AIDA-2020-PUB-2019-004

AIDA-2020

Advanced European Infrastructures for Detectors at Accelerators

Journal Publication

Characterization Results of a HVCMOS Sensor for ATLAS

Ehrler, F. (KIT) *et al*

30 July 2018

The AIDA-2020 Advanced European Infrastructures for Detectors at Accelerators project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.

This work is part of AIDA-2020 Work Package **6: Novel high voltage and resistive CMOS sensors**.

The electronic version of this AIDA-2020 Publication is available via the AIDA-2020 web site <http://aida2020.web.cern.ch> or on the CERN Document Server at the following URL: <http://cds.cern.ch/search?p=AIDA-2020-PUB-2019-004>

NIMA POST-PROCESS BANNER TO BE REMOVED AFTER FINAL ACCEPTANCE

Characterization Results of a HVCMOS Sensor for ATLAS

F. Ehrler[a,*], M. Benoit[b], D. Dannheim[c], M. Kiehn[b], A. Nürnberg[a,c], I. Perić[a], M. Prathapan[a], R. Schimassek[a], T. Vanat[b], M. Vicente[b], A. Weber[a,d], H. Zhang[a]

[a] *Karlsruhe Institute of Technology, Germany*
[b] *Université de Genève, Switzerland*
[c] *Conseil Européen pour la Recherche Nucléaire, Geneva, Switzerland*
[d] *University of Heidelberg, Germany*

Abstract

High-voltage CMOS (HVCMOS) pixel sensors are depleted monolithic active n-in-p diode pixel sensors implemented in standard commercial CMOS processes. A substantial part of the readout electronics is placed inside each pixel. Due to high radiation tolerance and fast signal generation [1], HVCMOS sensors are going to be used (Mu3e, PSI) or are suggested for usage (ATLAS and CLIC, CERN) in High Energy Physics experiments. In this article characterization results of the ATLASpix_Simple sensor are presented. Special attention was paid to the novel time-over-threshold (ToT) measurement with adaptive sampling rate.

Keywords: HVCMOS, HVMAPS, Time walk correction by adaptive ToT, ATLAS, IsoPMOS, PPtB

1. Introduction

In 2017, four monolithic active pixel sensors and four small sensors have been produced in the AMS 180 nm technology aH18. They have been produced on wafers with different resistivities (20, 80, 300, 1000 Ωcm). MuPix8 aims for Mu3e experiment; three flavors of ATLASpix, two of CCPD [2] and one C3PD sensor [3] are designed for CERN applications.

For application in the fifth layer of ATLAS' pixel detector, the used sensors face several challenges: harsh radiation environment and high collision rate. At the same time, good spatial resolution and in-time efficiency (25 ns) have to be achieved.

Besides being designed in a proven to be radiation hard way, each sensors brings a different combination of unique features to meet these requirements: Isolated PMOS transistors for increased radiation hardness, Parallel Pixel to Buffer readout architecture and triggered readout for high rate applications, time walk correction by obtaining analog information by ToT measurement (indirect) or reading the signal height by ramp ADC (direct). Alternatively, time walk can be avoided using the two threshold method [4].

This article puts special focus on ToT measurements and the substrate resistivity's influence on signal strength on the ATLASpix_Simple matrix.

2. Key Data of ATLASpix_Simple

The pixel matrix consists of 25 columns and 400 rows of $130 \times 40\ \mu m^2$ large pixels. This leads, together with the digital periphery, to a total chip size of about $3 \times 20\ mm^2$. An amplifier is located inside each pixel with an 1-to-1 connection to the digital periphery. The time stamp speed is up to 80 MHz with a register size of 10 bit. The analog information is 6 bit wide. The optional isolation of PMOS transistors is illustrated in Fig. 1.

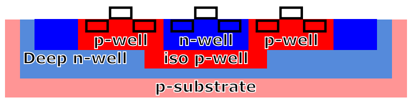

Figure 1: Isolated PMOS option: n-wells containing PMOS transistors are isolated from deep n-well by 'iso-p-well'.

3. Novel Time-over-Threshold Measurement

ToT can be used to determine the original signal height, which is related to time walk. Thereby, ToT can be used to

*Corresponding author
Email address: `felix.ehrler@kit.edu` (F. Ehrler)

correct for time walk in offline or online analysis. In order to minimize the additional data load introduced by ToT, resolution is limited to 6 bit. Individual adaptive sampling of both edges of the signal pulse ensures that with the limited bandwidth a maximum of information can be transmitted. Fig. 2 shows how the rising edge with low jitter is sampled with higher frequency, whilst the falling edge with high jitter is sampled with a lower frequency. A higher sampling rate would not lead to a gain in information, as jitter defines a lower boundary on resolution.

