Sensor Development for Picosecond Timing

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Primary CNF Tools Used: DISCO Dicing Saw, Westbond 7400A Ultrasonic Wire Bonder

Abstract:

Future particle detectors will require fast timing capabilities to handle the high luminosities planned for collider experiments. Research and development into 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 quanties 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. Prototype development is currently underway; the first wafers will be ready within the next six months.

Summary of Research:

The future of particle physics as a field will rely 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, 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 sensors are at various stages of production with varying fabrication parameters. Figure 1 shows a rough schematic of the masks used, which include sensors with active areas between 3 and 10 square millimeters.

Manufacture-side delays in wafer productions due to issues with contact metallization have limited production progress, thus limiting facility use. These technical hurdles are now resolved, and no further roadblocks are anticipated. A full set of pre-diced prototypes by the manufacturer are expected within the next six months; some smaller samples and partial wafers are already available and will need to be diced with the DISCO dicing saw. The Westbond 7400A Ultrasonic Wire Bonder has been used for wire bonding some of these samples to printed circuit boards.

Preliminary electrical testing of 3mm and 10mm square pads shows that increasing active area, and thus, capacitance, allows for more current to flow through the device, while the depletion voltage stays the same. Figure 2 shows a current vs voltage characterization curve that compares the two devices. In the coming weeks, the devices will be tested using transient current technique to study the differences in signal formation and to determine spatial and timing resolutions.

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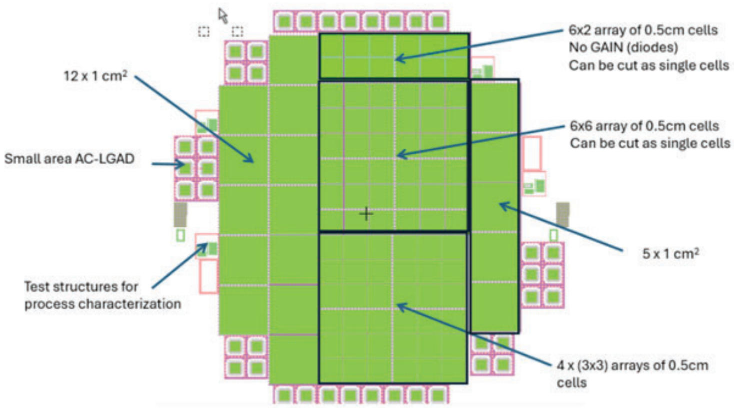

Figure 1: Rough schematic of masks used for wafer fabrication. Each wafer has a set of test structures, as well as diodes and low gain avalanche diodes of different sizes. Pairs of wafers are being fabricated with different implantation energies and epitaxial thicknesses.

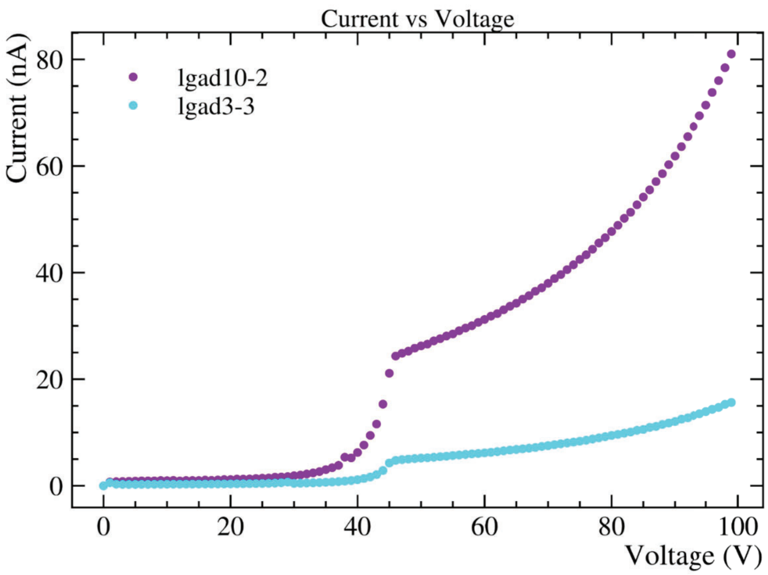

Figure 2: Current vs applied voltage for 10mm (lgad10-2; top curve) and 3mm (lgad3-3; bottom curve) devices. Both low gain avalanche diodes tested are from the same wafer and have the same epitaxial thickness and implantation energy.

Conclusions and Future Steps:

As more devices become available, they will be tested before being wire bonded at Syracuse University. For the periods of time in which the Syracuse wire bonder is down, the Westbond 7400A Ultrasonic Wire Bonder will be used. In addition to the prototypes from the manufacturer, several partial wafers from Hamamatsu with standard silicon diodes are being prepped to be diced using the DISCO Dicing Saw. After dicing, they will undergo electrical tests before they are also wire bonded to readout boards for further study. Comparisons between the low gain avalanche diodes and the standard silicon diodes will be made to further explore the capabilities and limitations of solid-state detectors for particle physics applications.

References:

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