PROCEEDINGS OF SCIENCE

MoTiC: Prototype of a Depleted Monolithic Pixel Detector with Timing

Stephan Burkhalter,[ab] **Lea Caminada,**[ac] **Aliakbar Ebrahimi,**[a,*] **Wolfram Erdmann,**[a] **Hans-Christian Kästli,**[a] **Beat Meier,**[a] **Branislav Ristić,**[b] **Tilman Rohe**[a] **and Rainer Wallny**[b]

[a] *Paul Scherrer Institute PSI,*
Forschungsstrasse 111, 5232 Villigen PSI, Switzerland

[b] *ETH Zurich, Institute for Particle Physics and Astrophysics*
Otto-Stern-Weg 5, 8093 Zürich, Switzerland

[c] *University of Zurich*
Winterthurerstrasse, 8057 Zürich, Switzerland

E-mail: aliakbar.ebrahimi@cern.ch

MoTiC is a prototype of a Depleted Monolithic Active Pixel Sensor capable of time measurements. The chip is produced in a modified LFoundry 110 nm process with a pixel pitch of 50 µm × 50 µm and three active thicknesses of 48, 100 and 200 µm. The chip comprises a number of different amplifier and sensor designs for evaluation. MoTiC was characterized with particle beams before irradiation. The characterization results presented in this paper demonstrate that a hit detection efficiency in excess of 99.8 %, a spatial resolution better than 5 µm and a coarse timing resolution better than 1.2 ns are achieved.

32nd International Workshop on Vertex Detectors (VERTEX 2023),
16-20 November 2023
Sestri Levante, Italy

*Speaker

PoS(VERTEX2023)044

1. Introduction

The high-energy physics group of the Paul Scherrer Institute (PSI) in collaboration with ETH Zürich has a generic R&D program for Depleted Monolithic Active Pixel Sensors (DMAPS) since 2019. The goal of this program is to develop position sensitive particle detectors capable of time measurements for possible applications at PSI in-house low-energy physics experiments. The aim is to develop detectors with a hit detection efficiency higher than 99 % before irradiation, a spatial resolution better than 10 µm and a timing resolution better than 1 ns.

The Monolithic Timing Chip, MoTiC, is produced in a modified LFoundry 110 nm CMOS process. The process modification and sensing elements have been developed by the ARCADIA collaboration [1, 2]. MoTiC features a pixel pitch of 50 µm × 50 µm and comes in two variants:

- MoTiC A: comprises of 5120 pixels arranged in 80 columns and 64 rows. There are 7 different amplifiers in different sections of the chip while all pixels have identical sensors;
- MoTiC B: has 3840 pixels arranged in 80 columns and 48 rows. It comprises 5 different sensor designs. Four sensors designs have the same amplifier while one is AC coupled with a different amplifier.

The chip and amplifier designs are described in [3].

2. Characterization with Particle Beams

Non-irradiated chips have been tested with 4 GeV electrons at room temperature at beam line 24 of the DESY test beam facility [4]. A beam telescope consisting of six planes of ALPIDE [5] sensors were used for track reconstruction. The beam test data were analyzed using the Corryvreckan framework [6].

2.1 Hit Detection Efficiency

Hit detection efficiency of a chip is defined as

$$\epsilon_{hit} = \frac{N_{\mathrm{hit}}}{N_{\mathrm{t}}}, \tag{1}$$

where N_{hit} is the number of reconstructed tracks traversing the chip with a corresponding hit in the chip and N_{t} is the total number of tracks passing through the chip. Many envisaged applications require a hit detection efficiency $\epsilon_{hit} > 99\,\%$ at vertical incidence at room temperature before irradiation.

The inefficiencies of 200 µm thick MoTiC A and MotiC B chips are shown in Fig. 1a and 1b, respectively. All amplifier and sensor variants reach an efficiency in excess of 99.8 % for a bias voltage of 60 V at vertical incidence. Fig. 1c and 1d show hit efficiency as a function of bias voltage for MoTiC A and MoTiC B. MoTiC A reaches the maximum efficiency at bias voltages greater than 55 V. All sensor variants of MoTiC B reach the maximum hit detection efficiency at bias voltages above 50 V except the AC coupled variant which needs only 40 V to reach the maximum efficiency. This is expected since owing to the AC coupling the collection electrode can be biased to voltages different than the fixed voltage of DC coupled electrodes.

