Cactus Materials, Inc.

A New Approach to Achieving High Granularity in Low-Gain Avalanche Detectors

Rafiqul Islam, PhD. Cactus Materials, Inc. (PI)

Rafiqul.islam@cactusmaterials.com

Collaborator: BNL, UCSC

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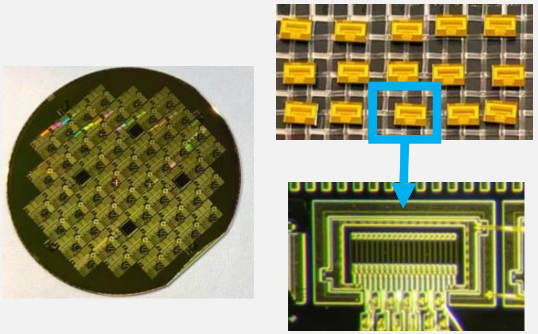
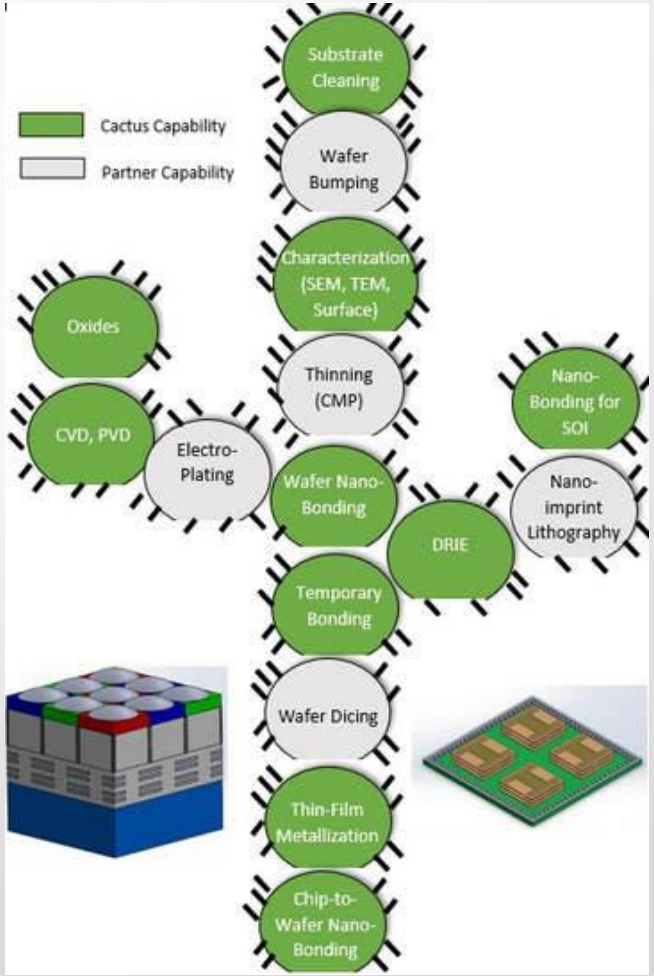
Products

- **Ultra-fast silicon detectors -** Designed and fabricated in-house at Cactus Materials, Inc.
- **3D integrated Silicon Detector using direct wafer bonding and TSV** (Q2, 2022)



Products

- Manufactures low volume in-house and with partners within the same manufacturing complex (up to 1000 wafers/month, 2x shift) in class 100 cleanroom
- Cactus Materials, Inc. in process of acquiring a dedicated facility where productions can be as high as 6000 wafers/month



Outlines: A New Approach to Achieving High Granularity in Low-Gain Avalanche Detectors

Deep Junction LGAD

- Deep Junction (DJ) LGAD Concept
- Developments in DJ-LGAD
- DJ-LGAD fabrication Progress
- Commercialization
- Next steps/Help needed

