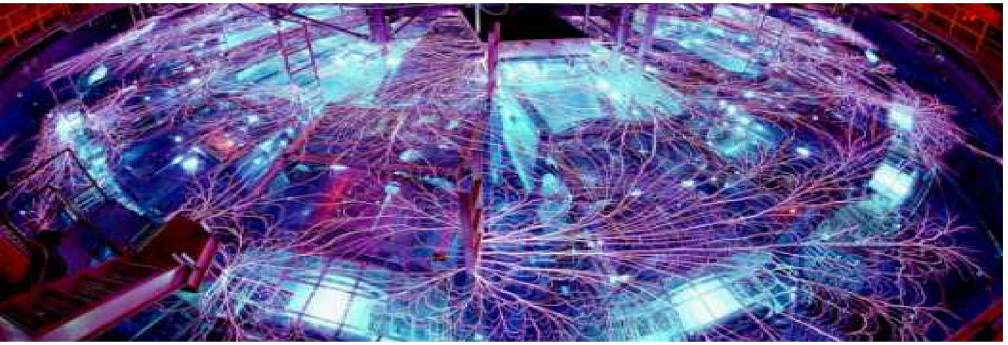
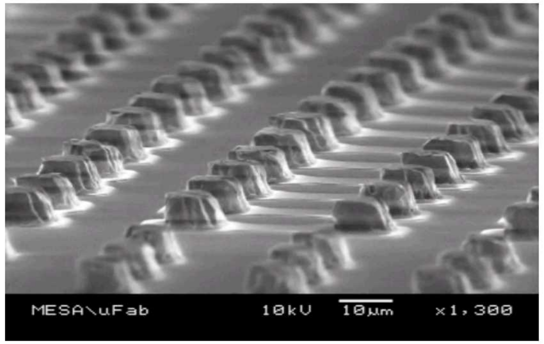
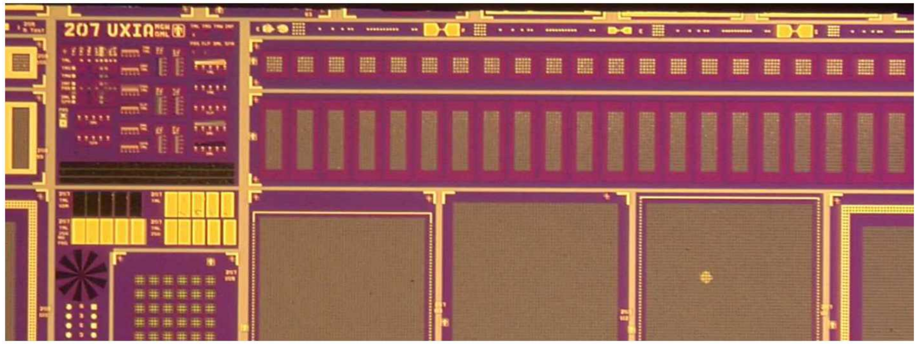
SAND2019-15254PE







Fast GaAs Detectors for Hard X-Ray Detection

Quinn Looker, Michael Wood

12/11/2019

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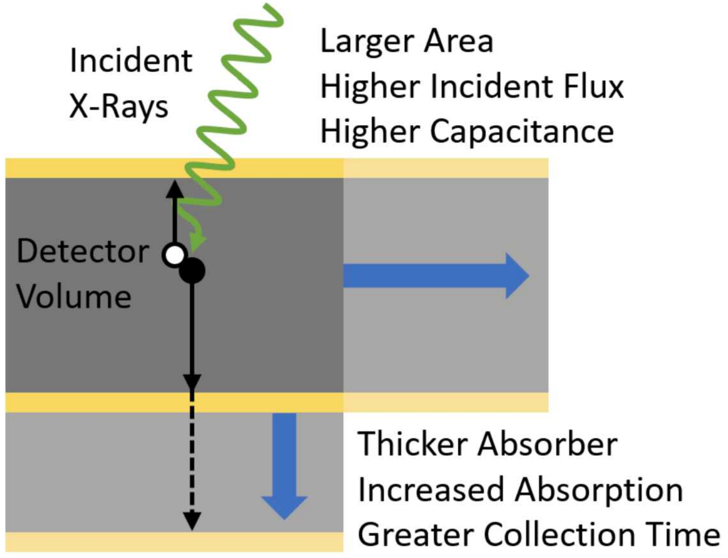
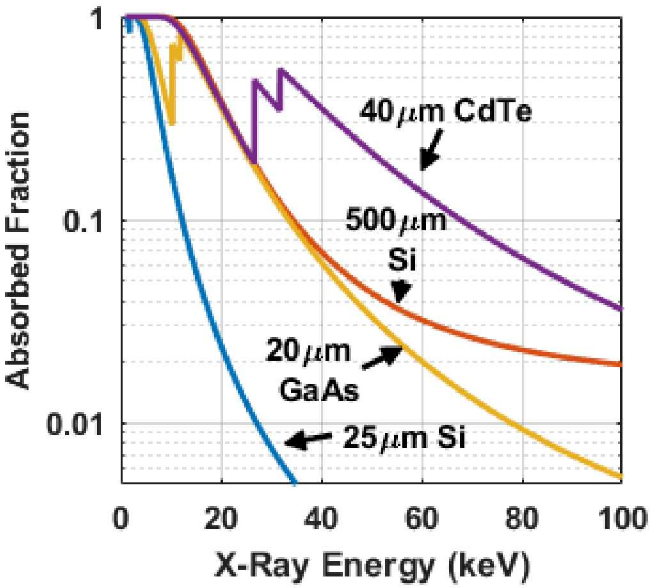
We Are Exploring High Atomic Number Semiconductors

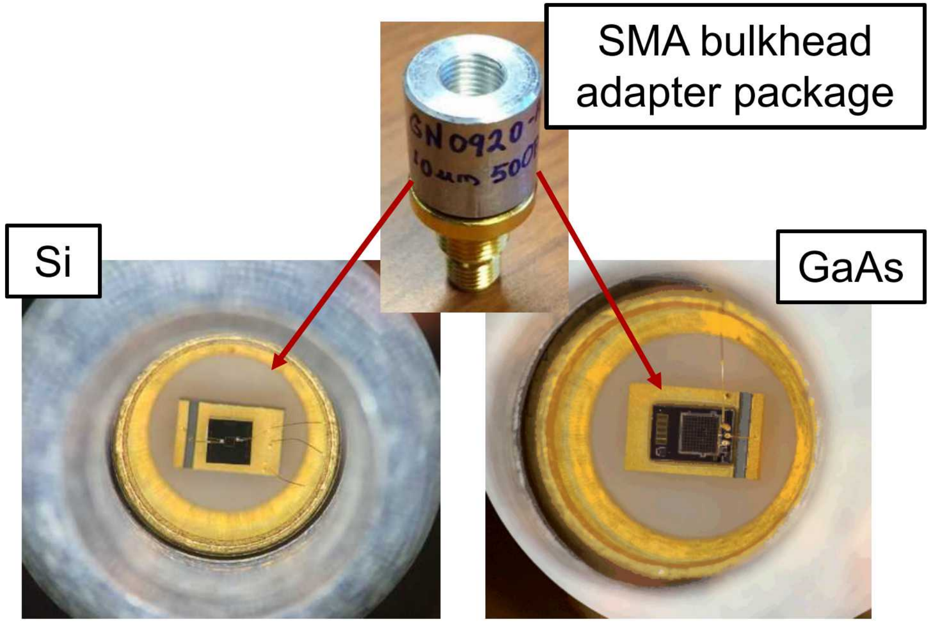
Detector efficiency and speed are in direct competition



Photoelectric absorption scales as ~Z^4



Single-element GaAs detectors developed to replace existing Si detectors



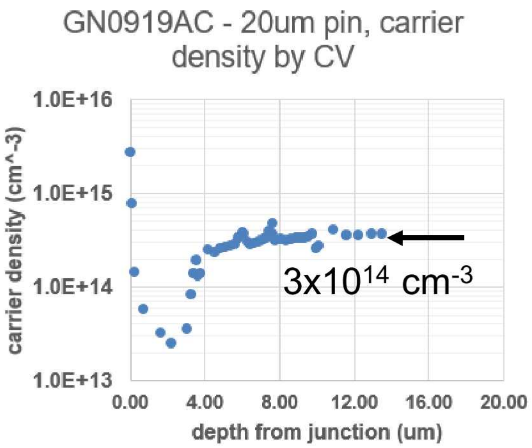
We Developed a GaAs Detector Fabrication Process

