PRECISION TIMING DETECTORS FOR FUTURE COLLIDERS

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Thematic Areas

- IF3: Solid State Detectors and Tracking
- IF7: Electronics/ASICs

1 Introduction

The next generation of high energy physics colliders call for major advances in tracking detector technology. For example, the proposed FCC-hh calls for a tracker with $5\,\mu\mathrm{m}$ spatial resolution per hit and $5\,\mathrm{ps}$ time resolution per track, in order to disentangle the expected 1000 proton-proton collisions per bunch crossing [1, 2, 3].

Low-Gain Avalanche Detectors (LGADs), developed for High Luminosity LHC experiments have demonstrated precise time resolution $(30\,\mathrm{ps})$, but only coarse position resolution $(1\,\mathrm{mm})$ [4]. With standard LGADs, pixel sizes of on the order of 1×1 mm are necessary to achieve reasonable fill factors and gain uniformity. Recent advances in design, including AC-LGADs and Trench-Isolated LGADs, can extend the LGAD concept to smaller pitch sizes, and spatial resolution on the order of $10\,\mu\mathrm{m}$ [5, 6, 7].

Another avenue for advancement in LGAD design is the possibility to develop sensors based on Depleted Monolithic Active Pixel Sensors (DMAPS) technology using a CMOS process. Monolithic sensors are expected to significantly reduce costs while maintaining radiation hardness and time resolution performance.

2 Proposal

In this LOI, we focus on a selection of new technologies that extend the LGAD concept to smaller granularity and improved spatial resolution. We propose to study these technologies in more detail as part of the Snowmass Instrumentation Frontier.

2.1 AC-LGADs

The key features of AC-LGADs are a continuous gain layer, a resistive n+ layer, and AC-coupled readout electrodes. Because the gain layer is uninterrupted, AC-LGADs inherently have a fill factor of 100%, and electrodes can be designed with smaller pitch and size than Standard LGADs. A key feature of AC-LGADs is the signal sharing between electrodes, which can be used to obtain position measurements with resolution smaller than $(\mathrm{bin\ size})/\sqrt{12}$. One major advantage of AC-LGADs is that they can obtain the spatial resolution necessary for future colliders with a reduced number of readout channels.

Recent studies have shown that AC-LGAD sensors with a pitch of at least $100\,\mu\mathrm{m}$ result in spatial resolution better than $5\,\mu\mathrm{m}$ [8], demonstrated with laser. Test beam measurements have also verified sensors have 100% fill factor and time resolution on par with standard LGADs [9].

2.2 Trench LGADs

The Trench Isolation technique has been demonstrated to reduce the size of the interpad gap region to less than $10\,\mu\text{m}$. In comparison, standard LGADs require a Junction Termination Edge to avoid premature breakdown, and p-stops, which result in large interpad gaps of on the order of 50-80 μm. The smaller interpad gap of Trench LGADs enable the production of sensors with higher fill factor and smaller pixel size, making them excellent candidate sensors for future colliders.

2.3 Monolithic timing detectors

Monolithic sensors combine the active detector with part or all of the readout circuitry into a single piece of silicon. By eliminating the need for bump-bonding, monolithic sensors can significantly reduce costs, while maintaining detector performance and withstanding high radiation doses.

There has been some success in designing monolithic sensors optimized for timing performance. A first version of the CACTUS (Cmos ACtive pixel Timing μ Sensor) design, 1mm^2 pixels in $150\,\text{nm}$ CMOS technology, demonstrated the reliability of the manufacturing process, the ability to apply high breakdown voltages, and good uniformity [10] Future iterations will focus on demonstrating precise time resolution and sensor efficiency. A particularly interesting extension is to design monolithic AC-LGAD or Trench-Isolated sensors with integrated electronics.

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