Conventional LGAD Coverage Gaps

Inter-pixel region in Standard LGADs

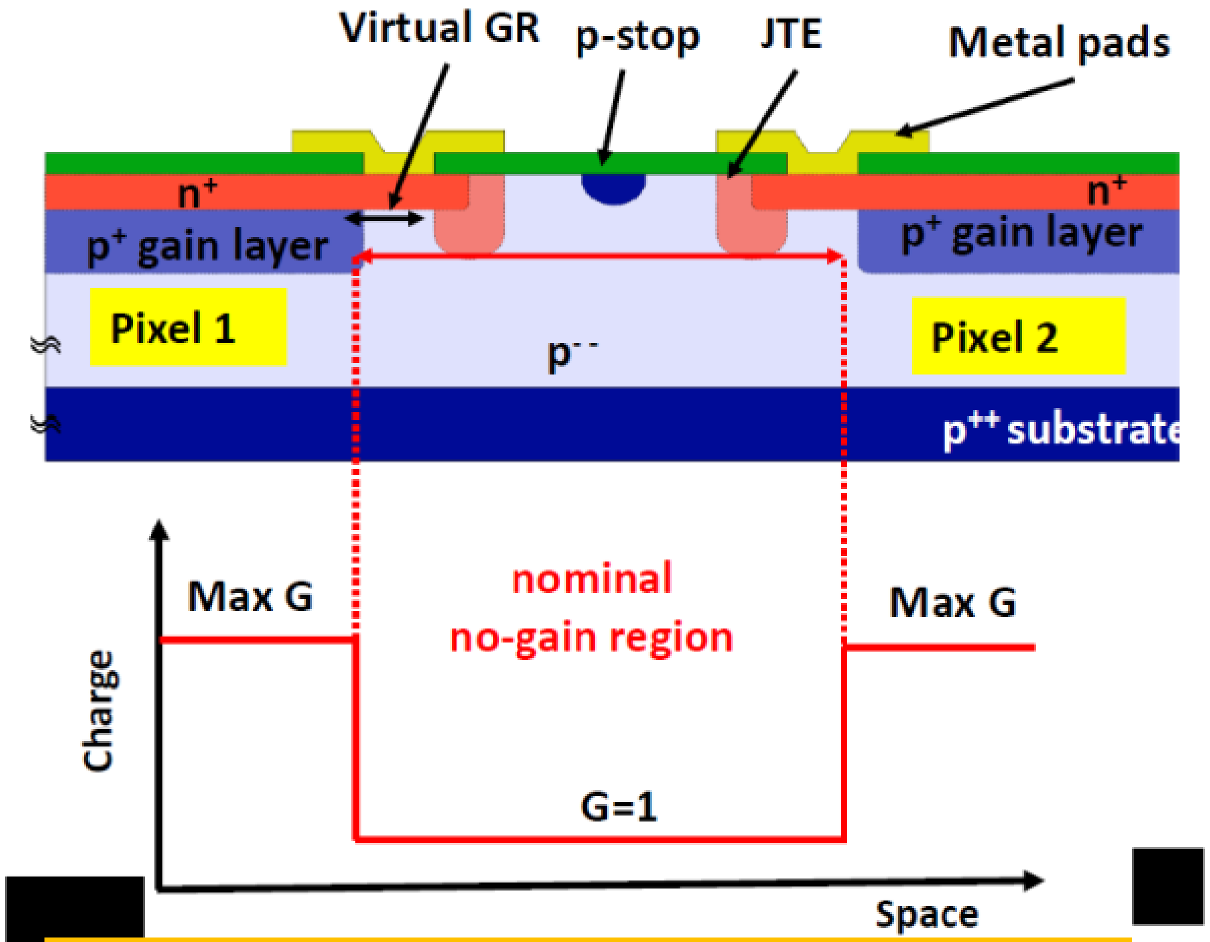
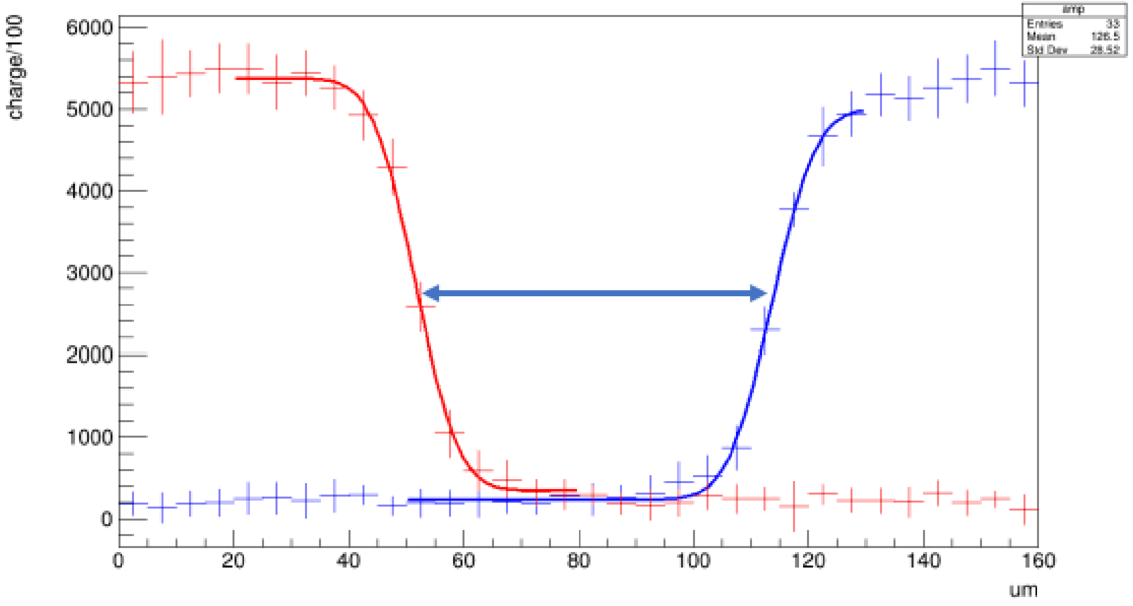


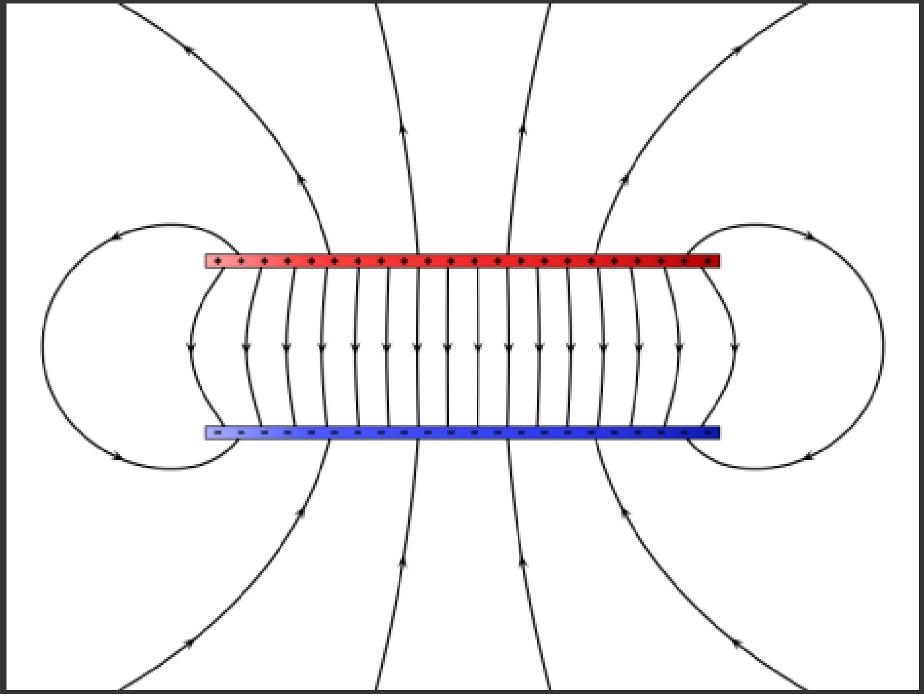
Diagram credit: FBK, Trento, Italy

Diagram credit: INFN, Torino



- Smallest safely achievable gap (50% criterion) is 60 µm
- Limits granularity to ~mm scale

The Deep Junction (DJ) LGAD Concept



Basic inspiration is that of the capacitive field: Locally large, but surrounded by low-field region beyond the plates.