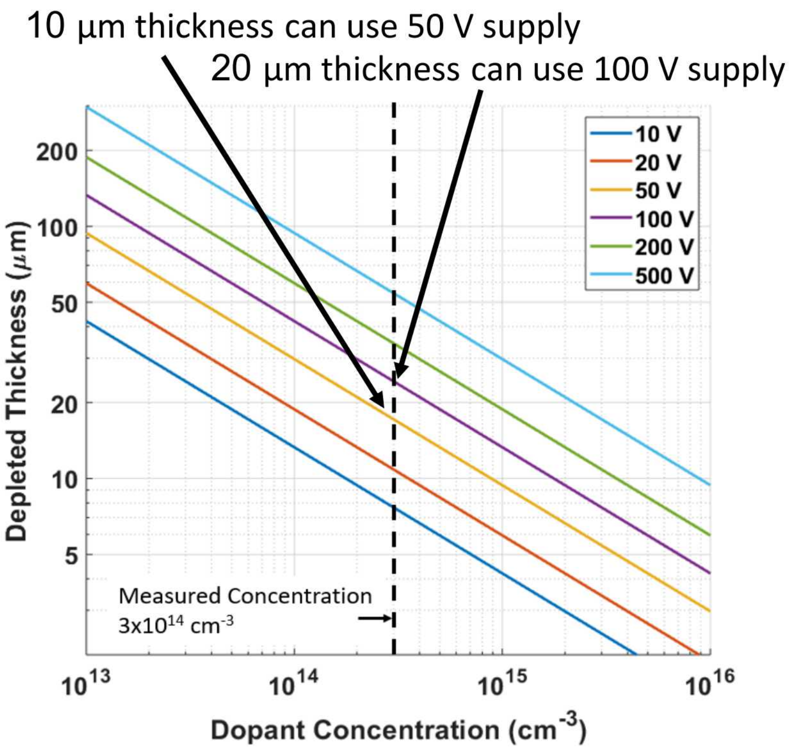
Developed material growth process for high-quality GaAs detector material 4-40 μm thick

$$x_d = \sqrt{\frac{2\varepsilon V}{qN_d}}$$

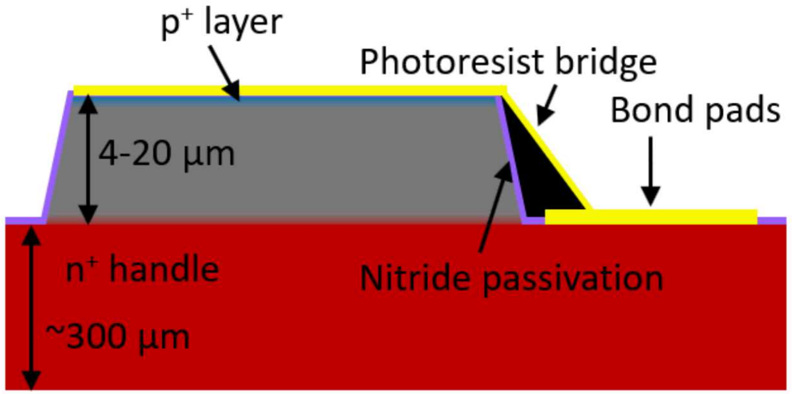
x_d: Depletion depth (cm)
ε: Dielectric constant (F/cm)
V: Applied bias (V)
q: electronic charge (C)
N_d: Dopant concentration (cm^{-3})

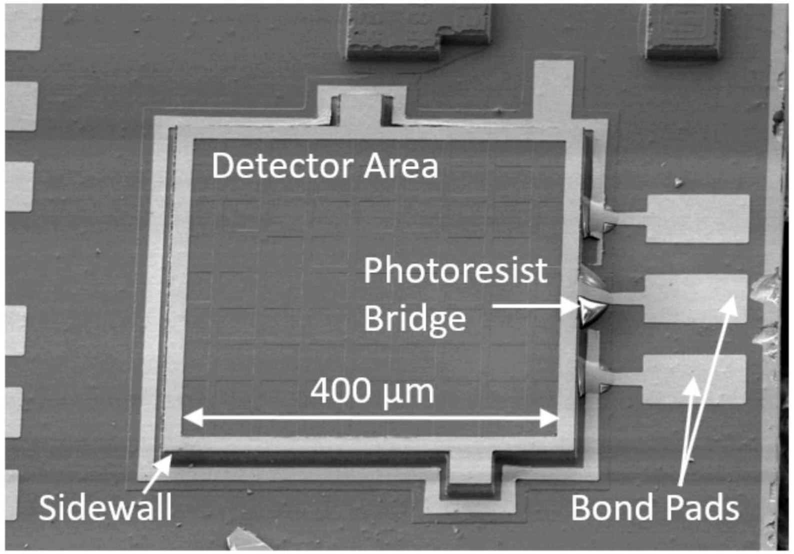
Sandia-grown GaAs epi





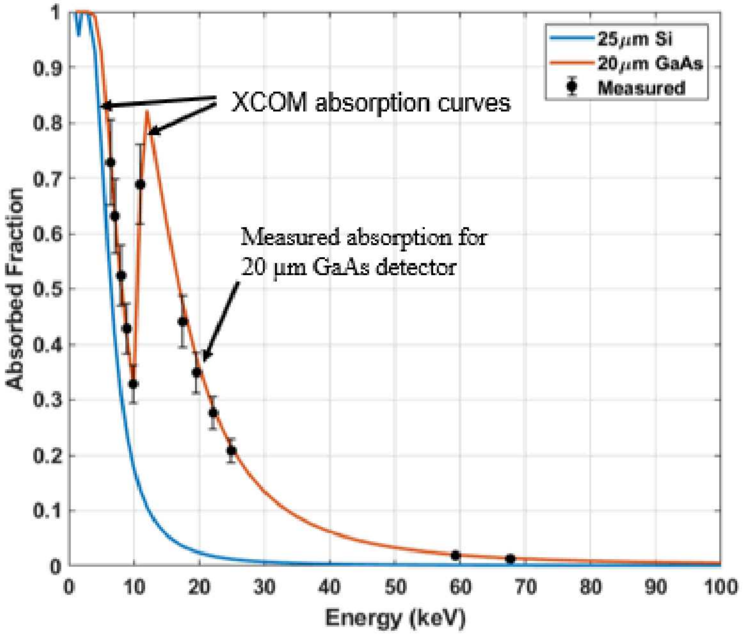
Developed single-element detector fabrication process



