FERMILAB-CRADA-FRA-2019-0025

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Radiation Hardened Engineered Substrates for Time and Space Resolution

Cooperative Research and Development Agreement Final Report

CRADA Number: FRA-2019-0025

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In accordance with Requirements set forth in Article X of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

CRADA number: FRA-2019-0025

CRADA Title: Radiation Hardened Engineered Substrates for Time and Space Resolution

Parties to the Agreement: Cactus Material, Inc.

Sponsoring DOE Program Office(s): Office of Science

Abstract of CRADA work:

Low Gain Avalanche Diodes (LGADs) have become sensors of choice for fast timing of minimum ionizing particles. The current generation of these devices suffer from only moderate radiation hardness, low fill factor, and limited design options. Cactus Materials Inc. proposes to develop sensors with gain layer implants buried beneath the surface which will, with AC coupling developed by Brookhaven National Laboratory (BNL) and University of California Santa Cruz (UC Santa Cruz) solve these problems. Fermilab has a major role in the CMS timing upgrade using the current generation of LGADs and development of AC-coupled, buried layer LGADs will solve some of the central problems inherent in this technology.

Annex B included a two-year work plan, deliverables, schedule and funding for the project's SBIR Phase II award to develop and test prototype LGADs utilizing wafer bonding technology and epitaxial growth, that will allow for fabrication of radiation hard AC coupled devices with 100% fill factor and adjustable operating point.

Summary of Research Results:
FRA-2019-0025 Annex A (Phase 1) was successfully completed but the devices had issues with "stacking faults" in the base wafers which caused high currents. Fermilab and UIC performed tests of selected devices in the test beam and in the laboratory.

FRA-2019-0025 Annex B (Phase 2) work was not completed.

Testing of the BL-LGAD

LGADs in all wafers were measured on a semi-automatic probe station. Figure 1 shows the results for a sample set of small area LGADs. There is significant device-to-device variation, presumably related to the density of stacking faults. Devices with low currents below 125 V were chosen for laser and beam tests

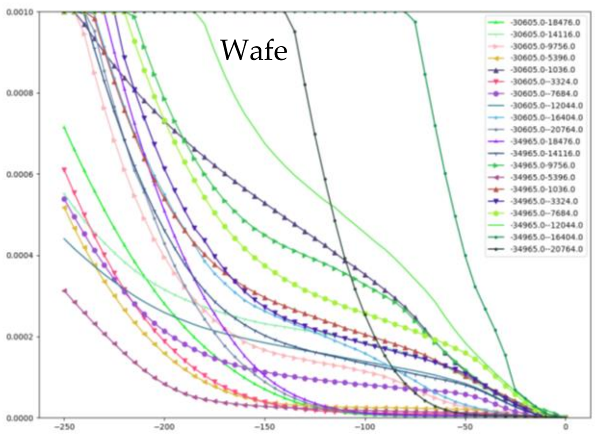

Figure 1 Probe test results for the current-voltage characteristic of the small LGADS on wafer "N"

We also verified the doping profile of the gain layer using the SIMS (Secondary Ion Mass Spectroscopy) technique, verifying the expected doping profile and density as input for

TCAD simulations.