Idea:

- Use symmetric P-N junction to act as an effective capacitor
- Localized high field in junction region creates impact ionization
- Bury the P-N junction so that fields are low at the surface, allowing conventional granularization

➔ **"Deep Junction" LGAD (DJ-LGAD)**

DJ-LGAD Fabrication Approaches

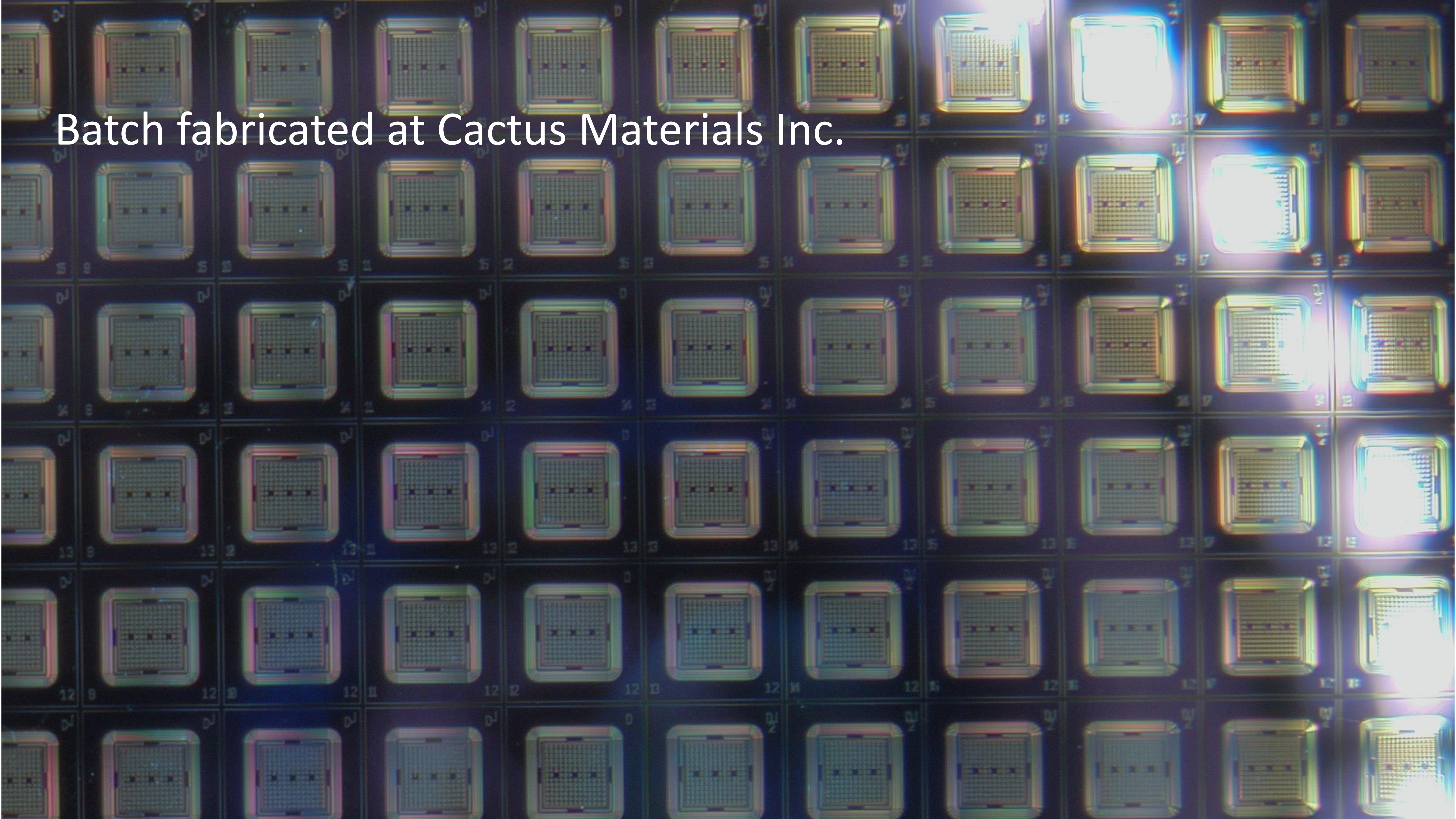
Two approaches will be employed:

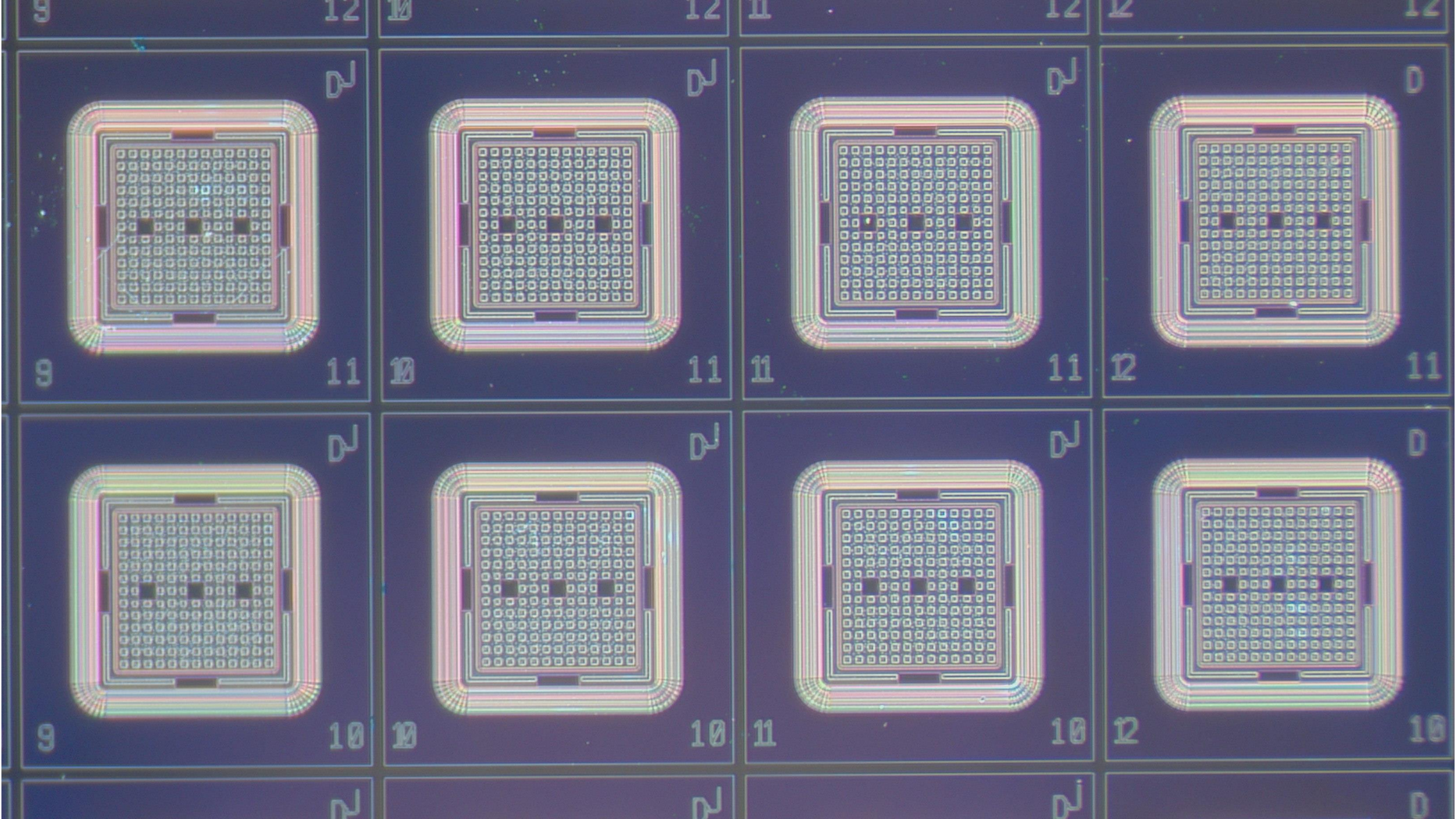
- Wafer Bonding method (transformational for many types of detectors)
- Epitaxial method

Fabrications Status

- Process is 140+ process steps and completed rev 1 design fabrications
  - Epitaxial approach - DONE.
  - Bonding approach - DONE
- Cactus Materials, Inc. and Brookhaven for testing and characterization-I-V and C-V done.

Batch fabricated at Cactus Materials Inc.