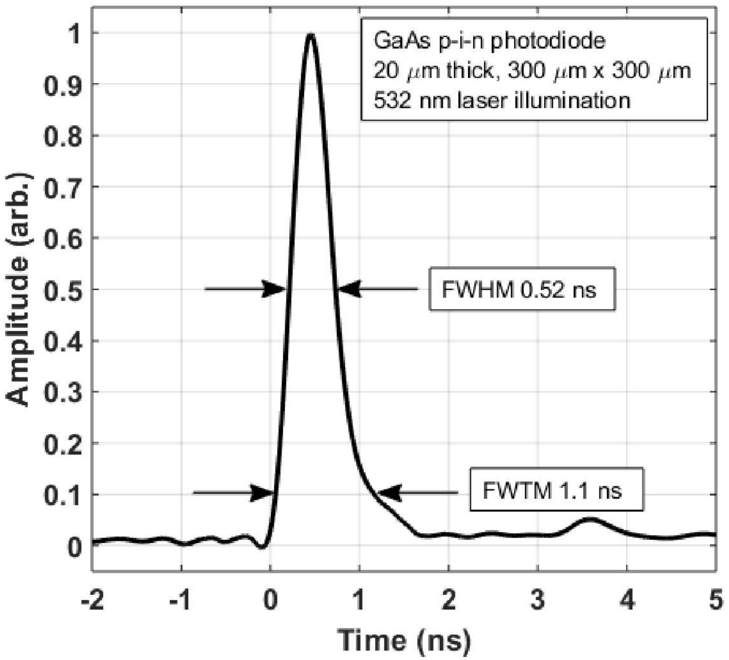


Demonstrated Enhanced Hard X-Ray Absorption and Fast Temporal Impulse Response

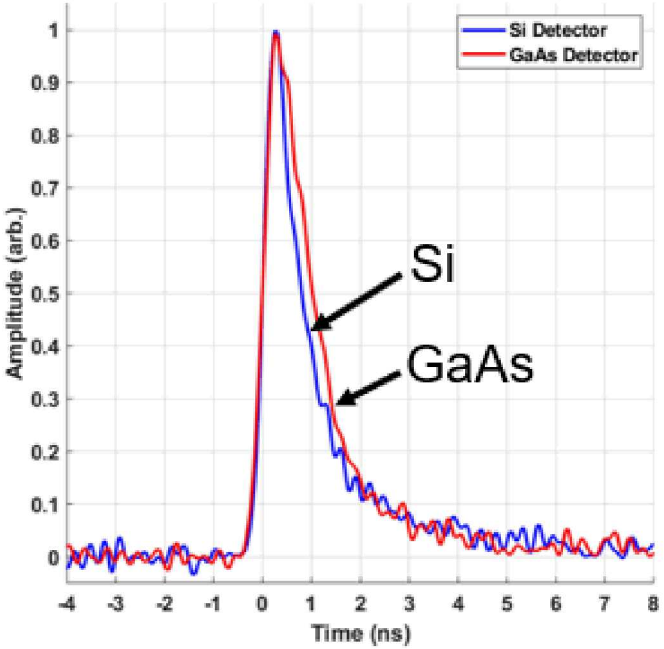
Steady-state x-ray sources



Pulsed laser (~100 ps)



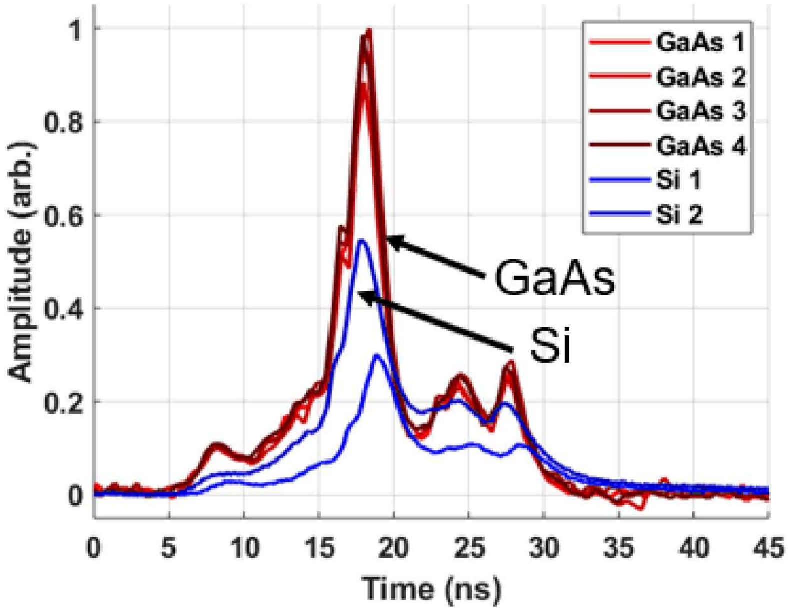
Pulsed x-ray (~1.35 keV, 1 ns)



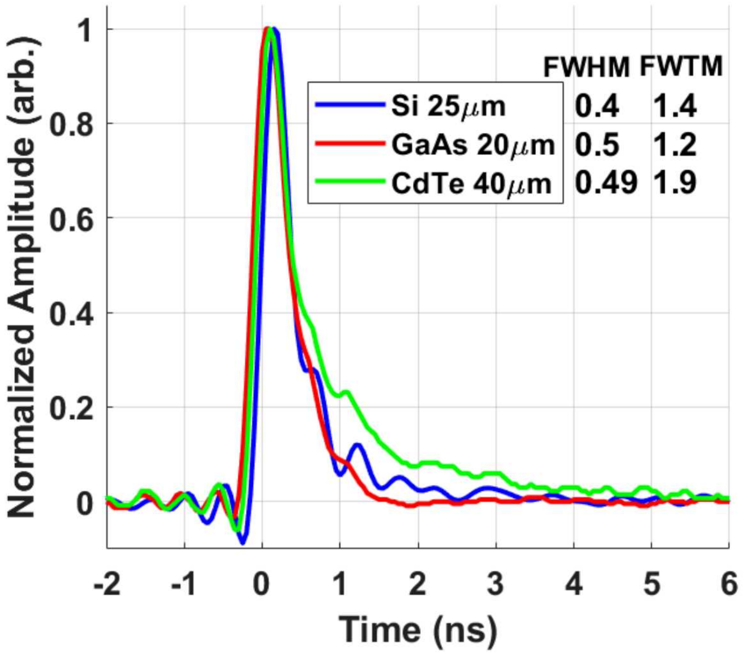
Q. Looker et al., *Rev. Sci. Instr.* vol. 90, p. 113505 (2019)

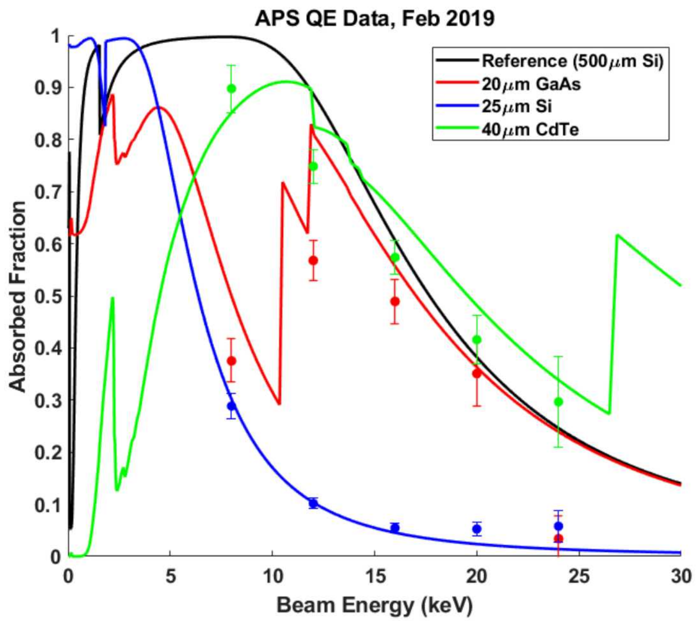
Demonstrated Improved Performance in Realistic Environments

Sandia Z Machine (hard x-rays)



Synchrotron white beam (~20-80 keV, 70 ps)

