Snowmass2021 - Letter of Interest

Silicon Pixel Detectors in Space

Thematic Areas: (check all that apply □/■)

□ (IF1) Quantum Sensors
■ (IF2) Photon Detectors
■ (IF3) Solid state tracking
□ (IF4) TDAQ
□ (IF5) MPGD
□ (IF6) Calorimetry
□ (IF7) Electronics ASICs
□ (IF8) Noble elements
□ (IF9) Cross Cutting

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Abstract:

Silicon pixel detectors have a wide range of applications. This letter supports the common development of monolithic CMOS pixel detectors with the goal of developing low power pixel sensors that can be sensitive to Compton Scattering and Minimum Ionizing Particles. This type of technology may be highly beneficial to experiments at future electron colliders, space applications, and other experiments where a low radiation length is key to precision performance. The intent of this letter is to explore the range of applications that would benefit from this technology and the potential physics benefit in order to promote collaboration across disciplines.

Introduction: Over the past several decades, silicon strip detectors (SSDs) have become a key detector technology in particle physics experiments both on the ground and in space. SSDs provide sufficient spatial and energy resolution as well as good timing capabilities with the main benefit of not requiring high voltages or pressurized gas. An SSD is an arrangement of strip implants on a wafer of Si that act as charge collecting electrodes. The strips are patterned on a low doped fully depleted silicon wafer and form a one-dimensional array of diodes. By connecting each of the metalized strips to a separate charge sensitive amplifier, we can measure the position of the interaction within the bulk Si material. To make two dimensional detectors, we can either apply orthogonal strips on the the backside of the wafer (double sided silicon strip detectors - DSSDs) or use an additional layer of SSDs, depending on the application. At lower energies, in the regime where the dominant interaction within the bulk Si is via Compton scattering, it is particularly important to have multidimensional readout because the Compton scattered electron will often become absorbed within a single layer of detector material. The main limitation of these DSSDs in particular is the technical complication of manufacturers to produce them and the process is both time consuming and expensive.

One promising alternative to both SSDs and DSSDs currently being developed in the particle physics community is monolithic CMOS Si pixel sensors. Monolithic detectors do not require a separate readout ASIC. Instead, they have signal amplification and readout circuits directly embedded in each pixel, reducing the pixel size, which improves spatial resolution, and limits the amount of passive material, which improves energy resolution. The design reduces both the overall mass of the detector and the payload size. Integrated designs have the potential to greatly reduce power consumption due to more efficient amplification (compared to a similar detector without on-board readout).

Developments in CMOS Silicon Pixel Detectors: The motivation driving the development of CMOS detectors in particle physics is to join the two main functionalities of silicon detectors: collect the deposited energy of particles interacting in the detector and amplify and discriminate that signal. This can be accomplished with the CMOS process. Combining these functions yields a tighter integration of the detector structure, fewer steps of integration, and a lower cost. **Because of the wide-spread commercial use of CMOS sensors in industry, the CMOS detectors are mass-produced making large-scale ($\sim$100s m^2) Si-based detectors easily realizable.**

The particle physics community, specifically the ATLAS, ALICE and Mu3e Collaborations, have invested heavily in fully monolithic silicon pixel CMOS sensors as a candidate for current and future upgrades of the Large Hadron Collider (LHC) [1–3;5]. Two important characteristics of CMOS devices are relatively low noise and low static power consumption compared with other logic families. Monolithic pixel sensors (**Fig. 1**) have amplification and readout circuits directly embedded on each pixel which enables reductions in pixel size improving spatial resolution and reduction in inactive material improving energy resolution. The design reduces the overall mass of the detector improving the spatial resolution and reducing the size of the payload. Integrated designs have the potential to greatly reduce power consumption due to more efficient amplification (compared to a similar detector without on-board readout). The ATLAS Collaboration's effort (ATLASPix) has focused on upgrades to their spatial resolution, radiation hardness and extremely fast timing.

Future Applications: Because of their relatively lower power and mass requirements and high spacial and energy resolution capabilities CMOS silicon pixel detectors have a broad range of applications from next generation high intensity particle experiments to space-based gamma-ray telescopes.

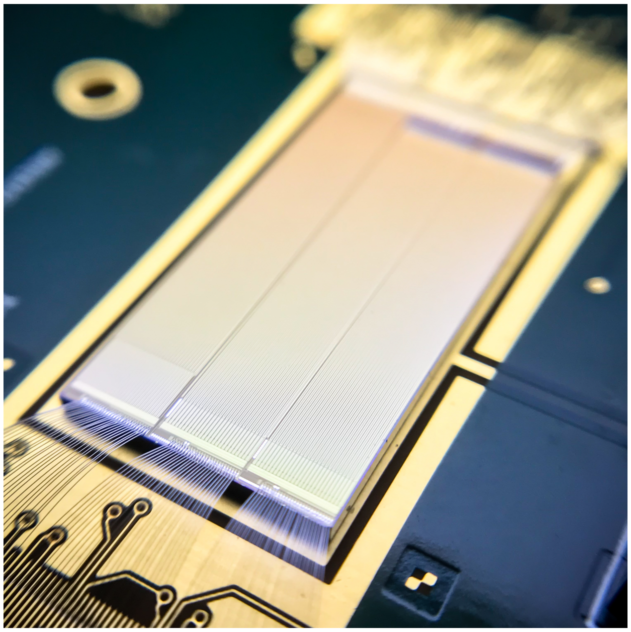

Figure 1: ATLASPix (left) has implemented CMOS-based technology for use in the ATLAS experiment. Although the current detectors are only $\sim$cm^2 in area (as shown), these detectors are easily scalable to 10s m^2 or even 100s m^2 by Si foundries. Currently large-scale foundries produce **100s** m^2 of CMOS Si-detectors per month. Pixel detectors are currently deployed in space for dosimetry and cosmic ray measurements[4;6] and similar performances are to be expected after optimization of the monolithic pixel sensor design. **The process of producing CMOS detectors is fully supported by the consumer electronics industry guaranteeing the support of this technology in the foreseeable future.**

References

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