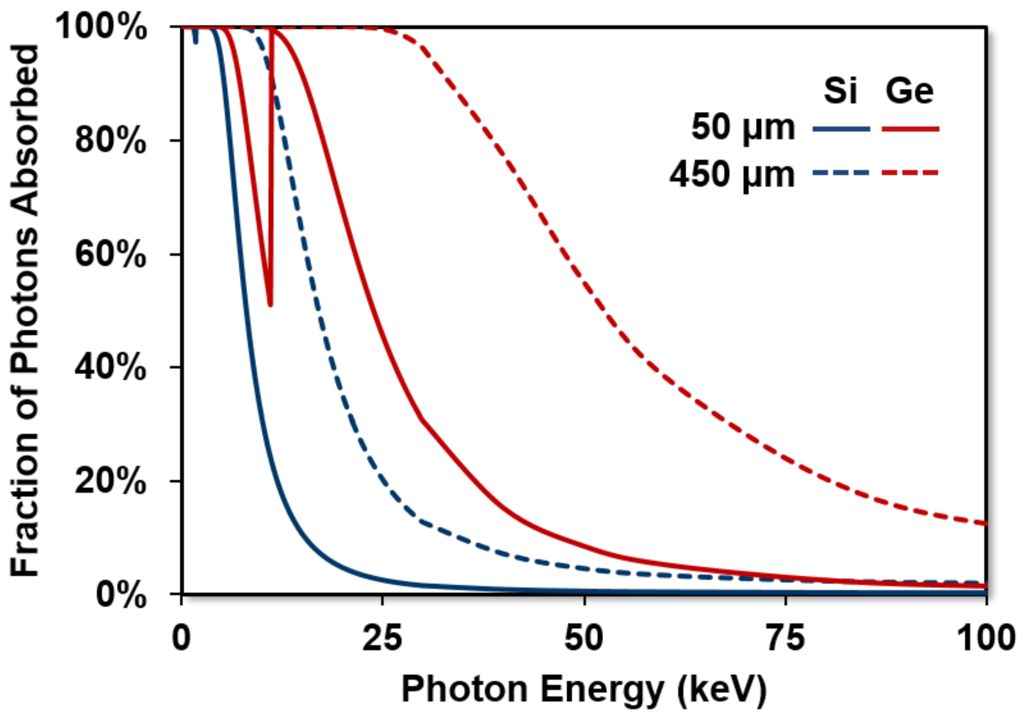
Acknowledgements:

We gratefully acknowledge support for this work from NASA's Astrophysics Division to MIT Lincoln Laboratory through Astrophysics Research and Analysis grant 80HQTR19T0048.

Germanium Detectors Opportunity

X-Ray Sensitivity Comparison



MITLL Microelectronics Laboratory

- Elemental high-Z detector material with broadband sensitivity

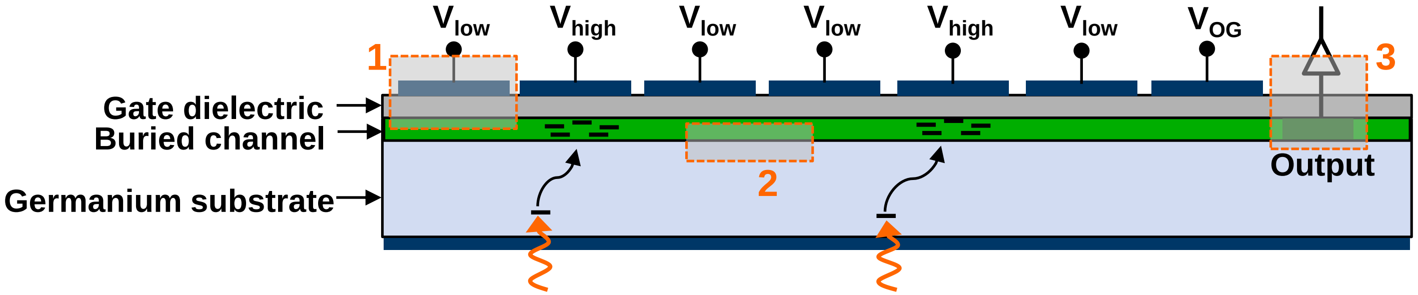
- Germanium wafers processed in same tools used to build silicon detectors for flight missions

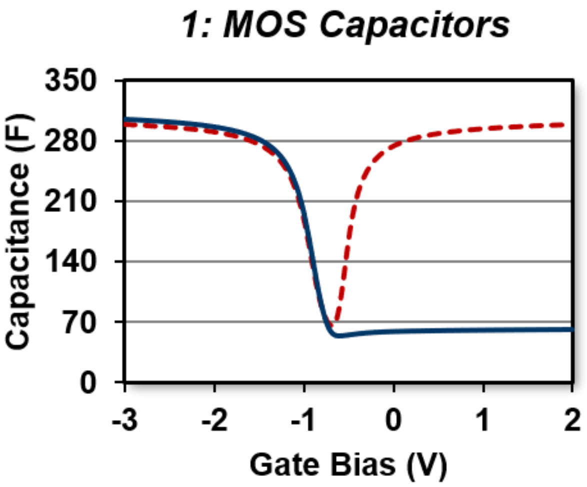
Vision: extend the advantages of CCDs (format, noise…) into new material