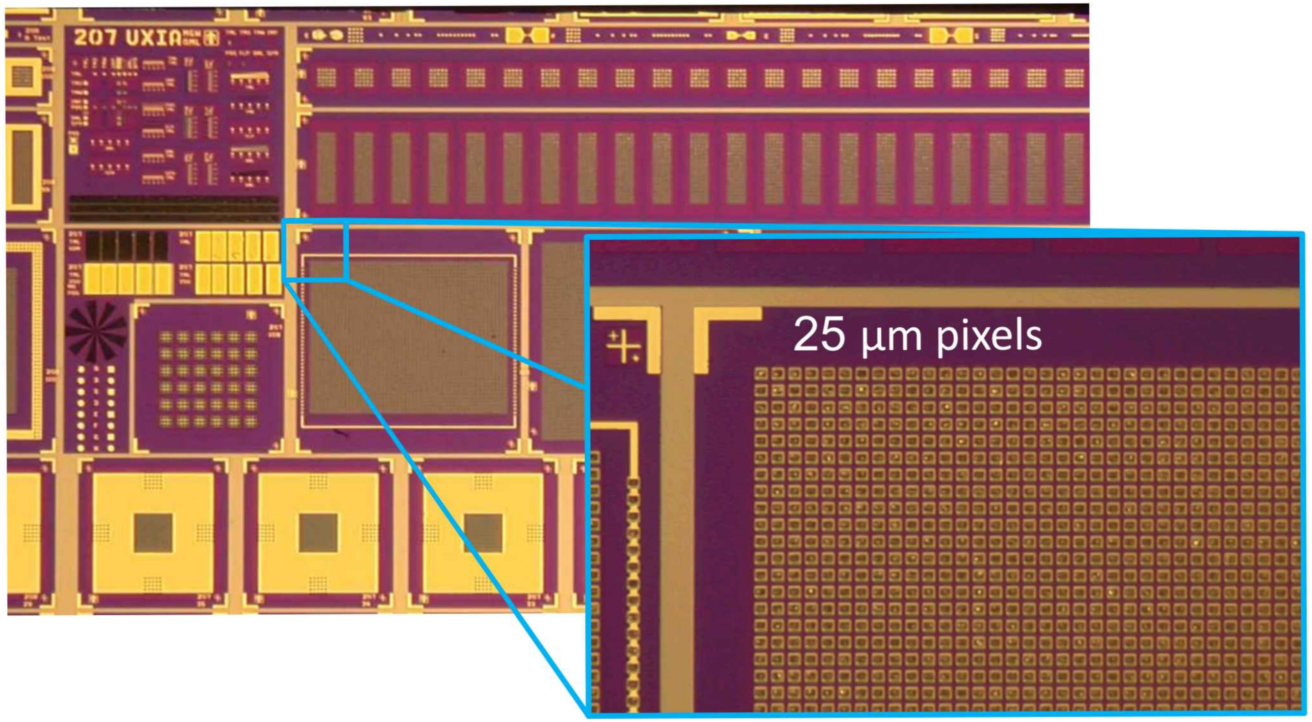


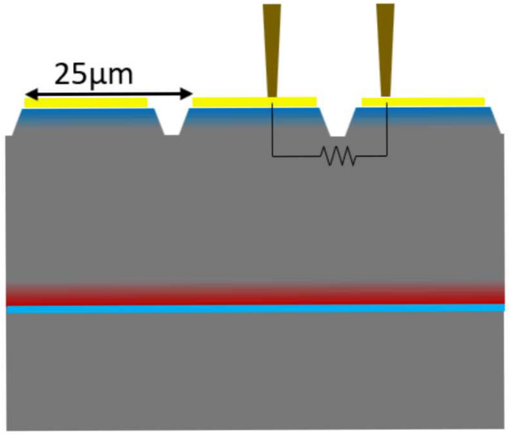


Q. Looker et al., submitted to RSI

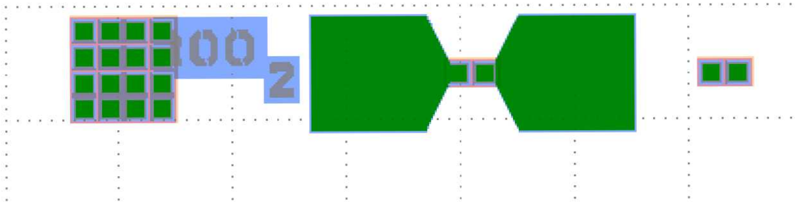
A Pixel Array Fabrication Process Is Now Ready

- Small pixel test arrays 3x3 to 36x36 pixels
- Rapid trial of 25 µm pixel design
- Test pixel isolation
- Hybridization process development
- Test results allow study of pixel temporal response and cross-talk
- Multiple 4 µm epi and 20 µm epi die processed





Pixel isolation test structures

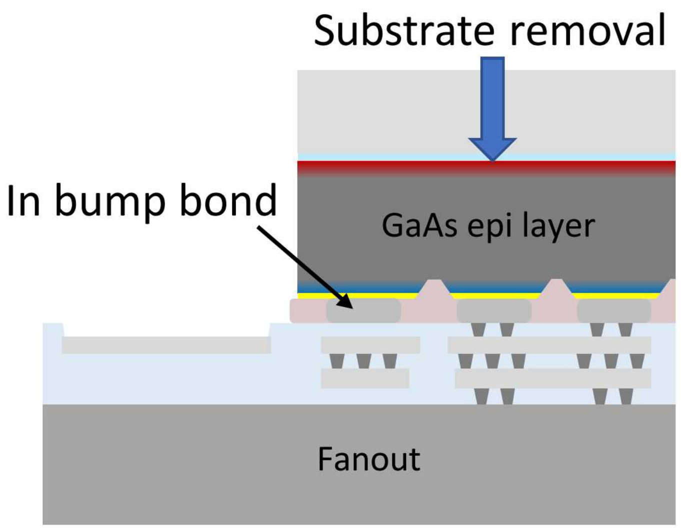


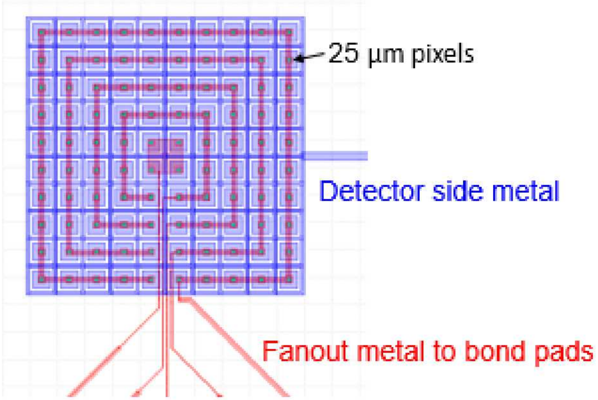
Inter-pixel resistance measurements

Wafer	Metal Only	Post-Etch	Post-Passivation
GN1565A	30	110k	>150k
GN1571A	33	65k	57k
GN1572A	33	65k	58k

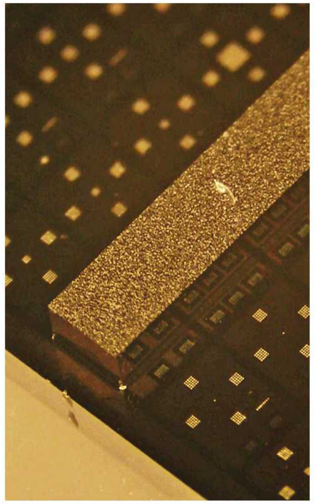
Hybridization Development

- GaAs test arrays In bump bonded to pixel fanout structure
  - 4µm and 20µm epi layer devices bonded
- Substrate removal development
  - Mechanical removal with X-prep miniature mill (better suited to small die)
  - Lapping (better suited to larger die)
- Backside metallization development

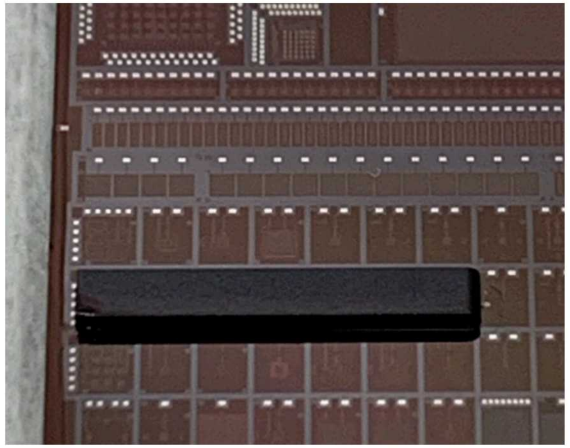




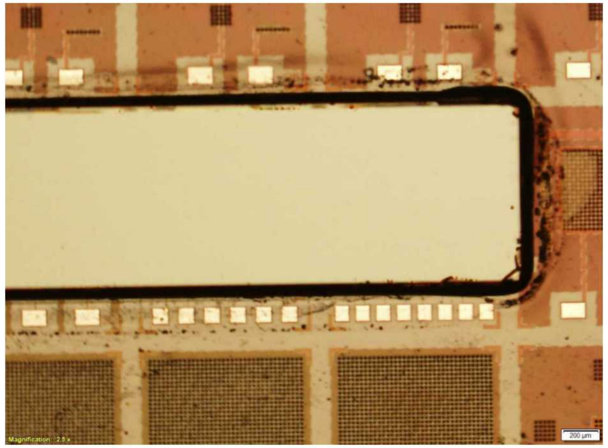
Bump bonded arrays



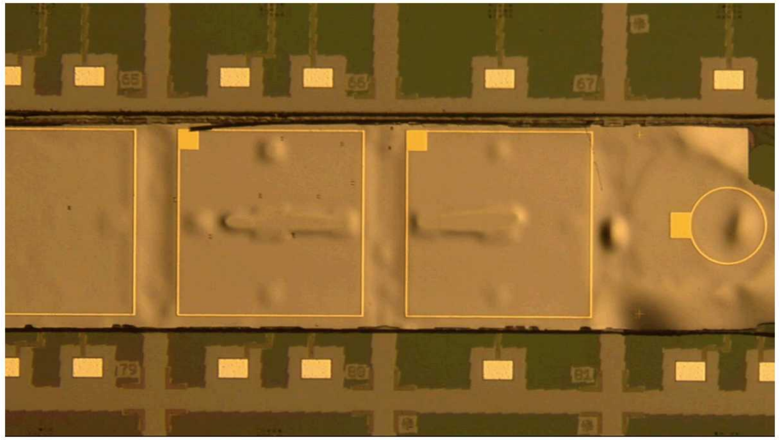
Post-lapping
(rough substrate removal)



