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INVITED: Monolithic Active Pixel Sensors for High-Energy Physics Applications

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The CMOS Monolithic Active Pixel Sensors (MAPS) technology combines sensitive volume and front-end readout logic in the same piece of silicon. Invented in the ‘90s as an imaging device, only in the last decade MAPS achieved the radiation tolerance, power consumption and integration time which are required to equip tracking detectors for high-energy physics experiments.

The first example of MAPS-based vertex detector in a collider experiment is the STAR Heavy Flavor Tracker (HFT) [1]. It consisted of 0.16 m2 of MIMOSA series sensors (developed by the IPHC PICSEL group) arranged on two layers. The sensor implemented a rolling-shutter readout architecture and was thinned down to 50 µm to minimize the material budget. The HFT operated from 2014 to 2016 at RHIC proving the CMOS MAPS technology as suitable for high-energy physics experiments.

Following this successful experience, the CMOS MAPS technology was chosen to upgrade the Inner Tracking System (now ITS2 [2]) of the ALICE Experiment at LHC. The ALPIDE chip, based on 180 nm TowerJazz CMOS Imaging Process, was specifically developed to equip the seven ITS2 layers, covering about 10 m2 of active area. The manufacturing process of the chip, implemented on wafers with a high-resistivity epitaxial layer, provides deep p-wells, allowing for the use of full CMOS circuits in the active area. The readout architecture is hit driven, with minimal power consumption and
integration time. After a multi-year construction process which involved more than 10 institutes, the ITS2 is now fully integrated in the ALICE Experiment and included in the data-taking campaign since 2022, while other Experiments, like sPHENIX at RHIC and MPD at NICA, have adopted replicas of this detector sections for their trackers.

In the continuous effort to improve the performance of the CMOS MAPS and extend their range of applications, an aggressive R&D program has started to develop wafer-size sensors based on a stitched design, with the possibility of thinning them down to 30-40 µm to produce flexible active detectors. A first example of such a novel sensor concept is being pursued for a further upgrade of the ALICE ITS, called ITS3 [3], which is now exploring the 65 nm TPSCo CMOS Imaging Process to build a truly cylindrical ultra-thin vertex detector to be installed in 2026. The same sensor is of interest for the tracking system of the future ePIC Experiment at EIC and will represent a proof of principle for the tracking system of the ALICE 3 Experiment, which has been proposed to replace ALICE after 2034.

This contribution will outline the evolution of the CMOS MAPS technology through the experience and the lessons learned from the implementation of these MAPS-based particle detectors for high- energy physics, also providing an outlook on the plans for future applications.

[1] G. Contin, et al., NIM A 907 (2018), 60-80,
[2] F. Reidt, ALICE Collaboration, NIM A 1032 (2022), 166632
[3] G. Aglieri Rinella, ALICE Collaboration, NIM A 1049 (2023), 168018

Presenter: CONTIN, Giacomo (Universita e INFN Trieste (IT))

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