DJ
9
11
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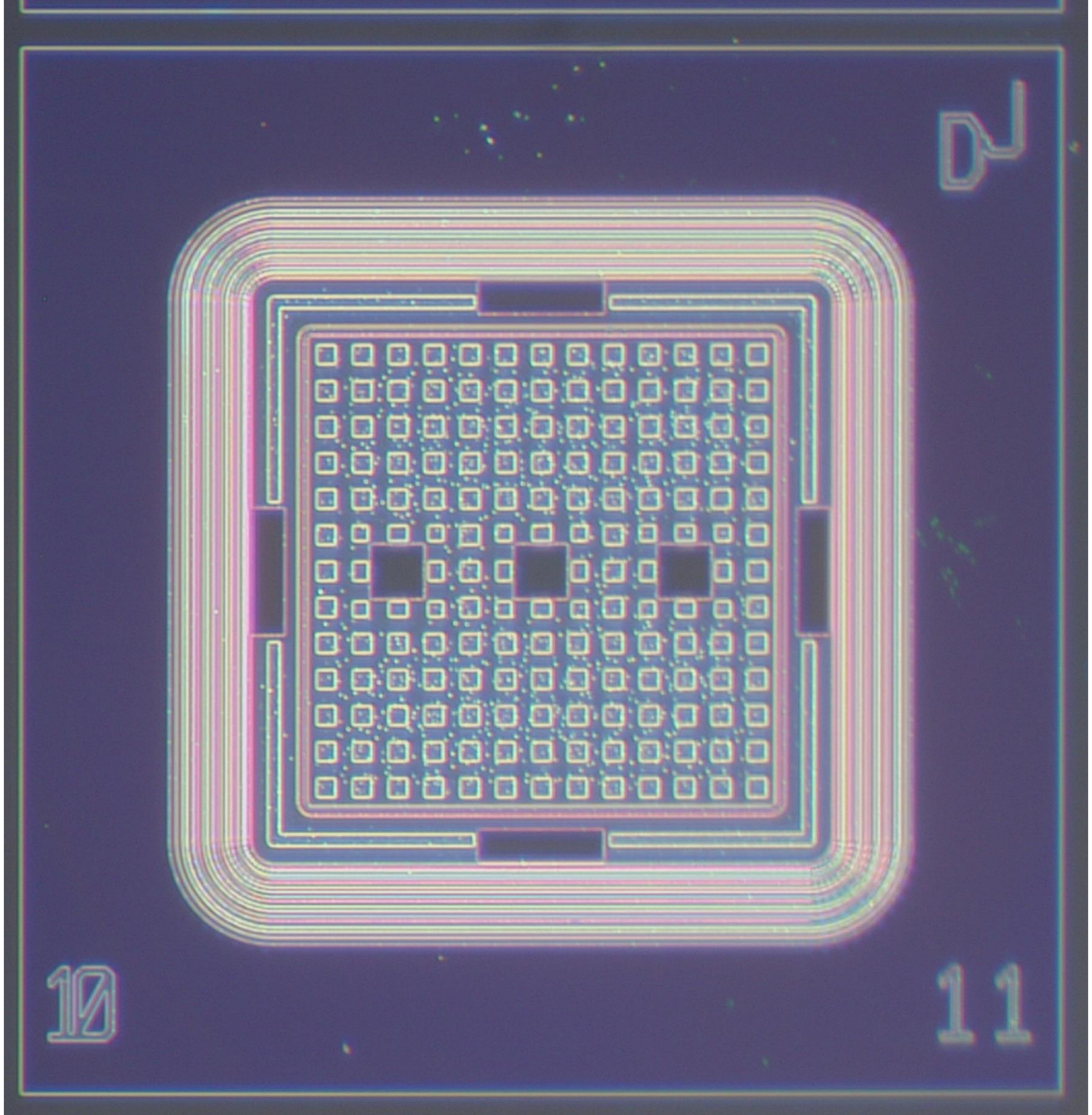
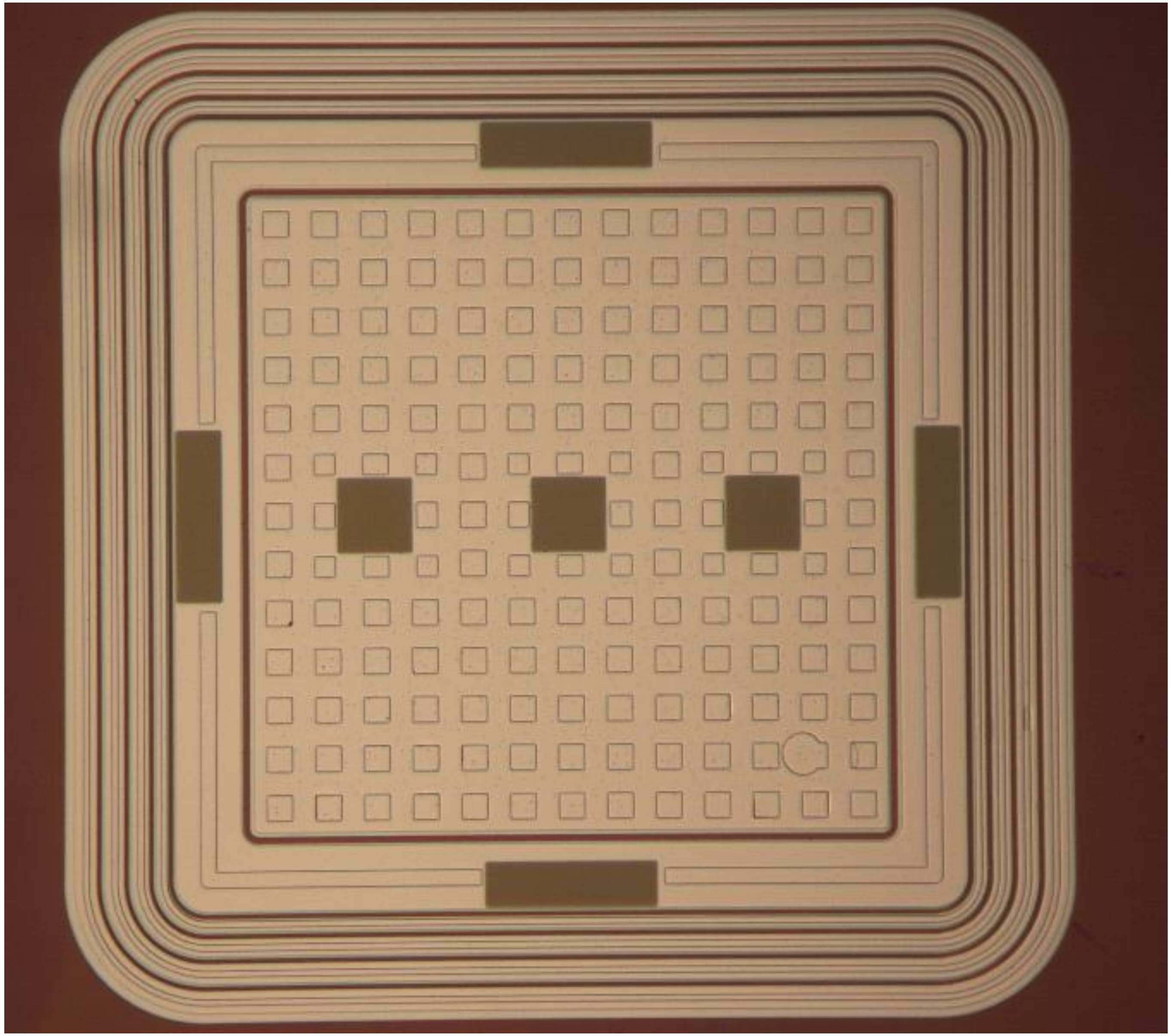