Post-etch
(final substrate removal)



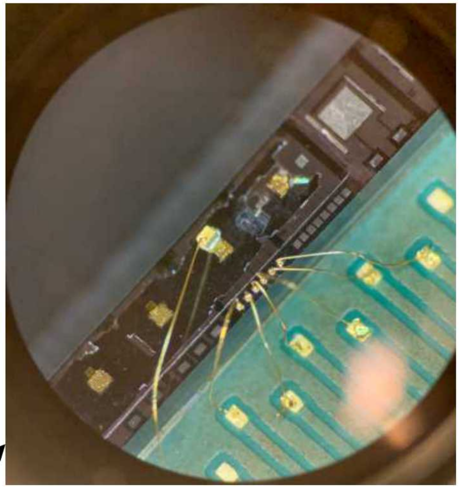
Backside metallization

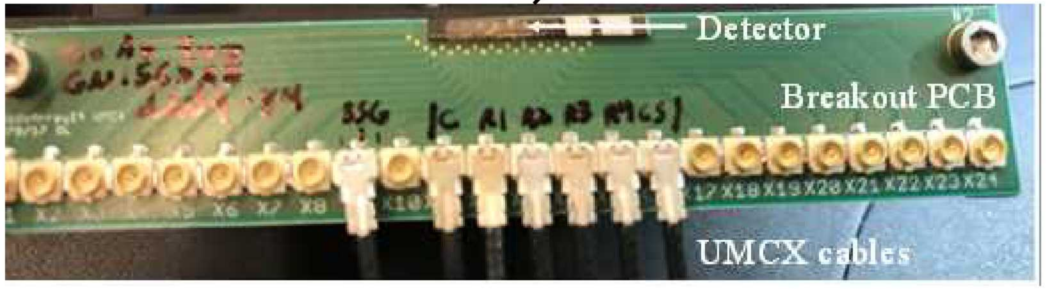


Packaging Development

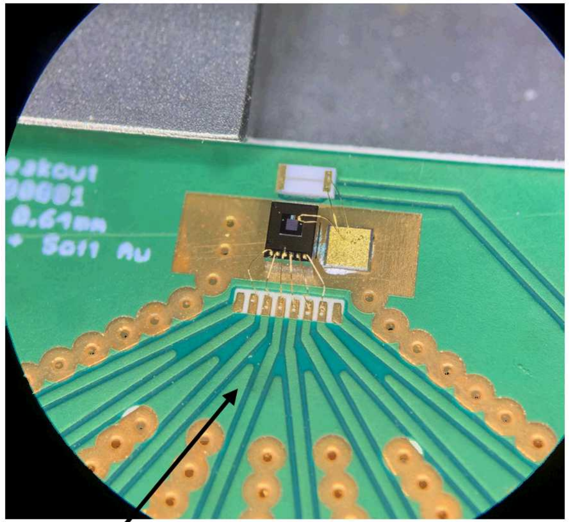
- Multi-electrode readout needed for pixel arrays
- ~10-20 GHz bandwidth needed to see features of interest