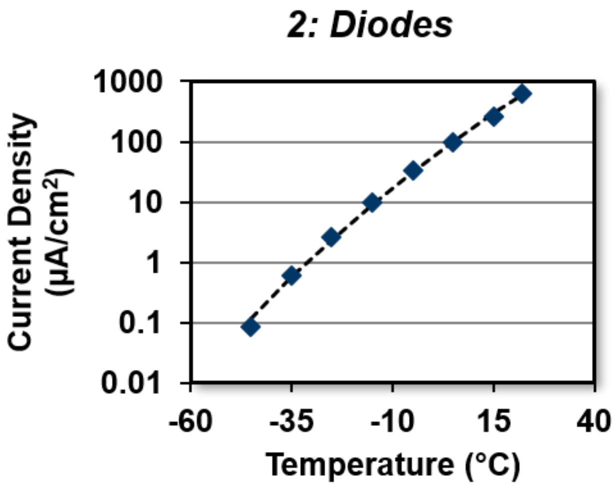
Path to a Germanium CCD

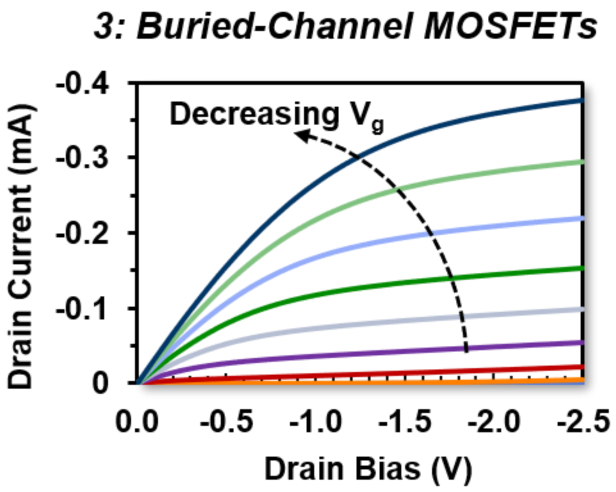
Discrete devices provide insights into CCD performance

CCD Viewed Along Charge-Transfer Direction





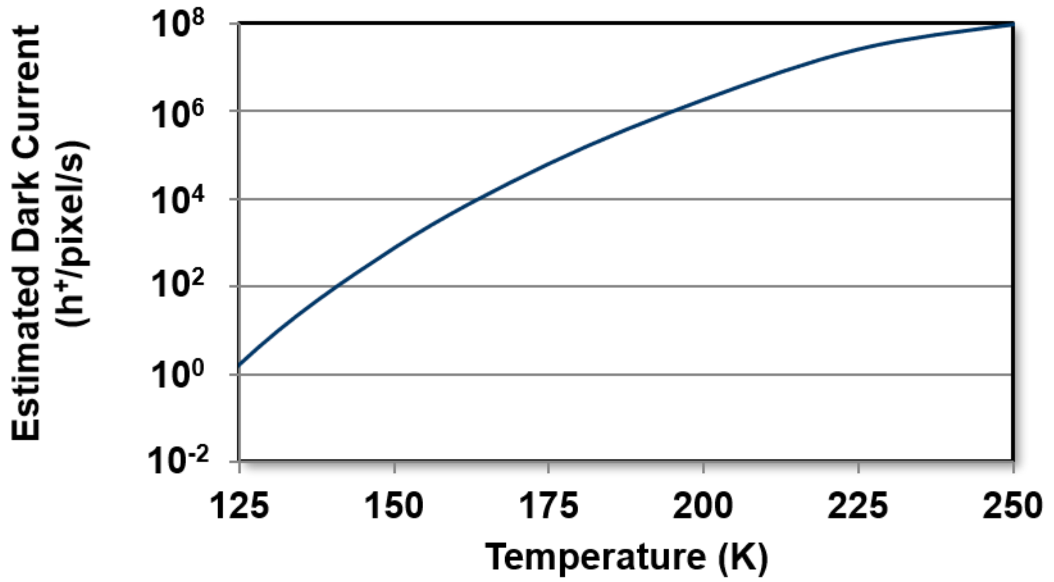




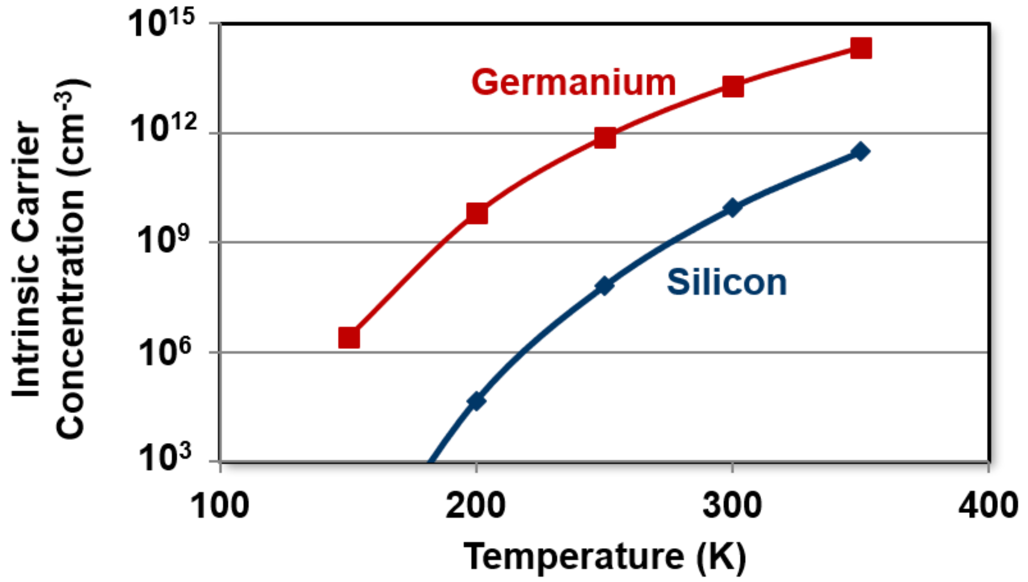
Estimating Dark Current in a Germanium CCD