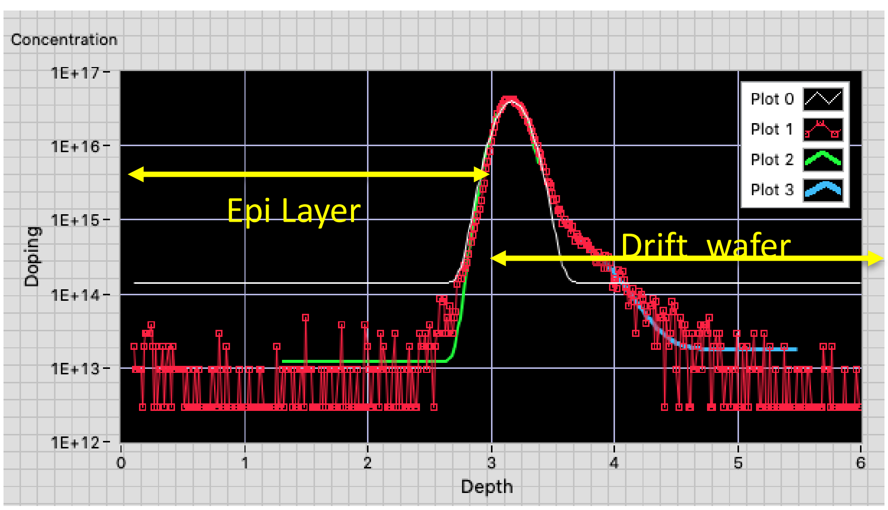

Figure 2 SIMS measurement of the gain layer boron doping profile.

In collaboration with the University of Illinois-Chicago and Fermilab the prototype DL-LGADs were tested both with a 1064 nm laser and in the Fermilab test beam. Sample parts which were

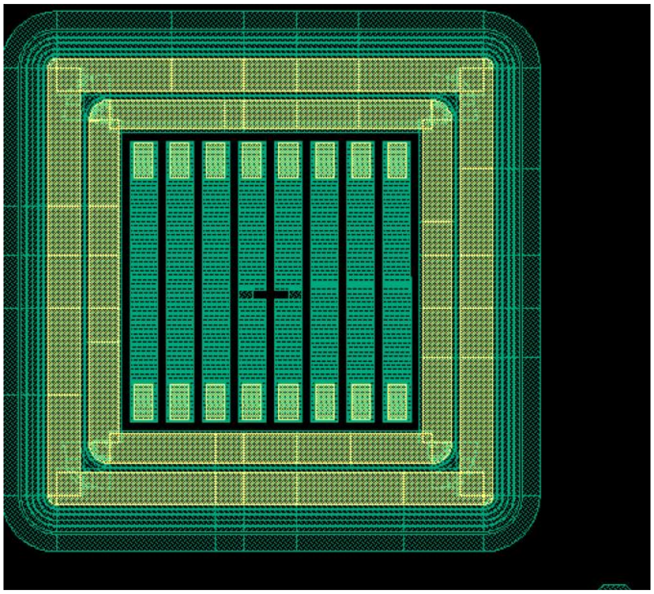

Figure 3 A typical strip test structure. Laser scans are made in the laser test opening in the center of the device.

chosen for a low density of stacking faults and voids were connected to a 16-channel fast amplifier board developed by Fermilab and read out using Tektronix oscilloscopes.

Laser Tests:

A focused 1064 nm laser was scanned across the metal opening at the center of figure _ and past the accompanying neighbor strips. Figure _ shows the measured pulse amplitude and calculated gain for the 3 micron layer depth and nominal gain layer dose. There is a characteristic fast increase in gain when the device is initially depleted followed by a slower rise corresponding to the slow dE_{gain}/DV_{bias} after full depletion.

