

Sensor Development for Picosecond Timing

CNF Project Number: 3213-24

Principal Investigator(s): Marina Artuso

User(s): Bridget Mack

Affiliation(s): Department of Physics, Syracuse University

Primary Source(s) of Research Funding: National Science Foundation

Contact: martuso@syr.edu, bjmack@syr.edu

Research Group Website: <https://hep.syr.edu/>

Primary CNF Tools Used: DISCO Dicing Saw, Westbond 7400A Ultrasonic Wire Bonder, Everbeing EB-6 Probe Station with Keithley 4200 SMU unit

Abstract:

Future particle detectors will require fast timing capabilities to handle the high luminosities planned for collider experiments. Research and development into ultrafast silicon detectors such as low gain avalanche diodes is needed to reach resolutions on the order of 10 picoseconds. Multiple fabrication parameters, including implantation energy, thickness, and mask area need to be optimized for sensing large quantities of particles in high radiation environments. Several of these design parameters are being tested, with goals to characterize design parameters of low gain avalanche diodes for precision timing applications in high energy particle detectors.

Summary of Research:

The future of particle physics as a field relies on heavy research and development in instrumentation motivated by the physics goals of the next generation of experiments. Proposed future collider experiments boast higher luminosities, meaning – from a detector standpoint – large influxes of particles and radiation over short timescales. The ability to attach a precise time stamp on the order of 10 picoseconds to position or energy measurements becomes crucial, with broad potential to be transformative not only in particle physics instrumentation, but also in other research areas such as medical imaging [1-3].

Low gain avalanche diodes are good candidates for use in both tracking detectors and hybrid calorimeters including layers with high granularity and timing resolutions. The added gain layer at the junction creates a high electric field, leading to charge multiplication and an amplified signal with a sharp rise time, thus yielding

good timing resolution [4]. Multiple parameters—including active area, thickness, and gain—must be tailored to the specific granularity, radiation hardness, and acceptance requirements of a given detector system. Ten 4-inch wafers with arrays of silicon low gain avalanche diode sensors are at various stages of production with varying fabrication parameters. Figure 1 shows a rough schematic of the masks used; each wafer includes sensors with active areas between 3 and 10 square millimeters.

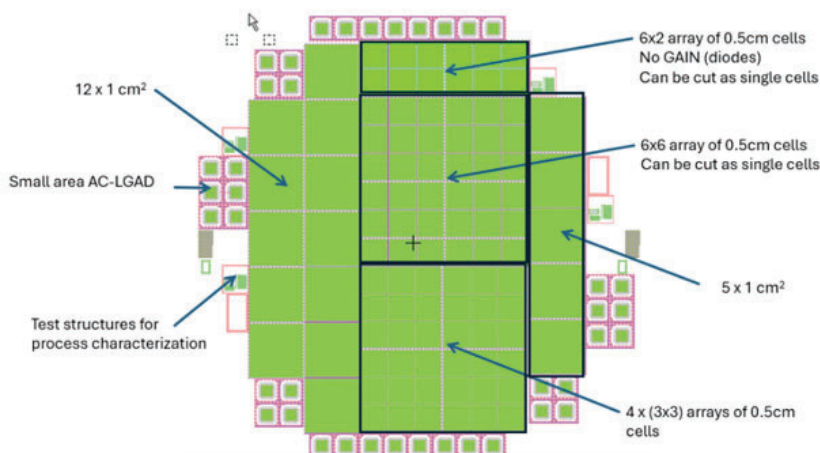


Figure 1: Rough schematic of masks used for wafer fabrication.

Each wafer has a set of test structures, as well as diodes and low gain avalanche diodes of different sizes. Pairs of wafers are being fabricated with different implantation energies and epitaxial thicknesses.

The first sets of wafers, including pre-diced prototypes, are now ready to be tested. Testing will include current vs voltage and capacitance vs voltage characterizations to be done using a combination of Syracuse's facilities and the Everbeing probe station at Cornell. After characterization, wafers will be diced using the DISCO dicing saw before being mounted to printed circuit boards and wirebonded. Wirebonding will be done primarily with Syracuse's Hesse bonder, with the Westbond 7400A Ultrasonic Wire Bonder to be used should complications arise. Once the low gain avalanche diode samples are mounted and bonded, the devices will be tested using transient current technique to study the differences in signal formation and to determine spatial and timing resolutions.

Conclusions and Future Steps:

Low gain avalanche diodes are promising sensors to be used in upcoming particle collider experiments, but more testing is needed to determine the precise fabrication parameters to best optimize to specific designs. Prototype wafers will be tested for electrical characteristics using a variety of probe stations before being diced using the DISCO Dicing Saw and wire bonded to custom printed circuit boards. After dicing, the samples will undergo electrical tests before they are wire bonded to readout boards for further study. Comparisons between the low gain avalanche diodes and standard silicon diodes

will be made to further explore the capabilities and limitations of different solid-state detectors for particle physics applications.

References:

- [1] W. Krüger et al., "LGAD technology for HADES, accelerator and medical applications", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 1039, 167046 (2022).
- [2] S. Dharani, "Particle Identification using Time of Flight in the International Large Detector ILD", Bachelorarbeit (Universität Leipzig, 2018), p. 41, <https://bib-pubdb1.desy.de/record/414330>.
- [3] S. V. Chekanov et al., "Physics potential of timing layers in future collider detectors", JINST 15, P09021 (2020), arXiv:2005.05221.
- [4] A. Apresyan et al., "Measurements of an AC-LGAD strip sensor with a 120 GeV proton beam", JINST 15, P09038 (2020), arXiv:2006.01999.