Measurements on discrete devices used to estimate dark current

Calculated Dark Current (24 µm pixel)



Intrinsic Carrier Concentration Comparison



High material quality enables conservative dark current target of ~ 1h^{+}/pixel/s at 125 K

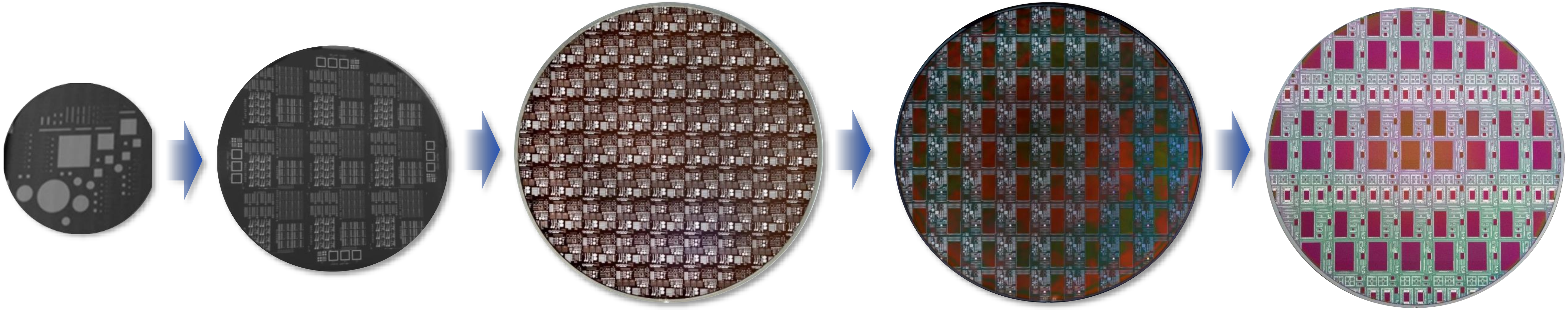
Germanium CCD Development at MIT Lincoln Laboratory

2013 | **2015** | **2017** | **2020+**

Test Devices

1st-Generation Imagers

2nd-Generation Imagers

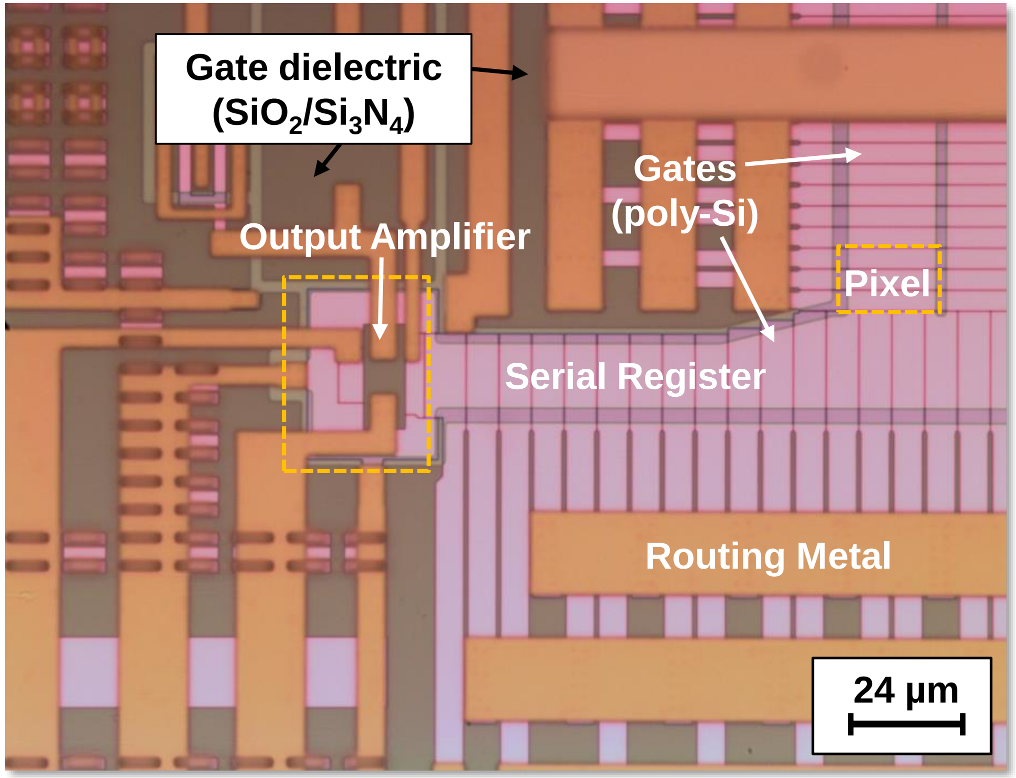


8 process steps	*75 process steps*	*180 process steps*	*280 process steps*	*> 300 process steps*
100 µm features	*2 µm features*	*1 µm features*	*0.2 µm features*	*≤ 0.2 µm features*