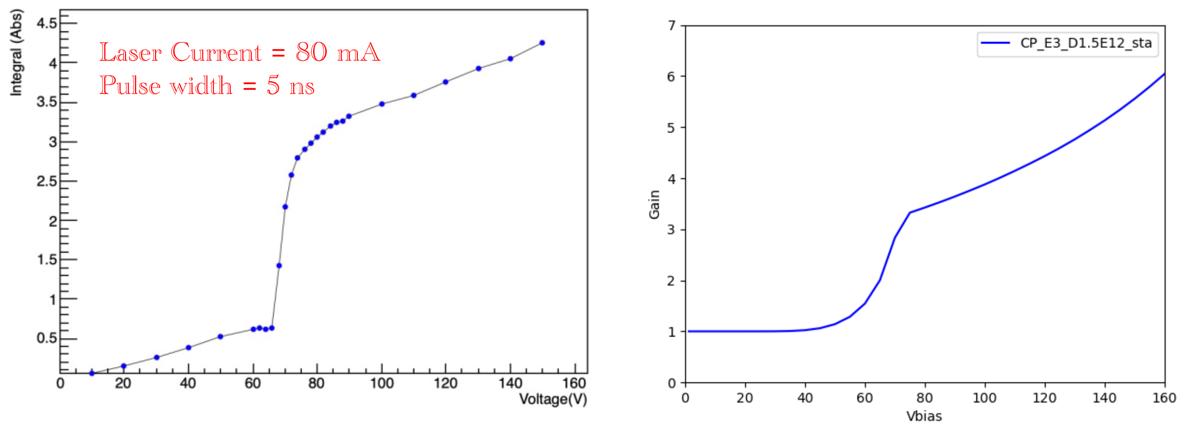

*Figure 4 Left - **Measured** pulse amplitude as a function of bias voltage. Right - **Calculated** gain as a function of bias for 3 micron epitaxial thickness, the nominal value for this run.*

Pulse shapes for various bias voltages are shown in figure __. This is an AC coupled pulse, so the integral must be zero.

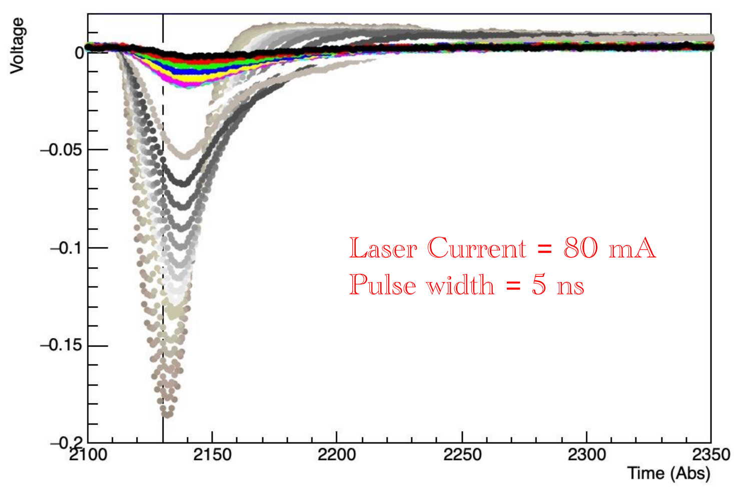

Figure 4.1 Pulse waveforms as a function of time for several bias voltage values

Figure 5 shows results of a laser scanned along the metal opening at the center of figure 3. The profiles clearly show the resistive charge sharing between the adjacent channels as the laser is scanned across the gap. The laser is extinguished when crossing the pad aluminization. The pattern is continued in the smaller gaps between channels 7 and 8 and 6 and 9.

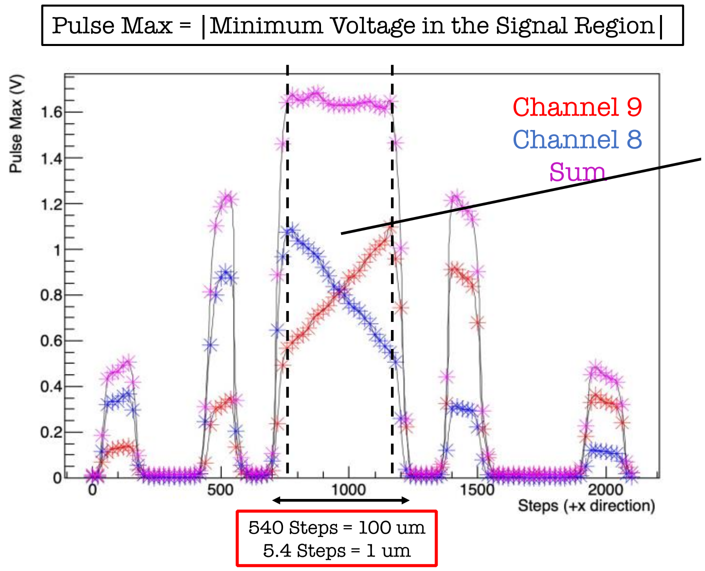

Figure 5 Results of laser scan for adjacent channels of an AC coupled strip sensor. The charge sharing between channels 8 and 9 due to the AC coupling is clear, while the sum of the two channels remains constant. The fall of the induced current as function of distance is continued for the neighboring strips.