1.3 mm x 1.3mm

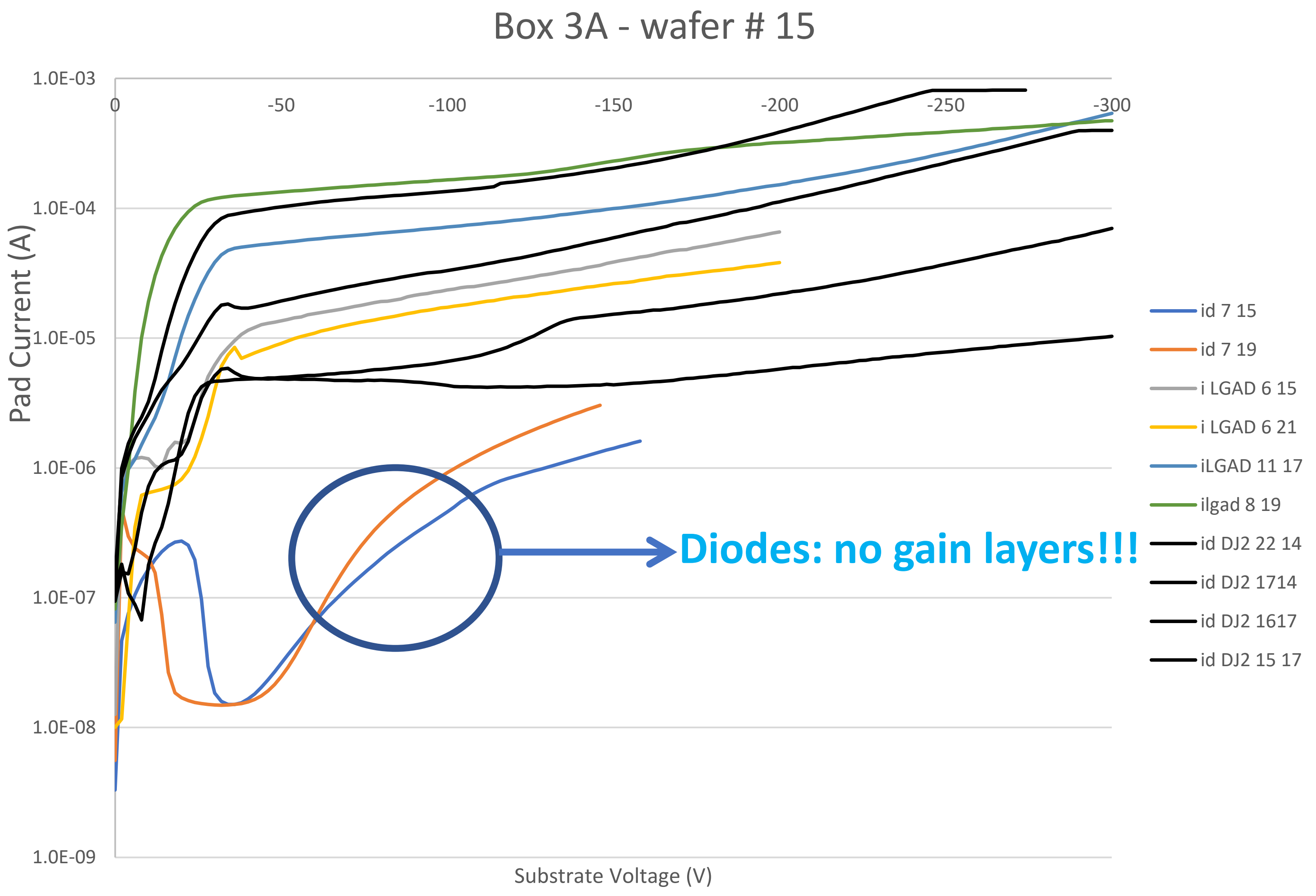
Three types of devices:
(labeled on the top right corner)

- DJ: gain layer within central pad
- DJ2: gain layer edge under the GR
- DJ3: pad divided in two sub-pads for charge sharing measurements with laser

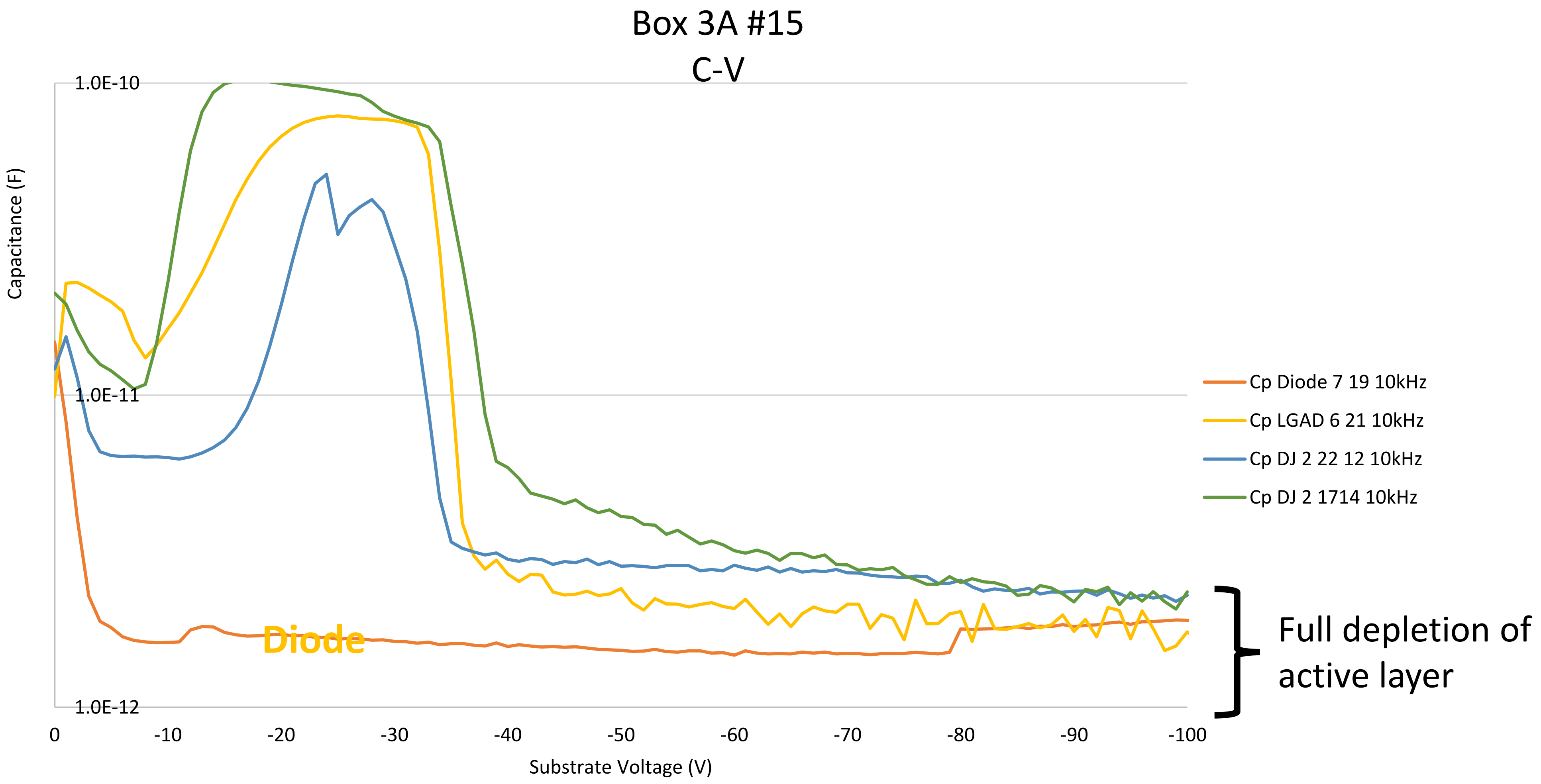
+ and diodes (no gain layers)