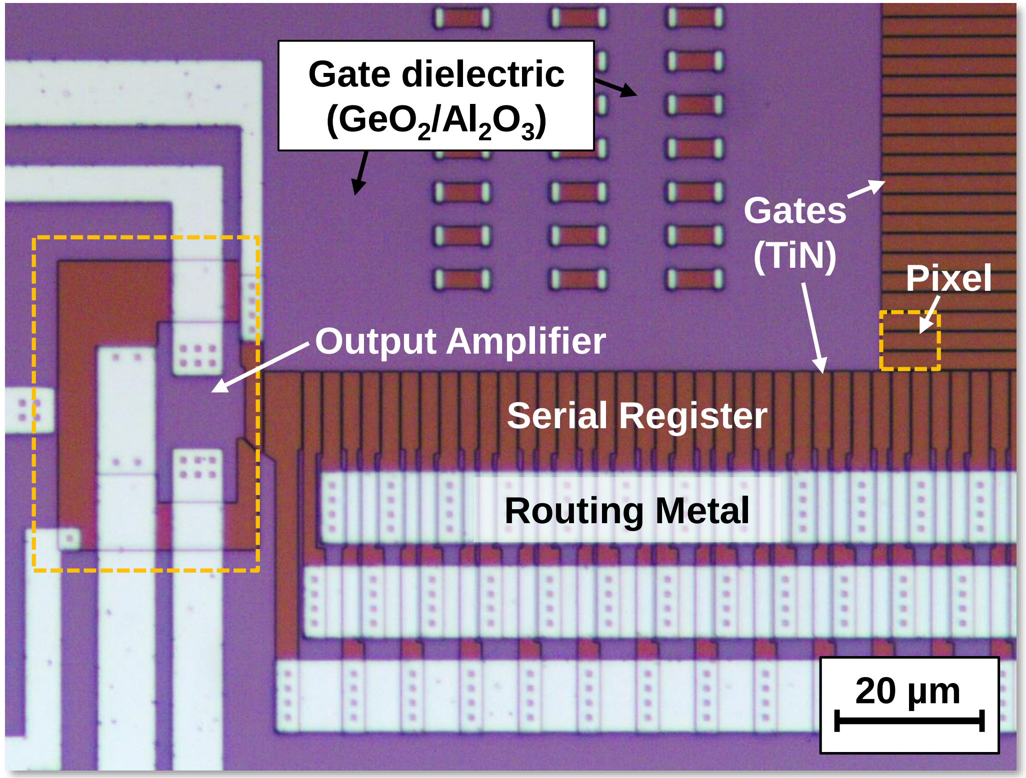
Silicon and Germanium CCD Comparison

Germanium CCDs draw upon long heritage of silicon CCD designs and processes

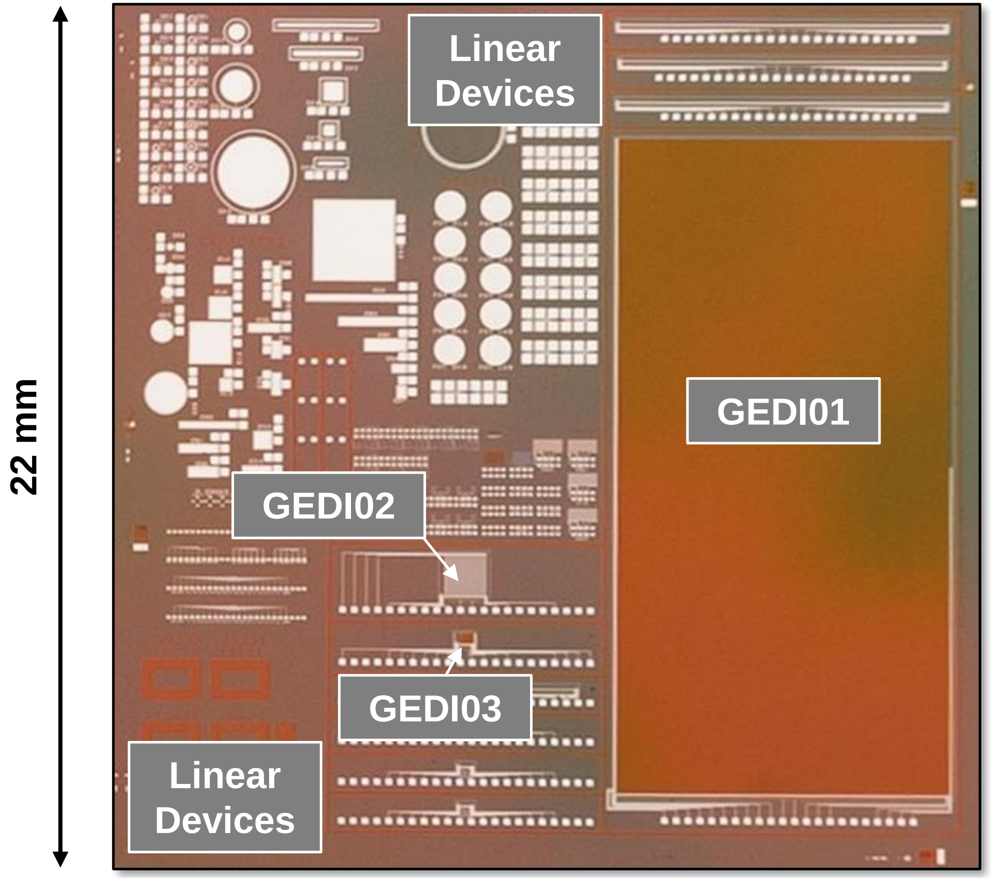
Silicon CCD



Germanium CCD



First-Generation Germanium CCDs

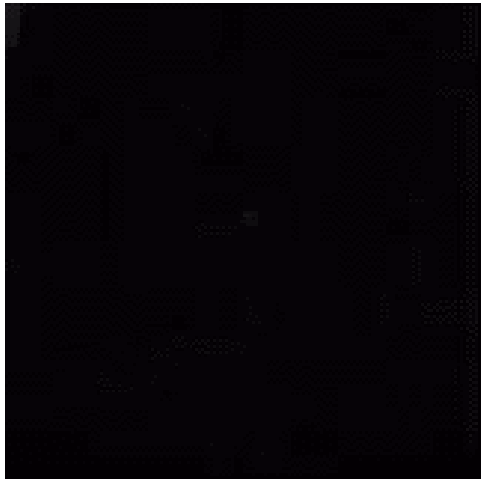


Device ID	Format	Device Type	Output
GEDI01	1024 × 2048, 8.1 µm pixels	Frame-transfer	Single-stage MOSFET
GEDI02	128 × 128, 8.0 µm pixels	Orthogonal transfer	
GEDI03	32 × 32, 8.1 µm pixels	Full-frame	
N/A	1 × 32 or 1 × 1024, 8.1 µm pixels	Linear	