A 200 micron pitch, 50 micron metal coverage sensor biased at -350 V was exposed to 120 GeV protons in the Fermilab test beam. Figure 6 shows the results for position and time resolution. The time resolution is limited by the gain at which the devices can be operated. The position resolution is ~19 microns when the beam resolution is unfolded.

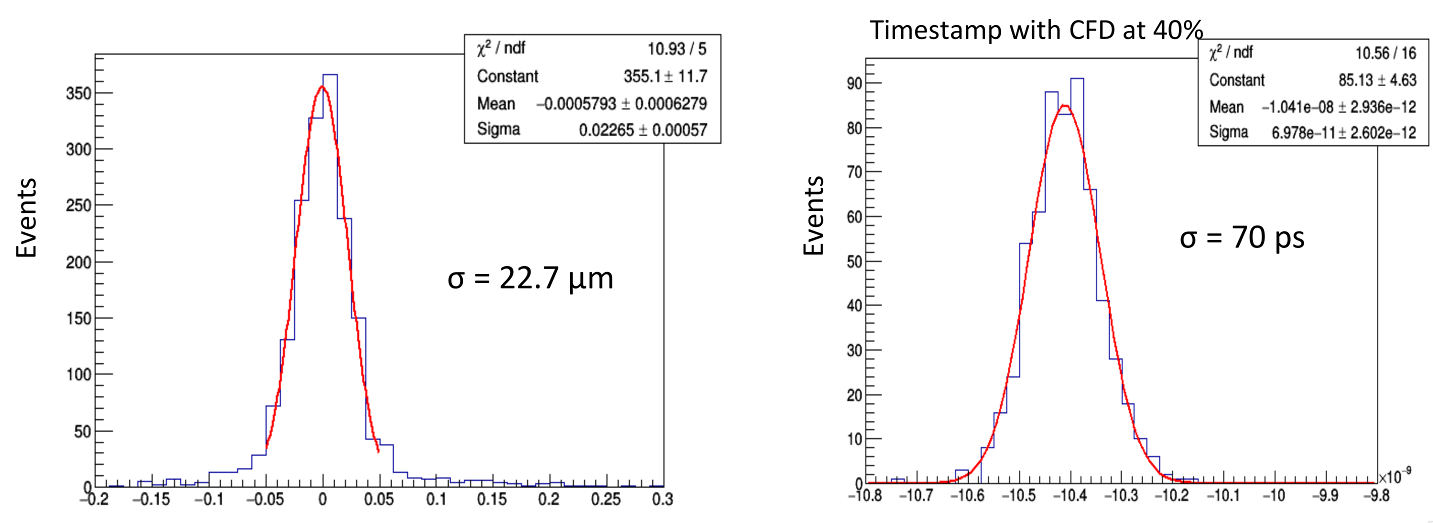

Figure 6 Test beam results for position (left) and time (right) resolution for the BL-LGAD.

Related Reports, Publications, and Presentations:

International Conference on Technology and Instrumentation in Particle Physics
Journal of Physics: Conference Series
Buried Layer Low Gain Avalanche Diodes
https://iopscience.iop.org/article/10.1088/1742-6596/2374/1/012166/pdf

Buried Layer Low Gain Avalanche Diodes
https://indico.cern.ch/event/981823/contributions/4293564/attachments/2251204/3818882/BL-LGAD-TIPP.pdf

Subject Inventions listing:

PCT WO2023229604A1
WO2023229604A1 - System: and method for radiation-hardened engineered substrates for time and space resolution - Google Patents

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