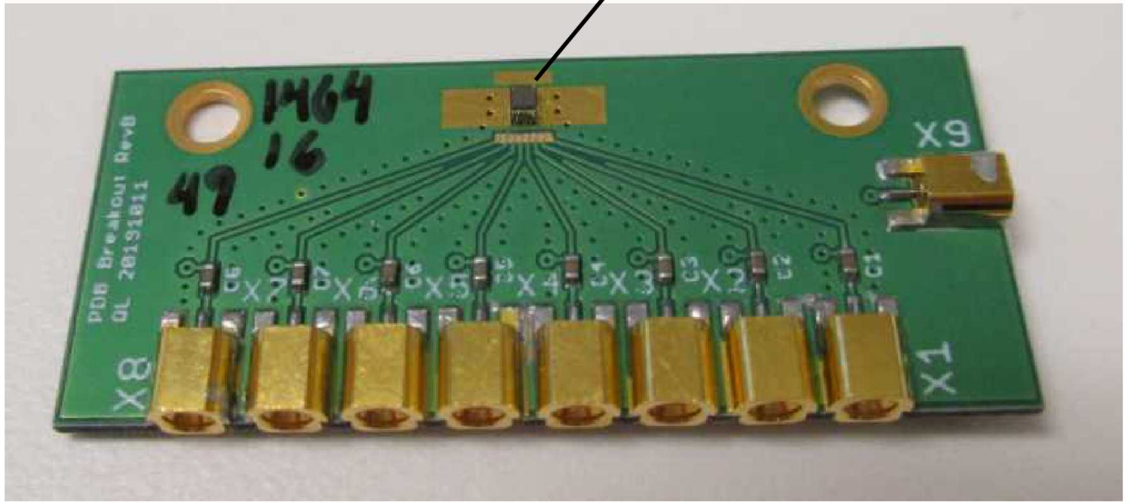
Initial implementation





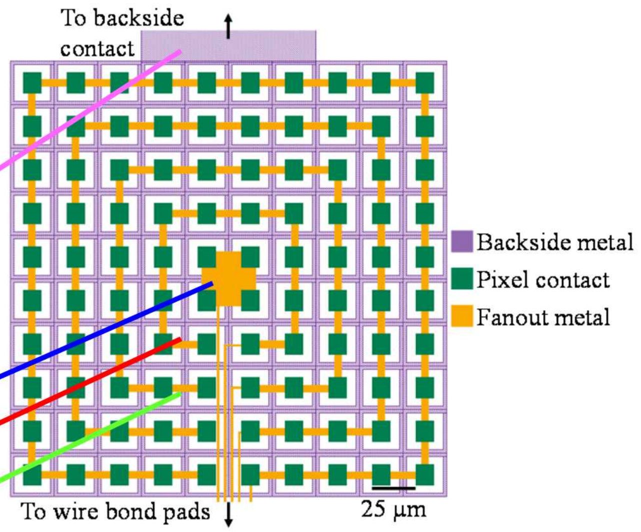
Next implementation



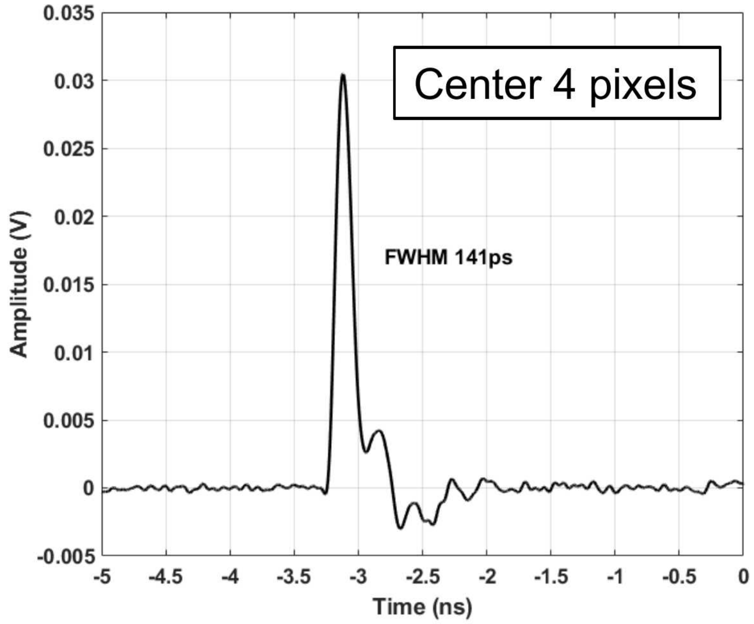


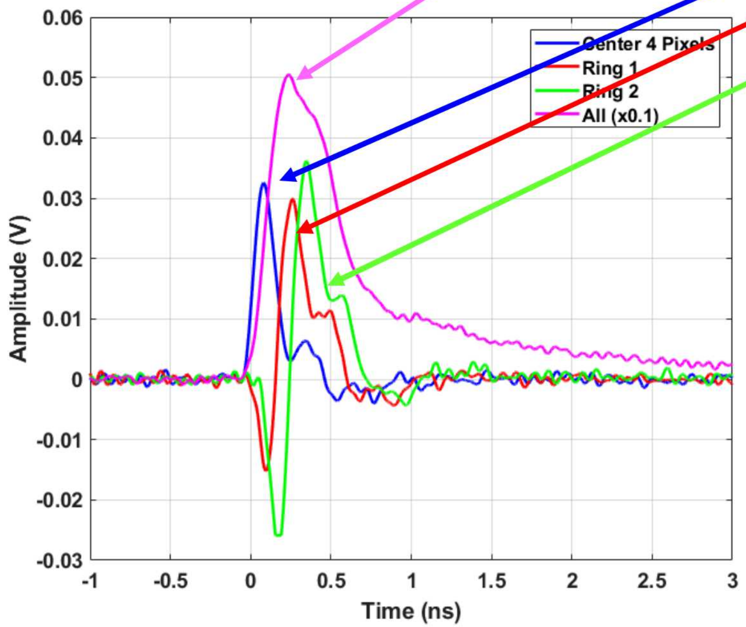
The First Small Pixel Array Has Been Tested in the Lab

- One backside-illuminated GaAs has successfully completed all steps
  - 4 µm epi layer
  - Concentric ring pixel structure (shown at right)
- Additional 4 µm and 20 µm thick devices at substrate removal step



Pulsed laser illumination (~100 ps, 670 nm)