Simple devices aimed at proof-of-concept rather than particular application

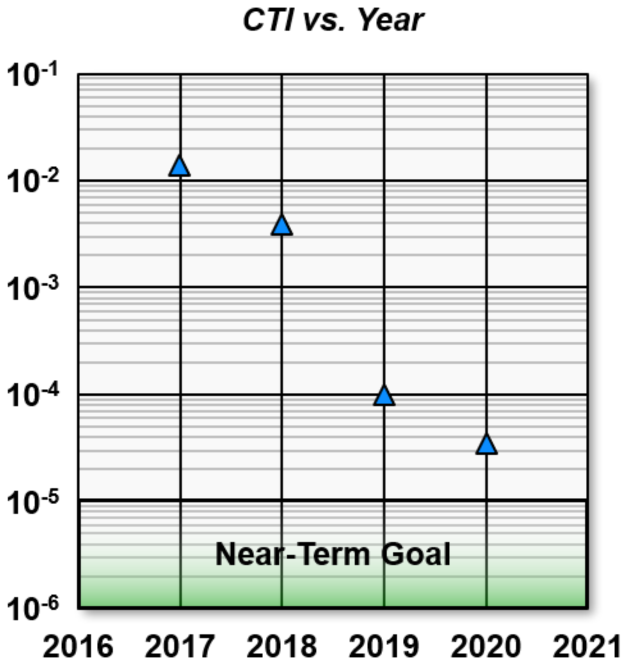
First-Generation Device Performance

Qualitative Imagery



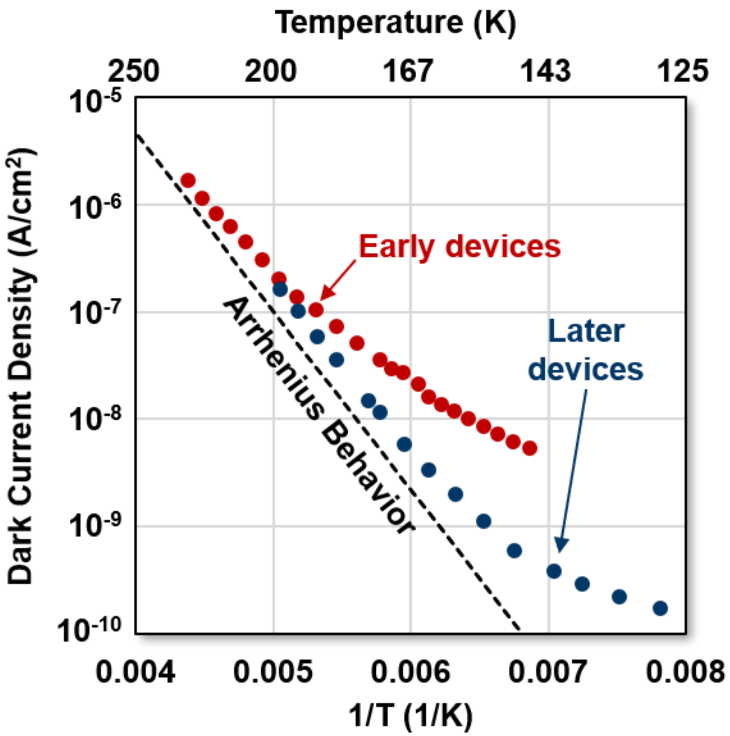
- Achieved good performance on small pixel arrays

Charge-Transfer Inefficiency (CTI)



- Steadily approaching values characteristic of scientific CCDs

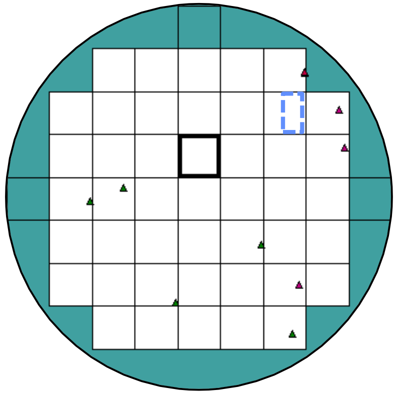
Dark Current



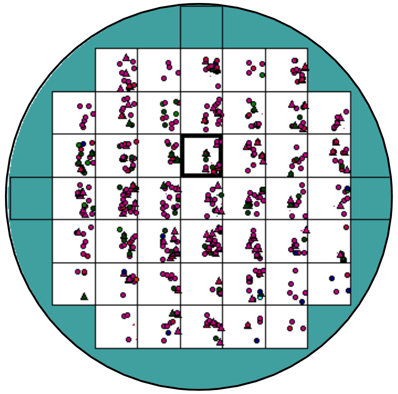
- Improving dark current with design & process modifications

Effect of Particles on Yield (1 Mpixel CCD)

