

Non-ionizing radiation hardness of CMOS Monolithic Active Pixel Sensors manufactured in a $0.18\mu\text{m}$ CMOS process*

D. Doering¹, M. Deveaux¹, B. Linnik¹, and J. Stroth^{1,2} for the CBM-MVD collaboration

¹Institut für Kernphysik, Goethe-University Frankfurt, Germany; ²GSI Darmstadt, Germany

Modern $0.18\mu\text{m}$ CMOS processes provide numerous features, which may allow for decisive progresses in the read-out speed and the radiation tolerance of the CMOS Monolithic Active Pixel Sensors (MAPS) to be used in the Micro-Vertex-Detector of CBM. Together with the PICSEL group of IPHC Strasbourg, we aim to exploit those features by migrating the successful architecture of our sensors toward this novel technology. This work reports about our findings on the first prototypes manufactured with the new technology.

A weak point of CMOS sensors is the slow diffusion of signal charge in the undepleted active medium. A sufficient radiation hardness was only achievable with very small pixels, which do not provide the required readout speed. A few years ago, this obstacle was alleviated by the upcoming availability of CMOS processes providing a high-resistivity epitaxial layer of $1\text{ k}\Omega\text{cm}$. It could be demonstrated that this increases the non-ionizing radiation hardness by more than one order of magnitude. Therefore pixels of this high-resistivity AMS-0.35-process having a pitch of $20 - 30\mu\text{m}$ achieved the design goal of a non-ionizing radiation hardness in the order of $10^{13}\text{ n}_{\text{eq}}/\text{cm}^2$ [1].

Using this technology, a first vertex detector based on CMOS sensors is taking data in the heavy-ion experiment STAR since 2014.

Achieving the required non-ionizing radiation hardness, the ionizing radiation hardness and read-out speed of sensors in the AMS-0.35-process were not sufficient for the application in modern vertex detectors, e.g. in ALICE and CBM. Therefore, a novel *TOWER* – $0.18\mu\text{m}$ process was exploited and found to provide a higher tolerance to ionizing radiation [2]. Moreover, the smaller feature size allows for the integration of a more complex logic into the pixel providing a faster read-out. An additional feature of this process is the use of very high resistivity epitaxial layers up to $6\text{ k}\Omega\text{cm}$. It was expected, that this would improve the non-ionizing hardness further, which would allow for larger pixels and therefore for a faster sensor readout.

To test this assumption, the prototype sensor MIMOSA-34 was designed, irradiated to $10^{13}\text{ n}_{\text{eq}}/\text{cm}^2$ and tested hereafter. The sensor provides elongated pixels with a pixel pitch between $22\mu\text{m} \times 33\mu\text{m}$ and $33\mu\text{m} \times 66\mu\text{m}$. Figure 1 shows the response to photons of an Fe-55-source of the largest pixel. Its charge collection efficiency is

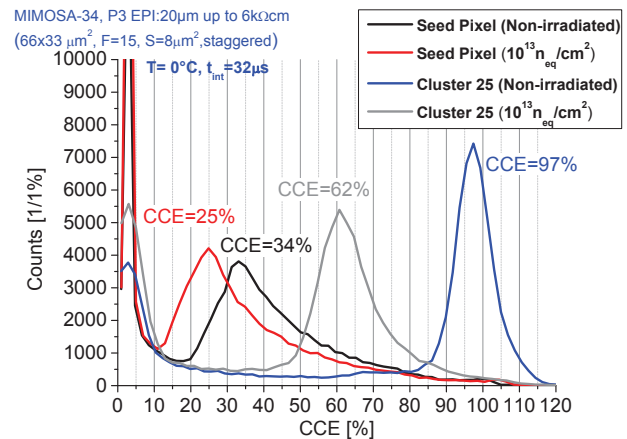


Figure 1: Signal response to photons after a radiation dose of $10^{13}\text{ n}_{\text{eq}}/\text{cm}^2$.

reduced by radiation damage from 34% to 25% for the seed pixel and from close to 100% to 62% for the charge of the full cluster. The signal to noise ratio, as measured with a Sr-90- β -source, decreases from 49 to 35. According to our experience with other sensors, this signal to noise ratio is sufficient to provide an excellent detection efficiency.

In conclusion, the novel process is likely to provide a tolerance to $10^{13}\text{ n}_{\text{eq}}/\text{cm}^2$ as needed for CBM even in combination with a $33\mu\text{m} \times 66\mu\text{m}$ pixel pitch. Consequently, this pitch seems now limited by the need for matching a spatial resolution of $5\mu\text{m}$ rather than by the radiation tolerance. The latter allows for increasing the pixel pitch of the vertex detector, which comes with significant advantages in terms of readout speed and reduced power consumption.

References

- [1] D. Doering et al., Pitch dependence of the tolerance of CMOS monolithic active pixel sensors to non-ionizing radiation, Nuclear Instruments and Methods A, **730**, 111, 2013.
- [2] D. Doering et al., Noise performance and ionizing radiation tolerance of CMOS Monolithic Active Pixel Sensors using the $0.18\mu\text{m}$ CMOS process, Journal of Instrumentation, **9(05)** C0551, 2014.

*This work has been supported by BMBF (05P12RFFC7), HIC for FAIR and GSI.