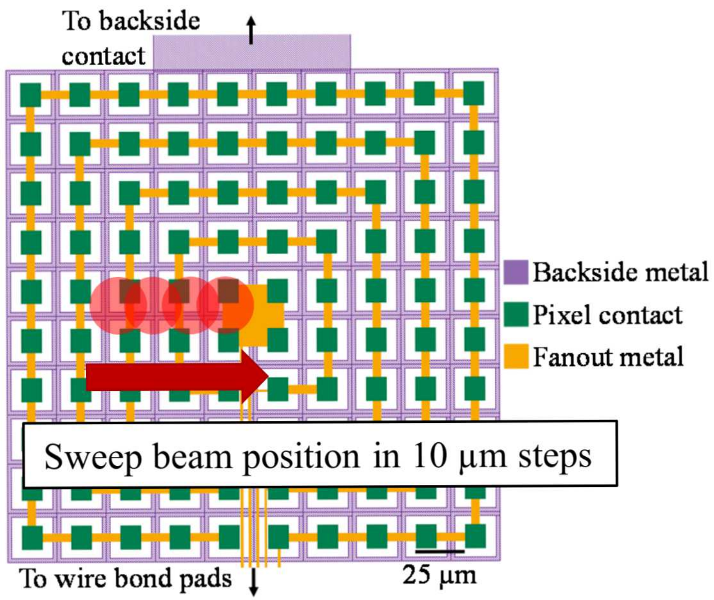


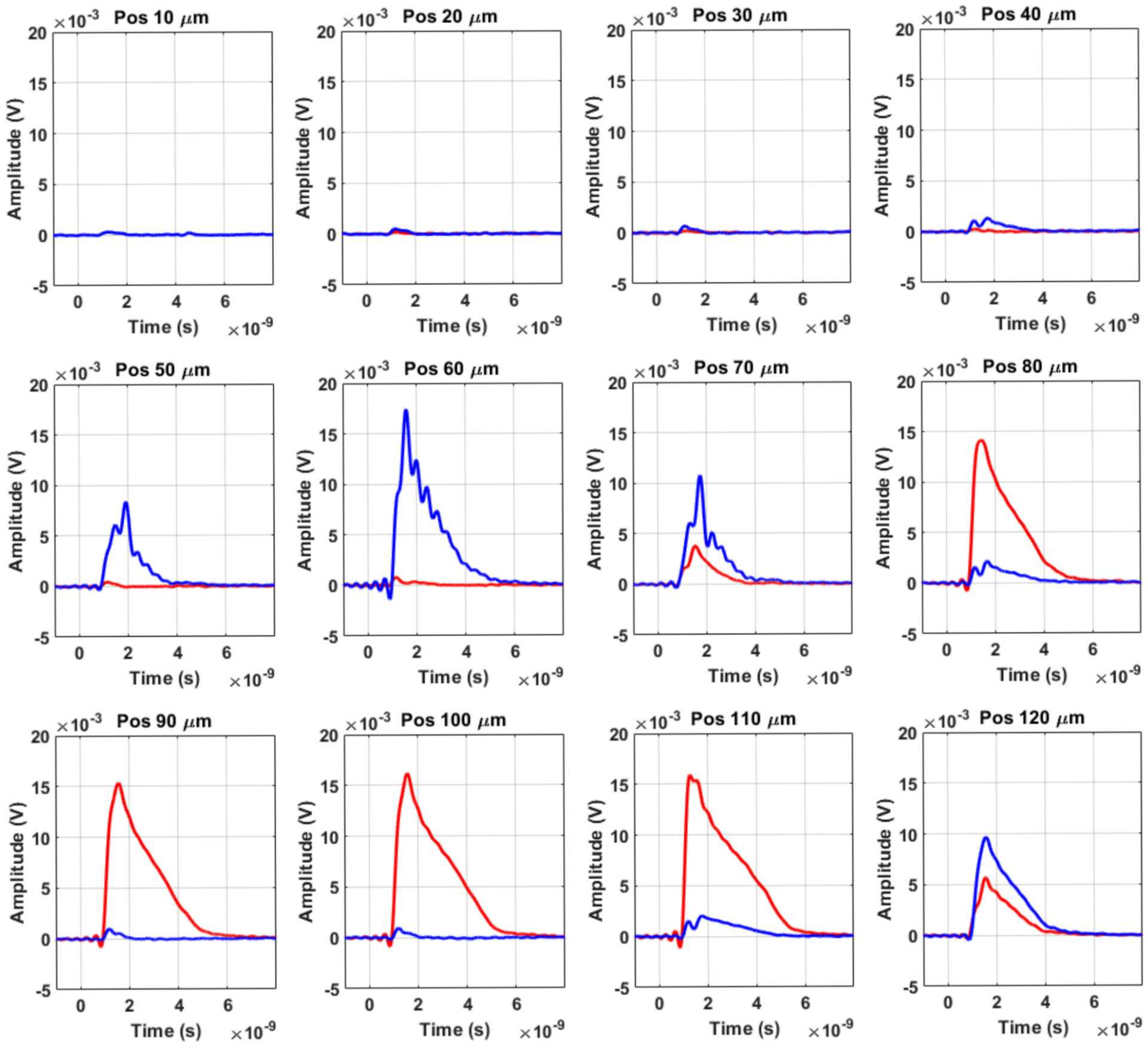


A Focused Beam Step Scan Measures Cross-Talk

Center 4 pixels

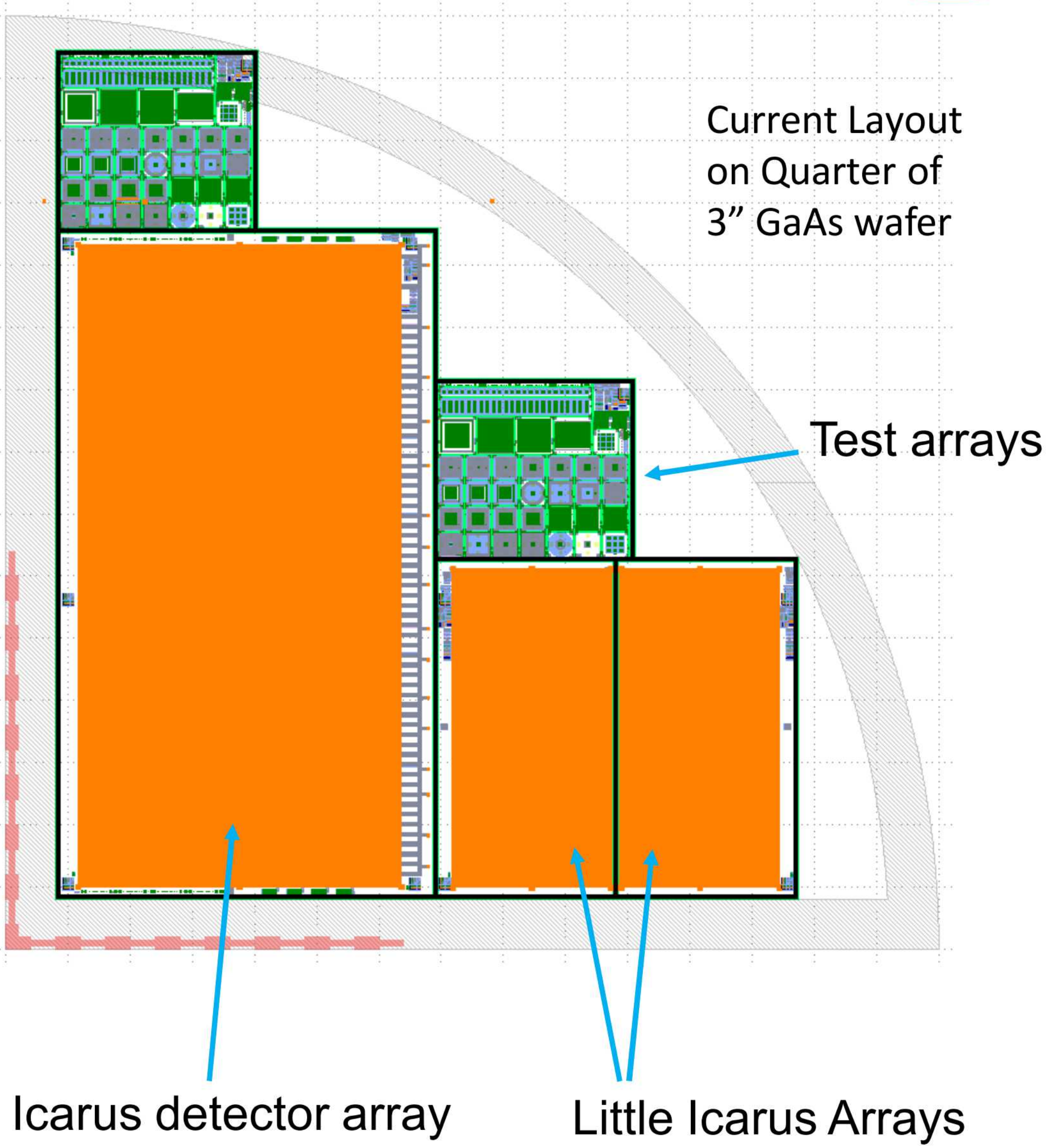
Ring 1





Icarus GaAs Array Design Has Been Completed

- Full-scale imaging array design completed, fabrication begins Dec 2019
- Icarus 512x1024 pixel array
  - Practice bonding and substrate removal of large array using fanout wafers
  - Bond to Icarus V1 spring 2020
- Little Icarus 256x512 pixel arrays
  - Mid-scale device size
  - Allow imaging tests of Little Icarus variants
  - Well-matched to higher capacitive density technologies being tried on these ROICs
- Additional test pixel arrays



Other Material Systems Have Been Investigated

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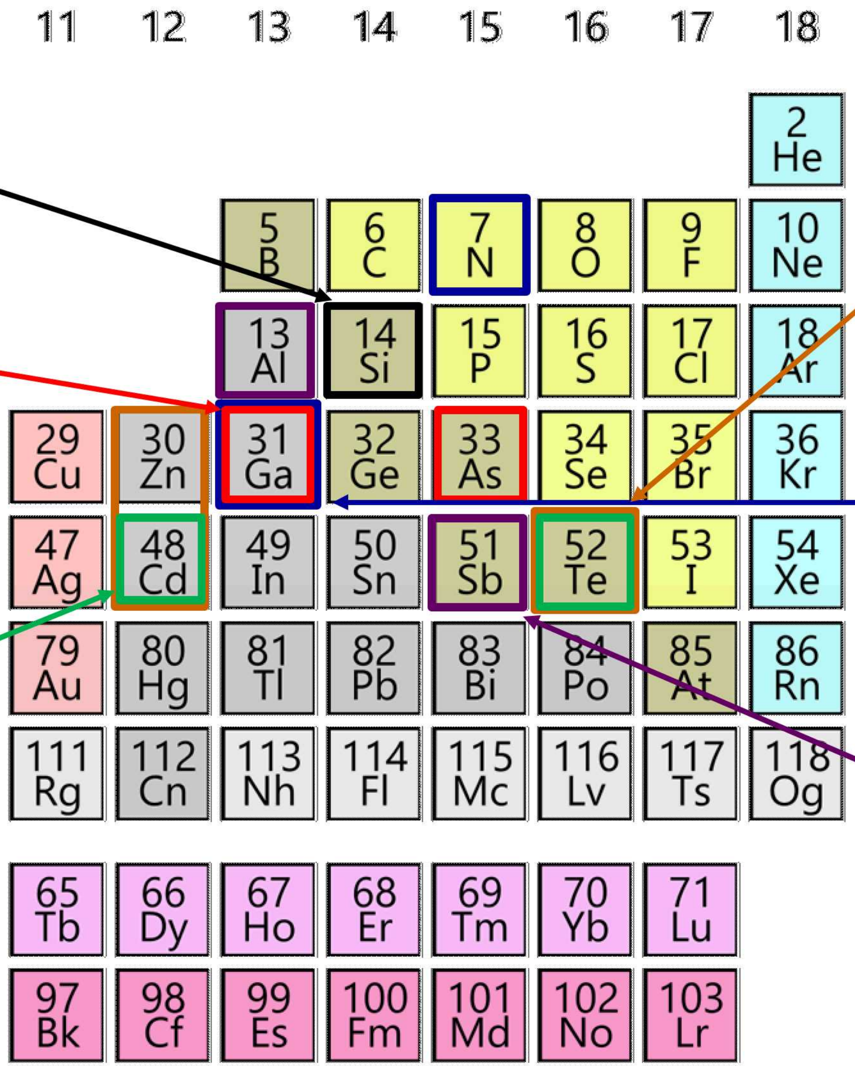
Si [Z=14]
- Mature fabrication
- Low Z

GaAs [Z=31,33]
- Successful development
- Max thickness limited

CdTe [Z=48,50]
- Early development
- Material availability extremely limited, polarization concerns



CdZnTe [Z=30,48,50]
- Extensive material development
- Cannot obtain small detectors

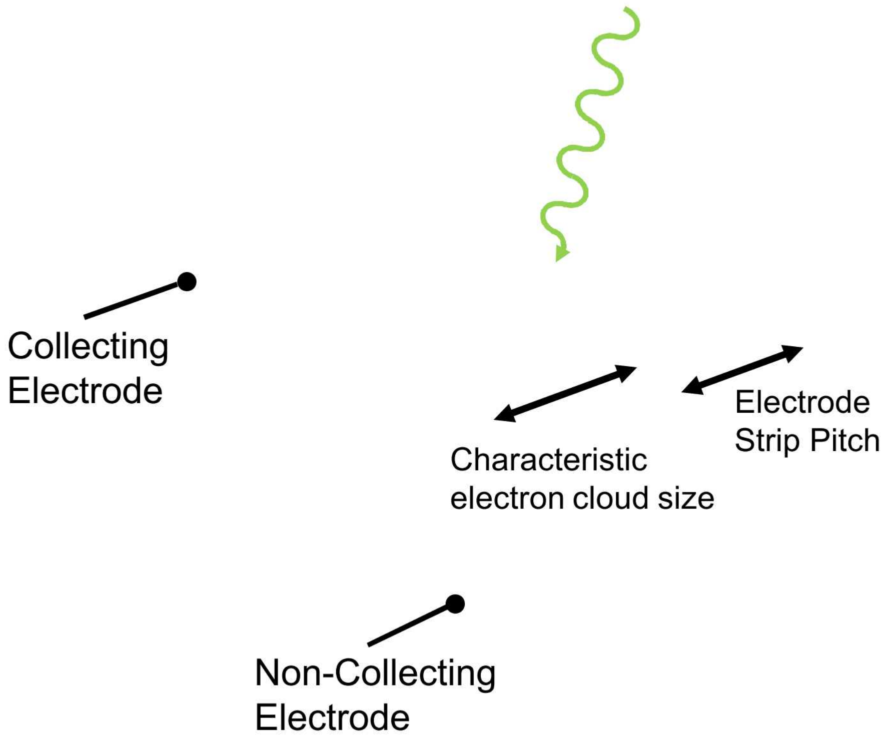
GaN [Z=31,7]
- High bandgap
- Background doping too high