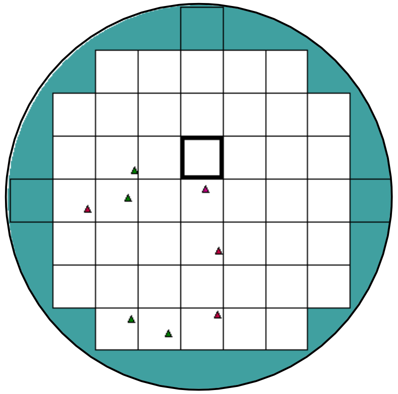
Defect Maps after Metal-1 Patterning



Metal-1 on SiO_2



Metal-1 on Al_2O_3 (existing system)



Metal-1 on Al_2O_3 (new system)

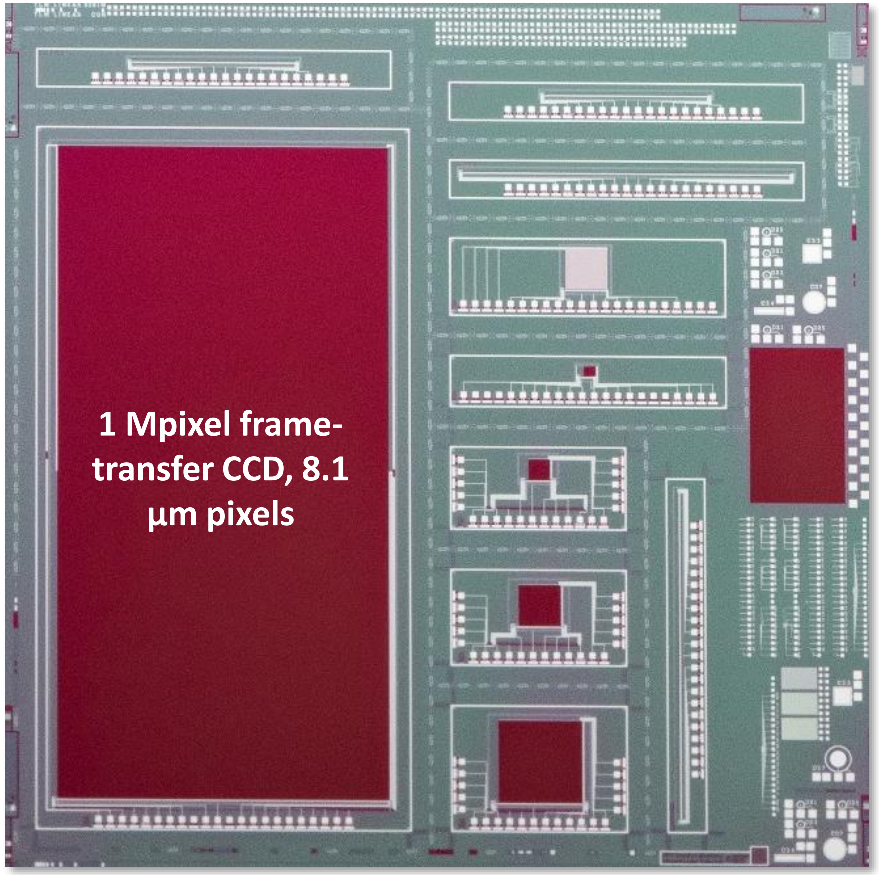
Shorts/Opens Evaluation on Metal Monitors

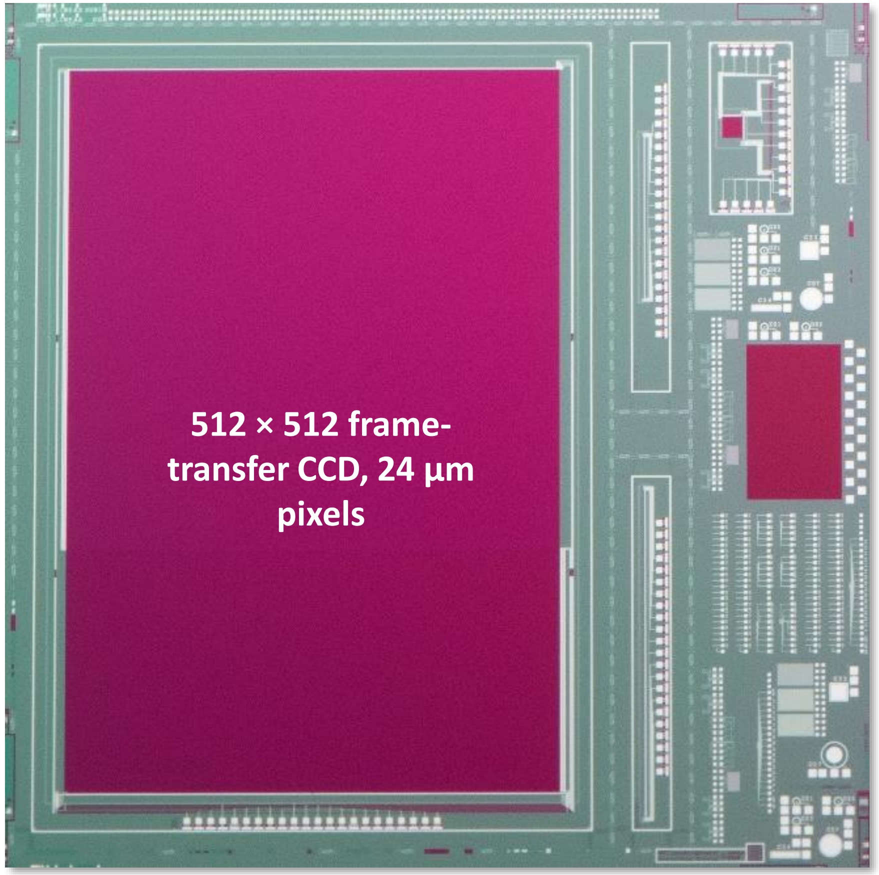
Process	Shorts/Opens Yield
Metal-1 on SiO_2	82%
Metal-1 on Al_2O_3 (existing deposition system)	0%
With Al_2O_3 (new deposition system)	81%