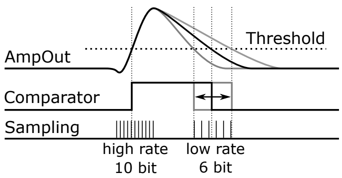

Figure 2: The precision of the threshold crossing time stamps can be adjusted individually, according to the precision of the analog information.

4. Measurements

The subsequent measurements have been performed on samples with 400 Ωcm resistivity using an in-house developed characterization setup. The sensor's readout speed was 800 MHz, corresponding to a time stamp speed of 40 MHz. The secondary timestamp (ToT) was running at 20 MHz.

Test signal injections of known charge were used to calibrate ToT. Fig. 3 shows that the relation can be assumed linear for a wide range and flattens for very high signals. Since time walk correction is important for small signals the nonlinearity is not a problem.

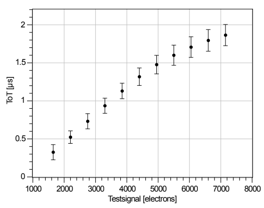

Figure 3: ToT as a function of signal strength (calibrated charge injections)

For calibration of ToT, X-ray fluorescence is used with seven target elements (Fig. 4).

Electrons from a ^{90}Sr-source are used to study the signal of charged particles in the sensor. The most probable value (MPV) of ToT is measured as a function of the depletion voltage (Fig. 5). In theory MPV is proportional to the square root of resistivity. At 70 V, the signal is 7500 e. This is an increase of ~60 % compared to the same sensor with 80 Ωcm.

Element	#e⁻ in Si
Fe	1778
Cu	2235
Zn	2399
Mo	4855
Ag	6156
In	6724
Sn	7018

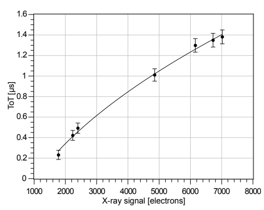

Figure 4: Left: The used targets and their expected charge generated in Si. Right: ToT as a function of signal strength.

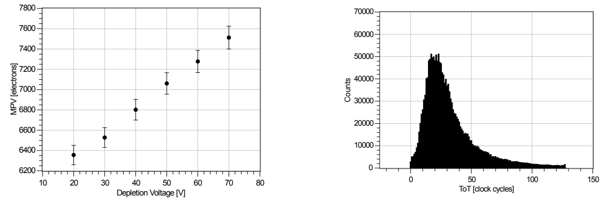

Figure 5: Left: MPV of ^{90}Sr electrons as a function of depletion voltage. Right: Landau-distribution of ^{90}Sr at 40 V.

5. Testbeam results

In October 2017, a beam test at SPS (CERN) was conducted. The device under test had 80 Ωcm substrate. The measured efficiency was >99.5 %. Before time walk correction, the time resolution had a sigma of 45 ns. Using ToT, it has been improved to 33 ns (Fig. 6). In this beam test, time resolution was limited by reduced operational speed (100 ns time stamps). Thereby the theoretical time resolution limit is 28.9 ns.

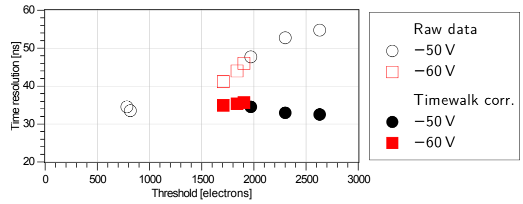

Figure 6: Time resolution as a function of threshold before and after correction.

6. Conclusion

The sensors work as expected. Testbeam showed that detection efficiency is > 99 %. Further, it was shown that ToT can be used to compensate for time walk. Time walk measurements on a sensor at full operational speed using precision laser pulses and another testbeam are planned.

Acknowledgments

This work was supported by the H2020 project AIDA-2020, GA no. 654168. and Institute of Experimental Particle Physics (ETP), KIT.

References

[1] I. Perić, Status of HVCMOS developments for ATLAS, JINST 12 (2017) C02030.

[2] I. Perić, Active pixel sensors in high-voltage CMOS technologies for ATLAS, JINST 7 (2012) C08002.

[3] I. Kremastiotis et al., Design and standalone characterisation of a capacitively coupled HV-CMOS sensor chip for the CLIC vertex detector, JINST 12 (2017) C12030.

[4] A. Weber, MuPix8 Large Area Monolithic HVCMOS Pixel Detector for the Mu3e Experiment, prepared for submission NIMA (2018).