I-V


Box 3A - wafer # 15
Pad Current (A)
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
0
-50
-100
-150
-200
-250
-300
Substrate Voltage (V)
Diodes: no gain layers!!!
id 7 15
id 7 19
i LGAD 6 15
i LGAD 6 21
iLGAD 11 17
ilgad 8 19
id DJ2 22 14
id DJ2 1714
id DJ2 1617
id DJ2 15 17

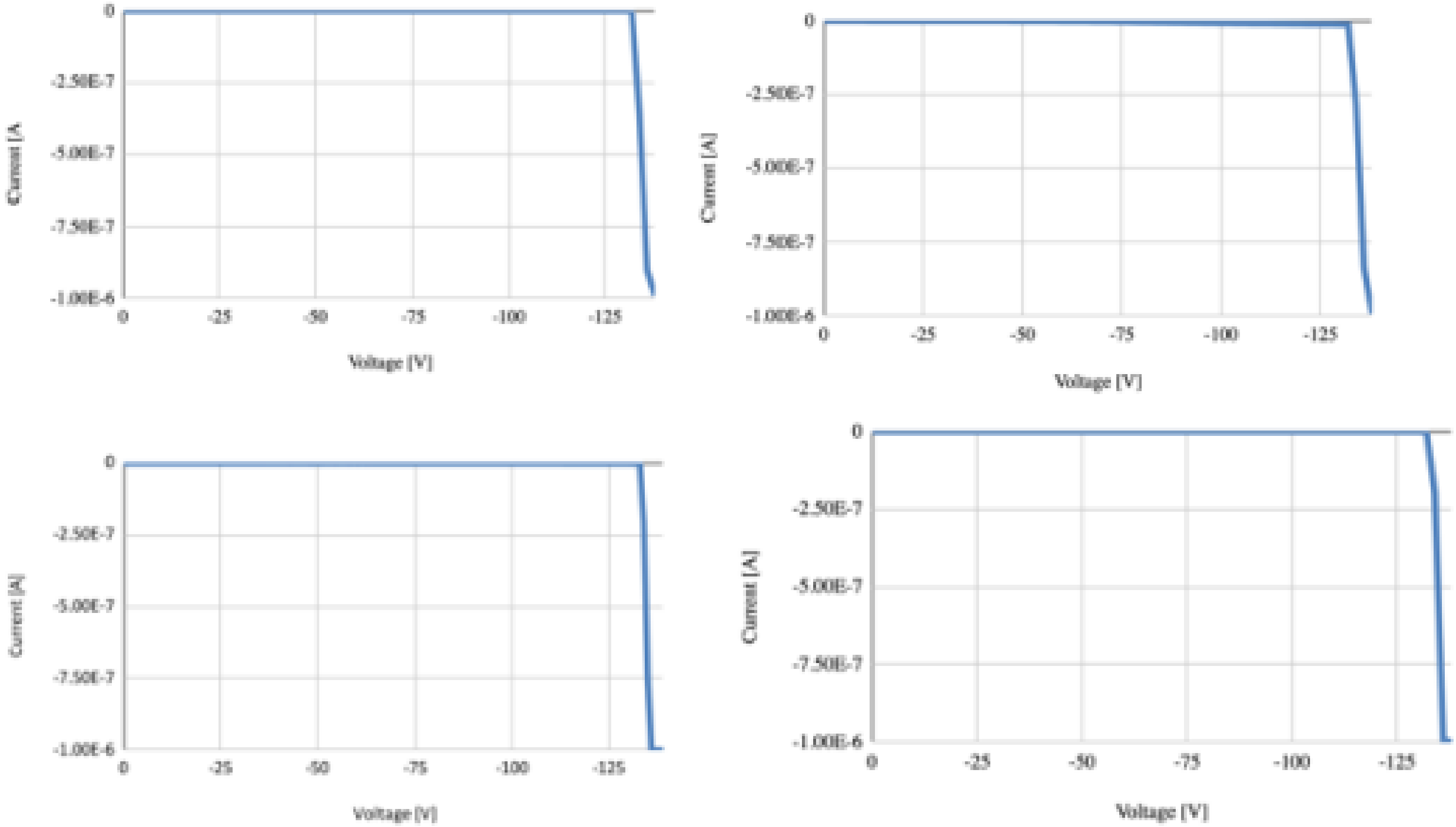
C-V


Box 3A #15
C-V
1.0E-10
1.0E-11
1.0E-12
Capacitance (F)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
Substrate Voltage (V)
Diode
Cp Diode 7 19 10kHz
Cp LGAD 6 21 10kHz
Cp DJ 2 22 12 10kHz
Cp DJ 2 1714 10kHz
Full depletion of
active layer

Results: I-V

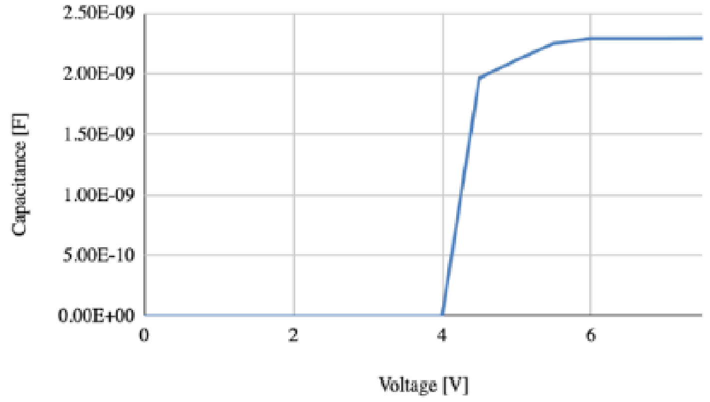
Epitaxial approach: Results from Epitaxial approach (Cactus/BNL)