- **Particles from existing Al_2O_3 deposition system cause patterning defects which short phases of device**

New Al_2O_3 deposition system will improve yield, enable large-format germanium CCDs

Second-Generation Devices

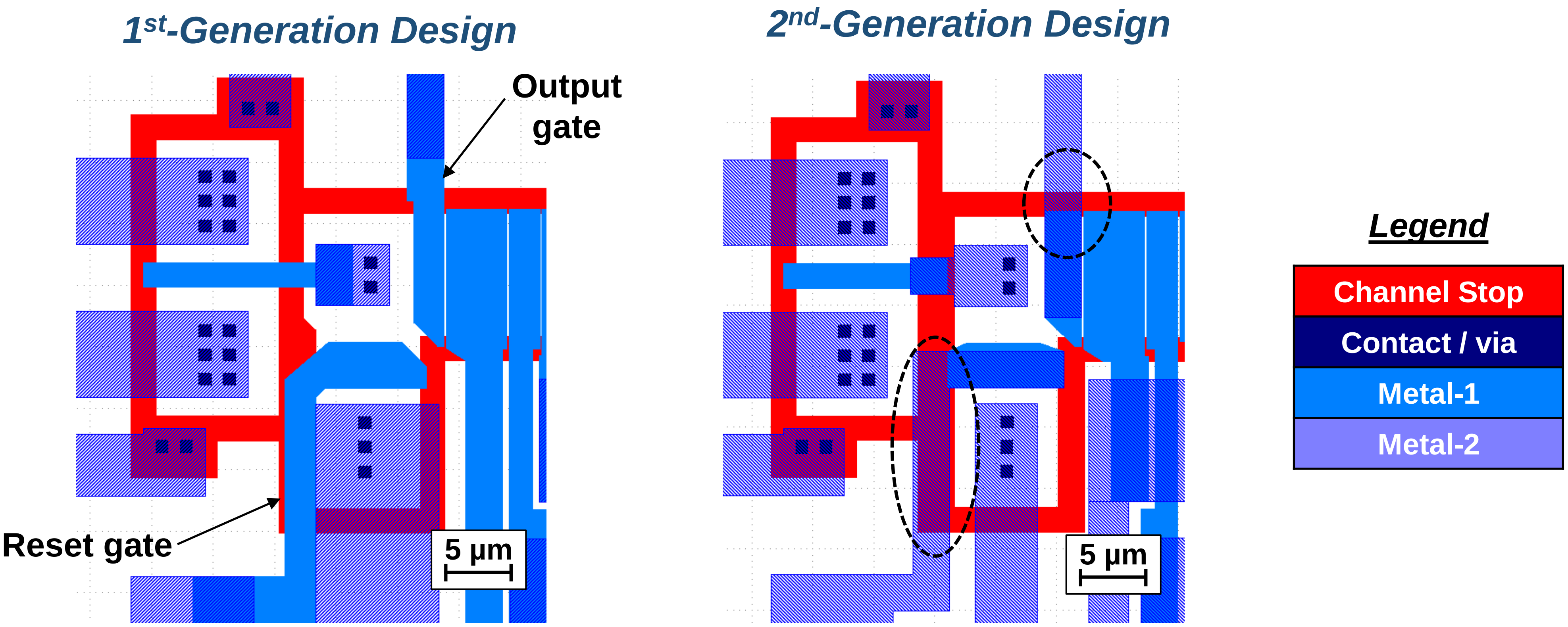




- **New 512 × 512 frame-transfer device with two MOSFET outputs**
- **Additional small arrays with one MOSFET, one JFET output**
- **Key yield diagnostic testable at metal-1**

Fabrication run with new designs has begun, utilizing new Al_2O_3 deposition system

Elimination of Parasitic MOSFET in Output Region



Rerouted metal-1 features to eliminate parasitic transistors caused by inversion of channel stop regions

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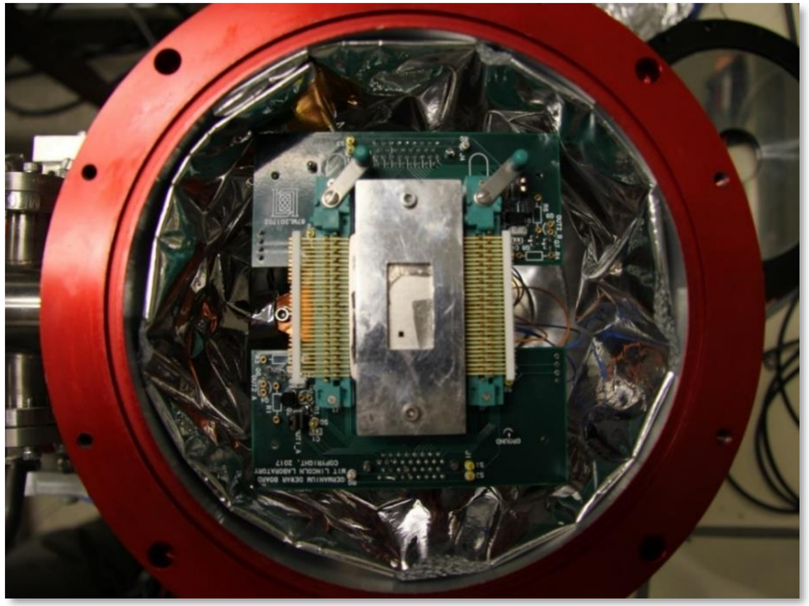
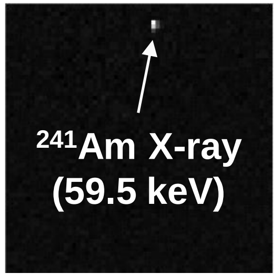
Backside Processing

