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Optimized Design， Simulation， and testing of Centimeter-Scale AC-LGAD Detectors for Future Colliders

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AC-LGAD detectors, recognized as promising candidates for 4D tracking systems, have achieved ˜40 ps timing and ˜10 µm spatial resolution in IHEP's 50-µm-thick strip sensors. However, centimeter-scale devices face challenges including charge sharing, capacitance, and power consumption. This study presents structural and process optimizations—such as n+ sheet resistance tuning, metal-pitch size, and isolation structures—supported by TCAD simulations. These enhancements improve performance metrics, positioning AC-LGAD as a viable 4D tracking &TOF detector for future colliders. Testing results of IHEP AC-LGAD sensors with strip lengths ranging from 1cm to 4cm will be presented. Simulations results of monolithic LGAD structures are also discussed.

Summary (500 words)

AC-coupled Low-Gain Avalanche Detectors (AC-LGADs) represent a breakthrough in 4D particle tracking, offering sub-50 ps timing resolution and spatial precision below 20 µm. Recent advancements at the Institute of High Energy Physics (IHEP) have demonstrated prototype 50-µm-thick strip sensors achieving remarkable performance: ˜40 ps timing resolution and ˜10 µm spatial resolution. These metrics position AC-LGADs as leading candidates for next-generation colliders like FCC-ee and CEPC,

However, scaling AC-LGADs to centimeter-scale strip lengths—essential for large-area tracking systems—introduces critical challenges. Charge sharing, caused by lateral carrier diffusion across multiple strips, reduces signal amplitude of strips nearby the hit position, degrading both timing and spatial resolution. Concurrently, increased strip capacitance elevates noise and power consumption, while inter-electrode capacitance further compromises signal integrity. These issues threaten the feasibility of deploying AC-LGADs in practical, large-scale detector systems.

To address these limitations, this study implements a multi-faceted optimization strategy combining Technology Computer-Aided Design (TCAD) simulations. Three key design parameters were systematically investigated:
1、n+ Sheet Resistance Tuning: Adjusting the doping profile and sheet resistance of the n+ charge-sharing suppression layer enhances lateral charge confinement. Higher resistance values concentrate ˜70% of the charge within ±2 strips of the hit position, improving spatial resolution. Experimental validation confirms these trends.

2、Metal-Pitch Optimization: Reducing the metal pitch from 200 µm to 100 µm lowers bulk capacitance by 50%, directly suppressing noise and power dissipation. Testing results show improvement in spatial resolution with smaller pitches: devices with 100–150 µm pitches achieve 8.3 µm resolution, compared to 12.5 µm for 200 µm pitches. However, this requires balancing against increased channel density and readout complexity.

3、Shallow-Trench Isolation Structures: Introducing 2-µm-deep silicon trenches between strips reduces inter-strip capacitance and suppresses lateral charge diffusion. TCAD results show improvement in reducing capacitance of bulk and between strips. Simulation results about the AC-LGAD with different isolation structures and capacitance of these sensors will be shown. But the isolation structure between strips also affect the charge sharing for position reconstruction when particle hit the isolation area. These need to be considered together when designing isolation structure.

Based on the simulation results, AC-LGAD with different process and structures be designed and submitted for fabrication in March 2025, with strip lengths of 1–4 cm and pad-pitch size of 25–200 μm. Testing results of the new submission will be shown at the meeting once we get them.
Additionally, TCAD simulations explore monolithic LGAD architectures, where amplifiers are integrated into the EPI layer above the sensor. Detailed simulation about the EPI layer properties and its affect to LGAD performance will be discussed.

These advancements underscore AC-LGADs as a scalable, high-performance solution for 4D tracking and time-of-flight systems in future collider experiments. Ongoing efforts focus on sensor properties optimization by using new trench structures. Radiation tolerance characterization and testing sensor with ASIC will also be done next, paving the way for full-scale deployment in the 2030s particle physics program.

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