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Increased radiation tolerance of CMOS sensors with small collection electrodes through accelerated charge collection

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Mini-MALTA is a Monolithic Active Pixel Sensor prototype developed in the TowerJazz 180 nm CMOS imaging process, with a small collection electrode design (3um), and a small pixel size (36.4 um), on high resistivity substrates and large voltage bias. It targets the outermost layer of the ATLAS ITK Pixel detector for the HL-LHC. This design addresses the pixel in-efficiencies observed in MALTA and TJ-Monopix to meet the radiation hardness requirements. This contribution will present the results from characterisation in particle beam tests that show full efficiency up to 1E15 neq/cm2 and 70 Mrad.

Summary

Several monolithic CMOS sensor technologies have been considered for the outer pixel layer of the ATLAS detector upgrade for the High-Luminosity LHC [1], requiring radiation tolerance to about 2E15 1 MeV neq/cm2 and 70 Mrad. The TowerJazz 180 nm CMOS imaging process with small, low capacitance collection electrodes offers a better combination of analog performance and power consumption. It allows full CMOS circuitry in the pixel, which in combination with a modification in the process allows full depletion of the epitaxial layer. First measurements performed on this technology showed improved radiation tolerance by an order of magnitude with respect to the un-modified process [2]. Following these results, two large scale prototypes were designed and fabricated. The TJ Monopix that used the well-known synchronous column drain readout architecture, and the MALTA that implemented a new asynchronous readout offering lower power consumption and higher matrix bandwidth. However, both prototypes showed severe charge collection inefficiencies near the pixel edges after irradiation despite the process modification [3-4]. Detailed investigation including TCAD simulations [5] showed the low lateral electric field near the pixel borders significantly increases the collection time for signal charge generated in that area, especially for larger pixel pitches. The study confirmed that the pitch increase from 25 and 30 micron of the relevant early test structures to 36.4 micron or more in the large scale prototypes caused a significant penalty. Two further sensor modifications were introduced to improve the lateral electric field at the pixel border and implemented on a new small prototype chip, the Mini-MALTA. The first sensor modification is the introduction of a gap in the low dose additional deep n-type implant, and the second is the introduction of a deep p-type implant, both near the pixel border. In addition to the sensor modifications the size of two NMOS transistors was increased in an effort to reduce the random telegraph noise observed on both TJ Monopix and MALTA. This paper presents first experimental results using source and test beam obtained with Mini-MALTA before and after irradiation. Efficiency measurements show significant improvement in the pixel edges. Thus confirm that both sensor and front-end modifications significantly improve the performance and bring sensors with 36.4 micron pixel pitch to practically full detection efficiency after irradiation up to 1E15 neq/cm2, an comparable with low energy proton irradiated devices up to 7.1e14 neq/cm2 and 94 Mrad.

[1] The ATLAS Collaboration, ATLAS Phase-II Upgrade Scoping Document, CERN-LHCC-2015-020
[2] H. Pernegger et al., 2017 JINST 12 P06008, https://doi.org/10.1088/1748-0221/12/06/P06008
[3] I. Caicedo et al, PIXEL 2018
[4] R. Cardella et al, PIXEL 2018
[5] M. Munker et al, PIXEL 2018

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