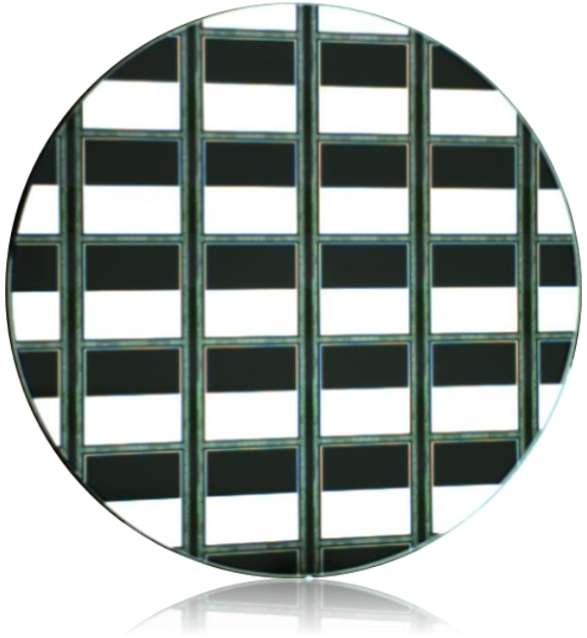
Chip-Level Back Illumination
Current Ge CCD





- Fast (as short as a few weeks)
- Likely requires > ~50 µm-thick chips to facilitate handling
- Requires optimization to minimize dark current

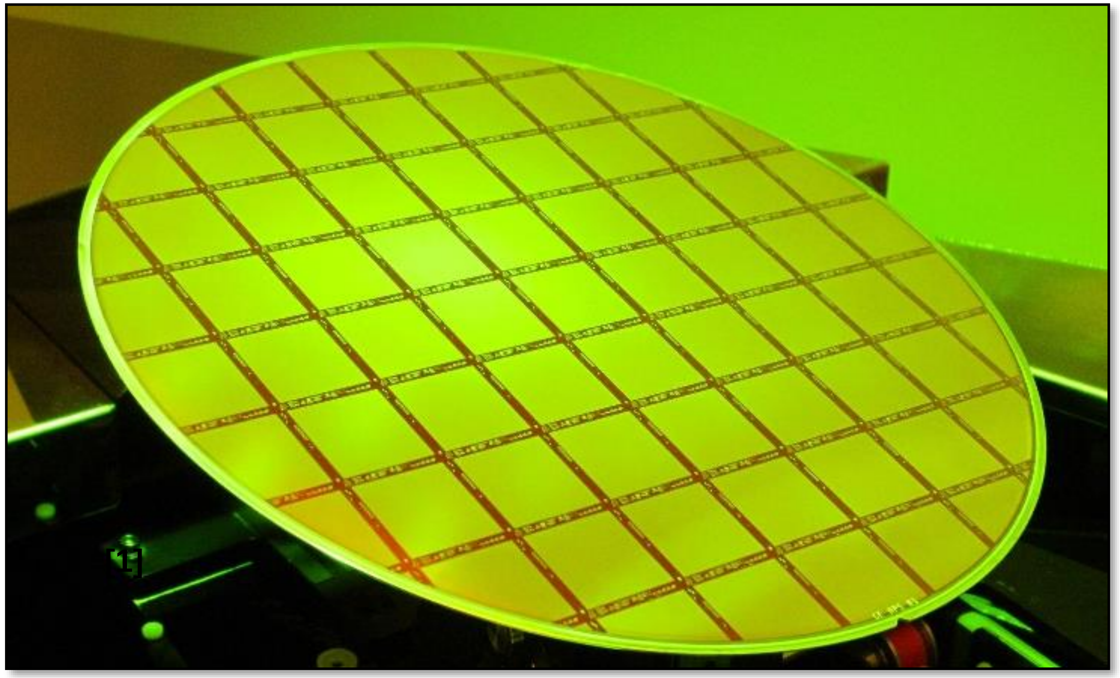
Wafer-Scale Back Illumination
Current Si CCD, Future Ge CCD



- Flight heritage, highest performance, most flexibility
- Process development required for Ge
- Forecloses option of packaging subset at front illumination

NASA-funded work beginning to develop wafer-scale back-illuminated germanium CCDs

Germanium Active-Pixel Sensors



Collaboration with Prof. Sol Gruner (Cornell)

- **Developing active-pixel sensors with germanium absorbers, hybridizing diode arrays to Si ASICs developed at Cornell**
  - **Higher frame rates, increased radiation hardness over CCDs**
  - **100% fill-factor**

M.W. Tate, et al., *Microscopy and Microanalysis* **22** (2016) 237.

Summary

- We have realized germanium CCDs with steadily improving performance and format
- Our current efforts are focused on improving performance and yield
  - Elimination of parasitic MOSFET in output region to reduce dark current
  - Optimization of extrinsic gettering process to improve charge-transfer efficiency
  - New Al_2O_3 deposition system to increase yield
  - Back-illuminated detectors for high sensitivity
- Second-generation devices, reflecting lessons learned in design and processing of first-generation CCDs, are currently being fabricated
- The same fabrication processes developed for Ge CCDs can be used for hybrid active-pixel sensors