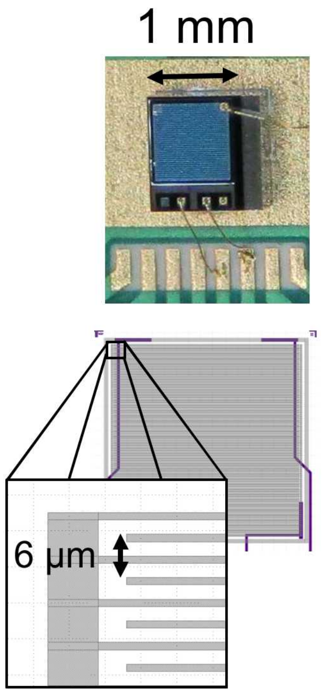
AlSb [Z=13,51]
- High Z
- Leakage current too high

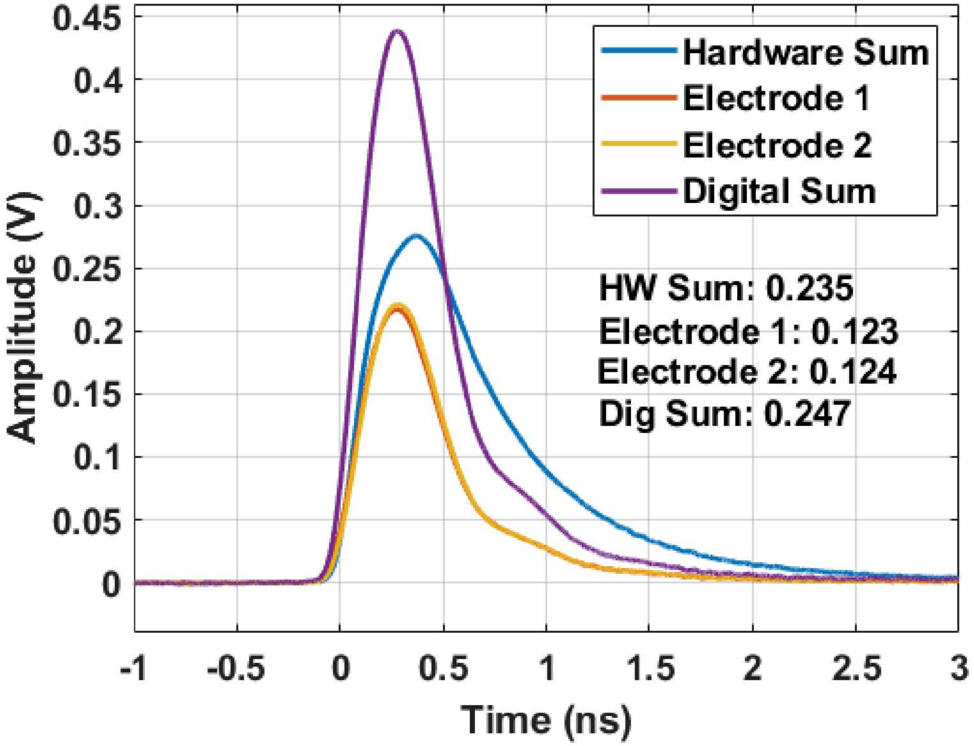
Coplanar Grid Electrodes Are a Potential Current Reduction Solution

- Reduce collection area *without increasing shot noise*
- Keep feature size less than characteristic charge carrier cloud size
- Can be recombined to operate as standard pixel

Pulsed laser demonstration of 1 mm CPG detector, current divided by 2

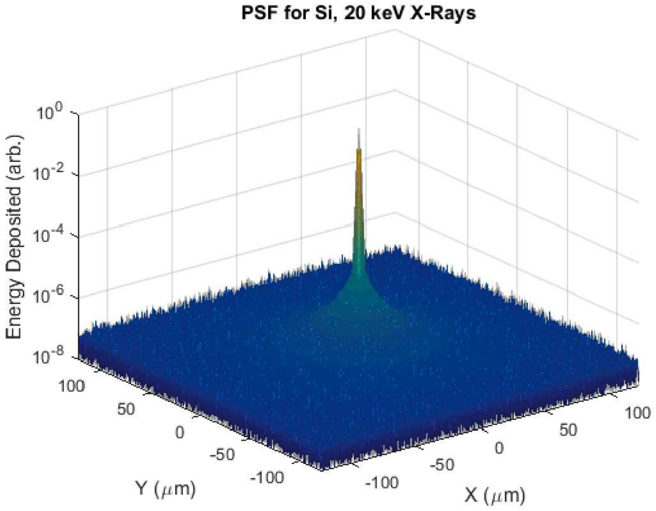


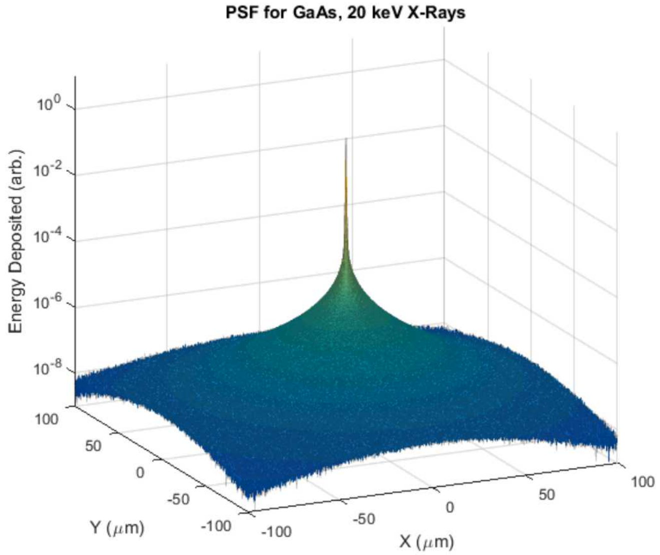


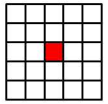
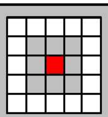
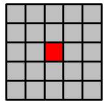


Higher Z Brings More Charge Spread Mechanisms

- Secondary energy cascade process is material dependent
- Higher Z => More x-ray fluorescence, higher energy fluorescence x-rays
- Result is larger spatial distribution of energy deposited by a single primary x-ray





Region	Si	GaAs
Pixel (25 µm) 	94.1%	89.3%
Pixel + 8 nearest neighbors 	99.8%	97.8%
Pixel + 24 nearest neighbors 	99.8%	99.3%

Multi-Year Timeline and Focus

- FY19:
  - Design, build, and test a ~3x3 and ~36x36 pixelated GaAs array at a thickness of 20 microns bonded to a fanout.
  - Design a 0.5 MP GaAs array for bonding to Icarus or Daedalus
- FY20:
  - Build and test a 0.5 MP GaAs array bonded to Icarus
  - Design a High Energy ROIC and/or diode array with charge handling capabilities for photon energies up to ~40 keV.
- FY21:
  - Deliver GaAs-Icarus sensors for use on Z and NIF
  - Build and test a High Energy UXI ROIC and/or diode array for photon energies up to ~40 keV
- FY22:
  - Deliver High Energy UXI sensors for use on Z and NIF