Radiation tolerance of a CMOS Monolithic Active Pixel Sensor produced in an $0.18\mu m$ CMOS process*

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So far CMOS active pixel sensors (MAPS) matched the requirements of CBM in terms of spatial resolution and material budget. During several years, their radiation tolerance has been adapted to the needs of this experiment. In 2012, the radiation tolerance of a sensor, produced in an 0.18 µm CMOS process was tested. It could be demonstrated that this sensor provides the radiation tolerance required for CBM at SIS-100.

In a first step, the tolerance of MAPS to non-ionizing radiation was improved by more than one order of magnitude. This was reached by partially depleting the active volume of the sensors [2, 3]. Still, the tolerance of the sensors to ionizing radiation remained to be improved. This was done by migrating a simple imager sensor from the established 0.35 µm process to an 0.18 µm process. It was hoped that this would allow for exploiting the known higher intrinsic radiation tolerance of deep sub-micron CMOS processes. Besides providing benefits in terms of radiation tolerance, the 0.18 µm process comes with additional features which are expected to allow for a better time resolution of the device.

To explore the new technology, three different prototypes named MIMOSA-32 (V1-3) were designed by the PICSEL group of the IPHC and tested in the laboratory and at the CERN-SPS.

Each flavor of MIMOSA-32 is composed of arrays of 32 different pixels with various parameters, which were put to study selected pixel parameters in a systematic way. To perform radiation tolerance studies, some of the sensors were irradiated with combined non-ionizing and ionizing doses of $10^{13}\ n_{eq}/cm^2$ and 1 Mrad. Those radiation doses match the design requirements of CBM running at SIS-100[1].

After being irradiated, the sensors were tested by the PICSEL group at the CERN-SPS. Some results for the particularly unfavorable running conditions of $T > +15\ °C$ and for relatively high pixel pitches of $20 \times 40\ \mu m^2$ are shown in figure 1. The non-irradiated sensor shows an excellent detection efficiency of $\gtrsim (99.78 \pm 0.08)\%$ independent of the operation temperature. The detection efficiency of the irradiated sensor keeps a very good detection efficiency of $(98 \pm 0.3)\%$ at even $T = +30\ °C$. When operating the sensors with a slight cooling at $T = +15\ °C$ this detection efficiency raises to $\gtrsim (99.5 \pm 0.3)\%$.

This work was complemented at IKF with studies exploring the properties of the sensor at higher ionizing doses of up to 10 Mrad. The gain shrinks slightly about 5% after 3 Mrad, while the noise of the sensor remains mostly constant. After a dose of 10 Mrad, the gain of the sensor is reduced by a factor of two and the noise raises by about 40%, which is not yet fully understood. The signal-to-noise ratio of this sensor was measured with a Sr-90-source and found to remain above 30 (Most Probable Value). This appears sufficient for obtaining a satisfactory detection efficiency for minimum ionizing particles.

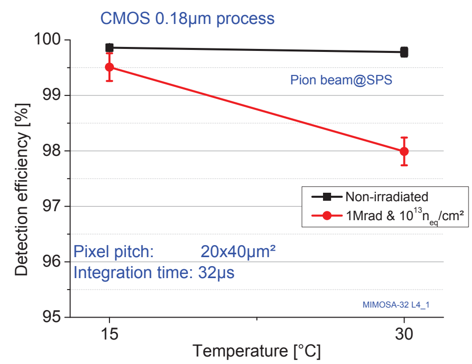

Figure 1: Detection efficiency of elongated pixels at a coolant temperature of $T = +15\ °C$ and $T = +30\ °C$ before and after irradiation ($1\ \mathrm{Mrad} + 10^{13}\ \mathrm{n_{eq}/cm^2}$).

We conclude MAPS manufactured in an $0.18\ \mu m$ CMOS process combined with a high-resistivity epitaxial layer provide the radiation tolerance required by the micro-vertex-detector of CBM at SIS-100. Moreover, there are first evidences that the technology might also match the higher needs of CBM at SIS-300. While this conclusion appears robust for simple imagers, it remains to be confirmed for the more complex sensors with integrated data processing circuits.

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References

[1] M. Deveaux. Status of the MVD - Getting prepared for SIS-100, 2011. CBM Collaboration Meeting Beijing.

[2] A. Dorokhov et al. Imp. rad. tol. of MAPS using a depleted epi layer. *NIM A*, 624(2):432–436, 2010.

[3] M. Deveaux et al. Rad. tol. of a column parallel cmos sensor with partially depleted sensitive volume. *NIM A*, 583(1):134 – 138, 2010.