I-V data: 4 measurements: Vbd ~ -132V Consistently

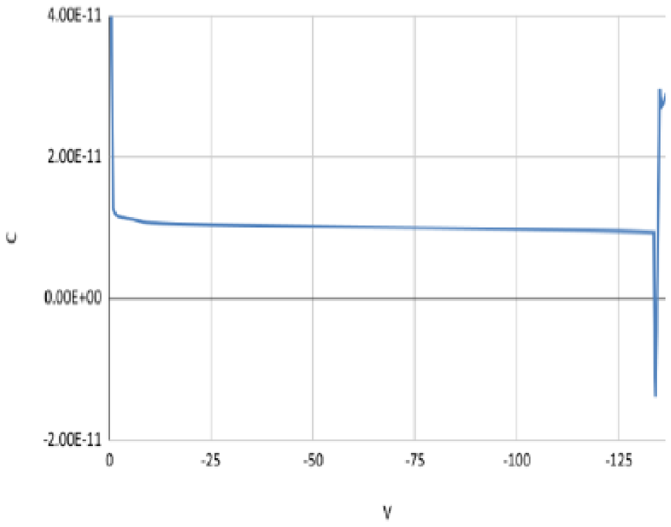


Results: C-V

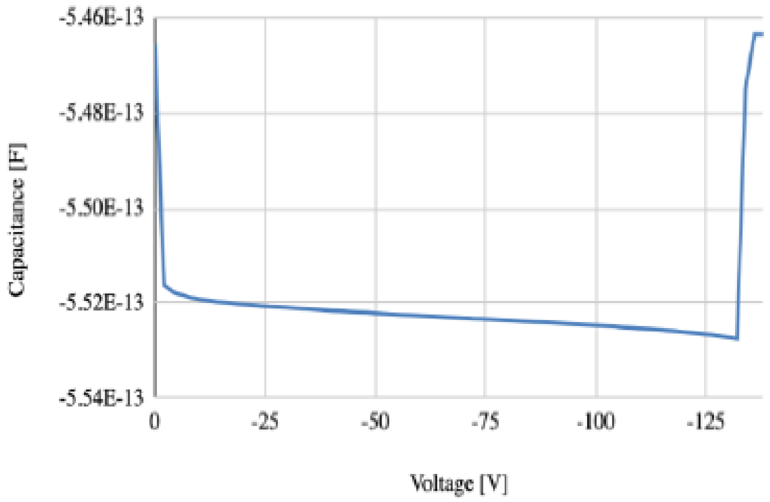
We observed sharp behavior from junction in first few microns of sensor, then slower in bulk until reaching breakdown voltage



Positive biasing: Positive biasing reaches compliance very quickly. 10KHz frequency, room temperature measurements, 0.5V steps.



Negative Bias: C sharply dips at breakdown. Visible now b/c smaller step size



2nd measurement: We observed sharp behavior from junction in first few microns of sensor, then slower in bulk until reaching breakdown voltage

Commercialization

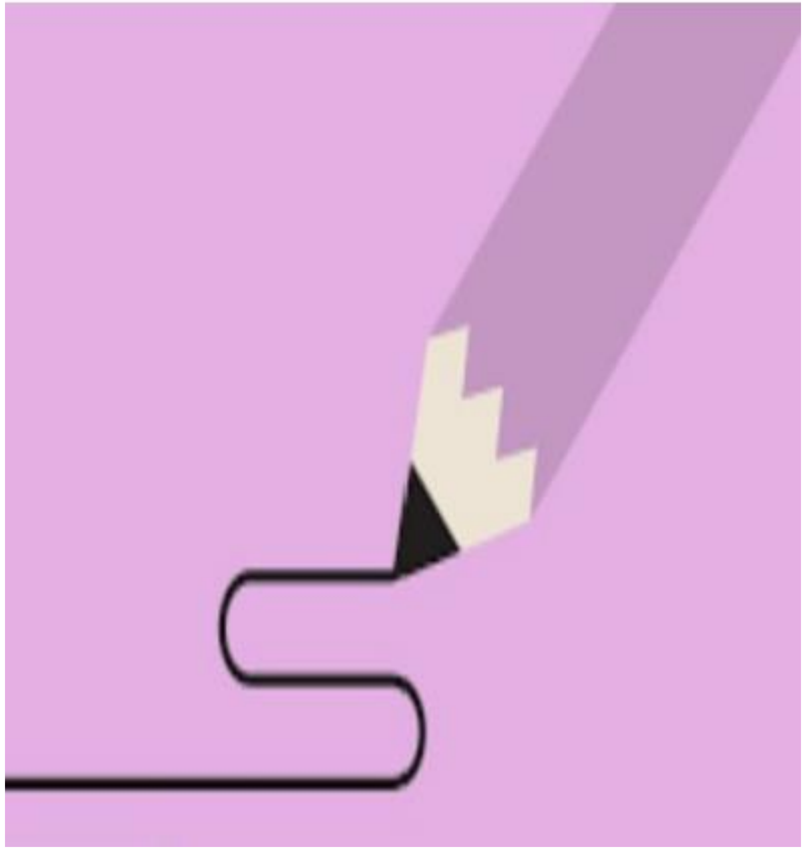
- Electron-Ion Collider (EIC), will start engaging
- 4D tracking in ion-ion collision
- X-ray imaging

<u>Need Help:</u>

- Understand market for LGAD
  - Potential usages by scientific community)
  - National labs and defense industry across the US and outside US
- Collaborate with ROIC supplier
  - ETROC designed for CMS experiments
    - Fermi Lab is helping
    - may need a commercial vendor
- 3D integrated designed ROIC – potential commercial vendor collaboration

Conclusion

- DJ-LGAD devices ready to support scientific community and commercial testing.
- DJ-LGAD is an enabling technology for high granularity detectors.
- Cactus’s material's wafer bonding capability can be extended to other absorber High-Z materials (III-V materials; GaSb, GaAs, InP)
- Cactus Materials, Inc. current capability from 1000 wafers/month to increase 6000 wafers/month in Q1, 2023



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