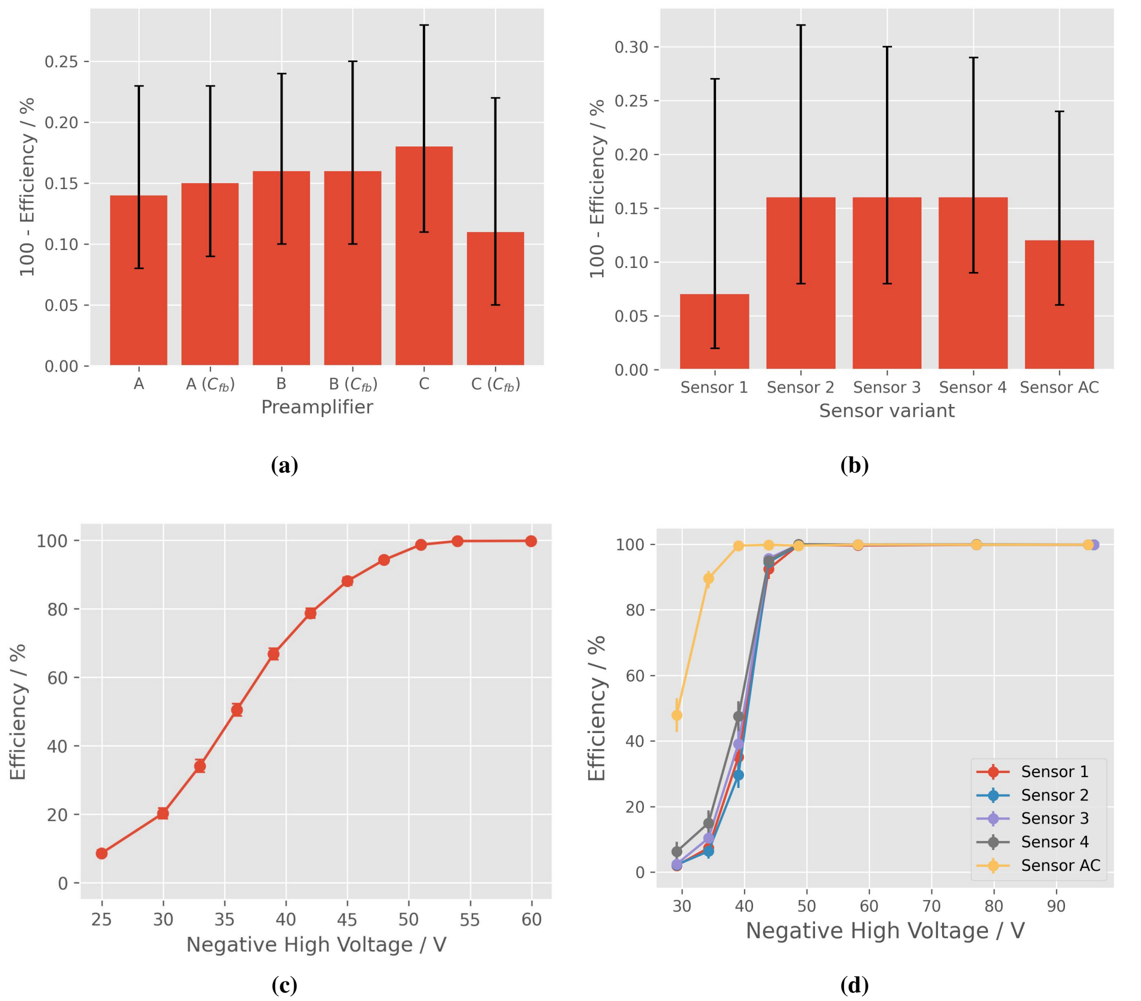
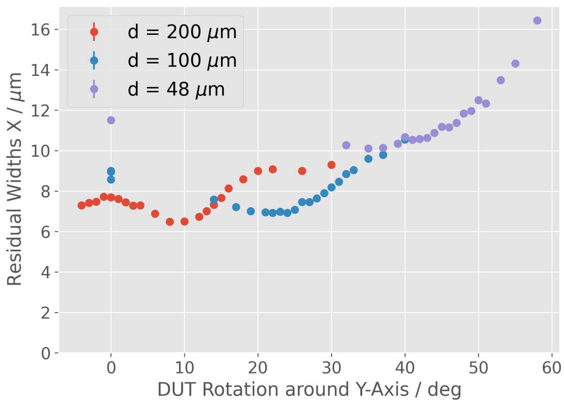


Figure 1: Hit detection inefficiency of 200 µm thick (a) MoTiC A and (b) MoTiC B. Hit detection efficiency as a function of bias voltage for (c) MoTiC A and (d) MoTiC B.

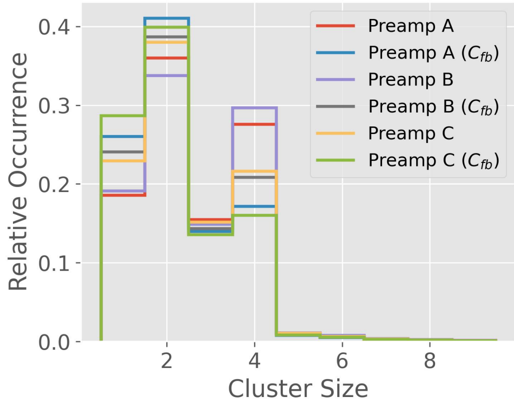
2.2 Spatial Resolution

To determine the spatial resolution of the assemblies a residual distribution is formed by subtracting the distance of a cluster in MoTiC to the impact point of the telescope track extrapolated to the position of MoTiC in each event. To suppress the deteriorating effect of outliers on the RMS of the residual distribution, a truncated RMS of the residual distribution is calculated by iteratively discarding entries outside of ±6 RMS. The truncated RMS is taken to be the spatial resolution of the detector.

Fig. 2a shows the residual width as a function of angle of incidence for MoTiC A chips with different active thicknesses. Owing to high charge sharing even at vertical incidence in MoTiC as can be seen from cluster size distribution shown in Fig. 2b, the residual width at vertical incidence is better than the expected binary resolution in absence of charge sharing. After subtraction of 4.4 µm telescope resolution from the residual width, the best spatial resolution of 4.8 µm is obtained

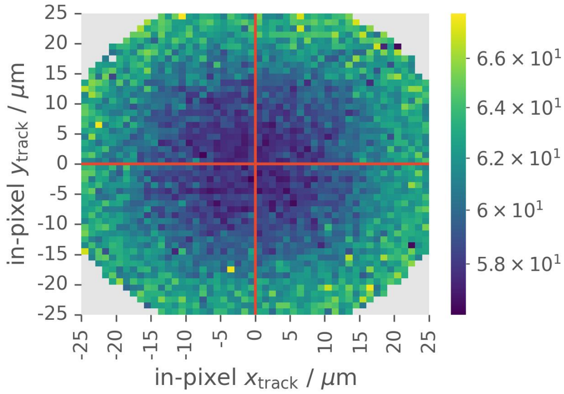


(a)

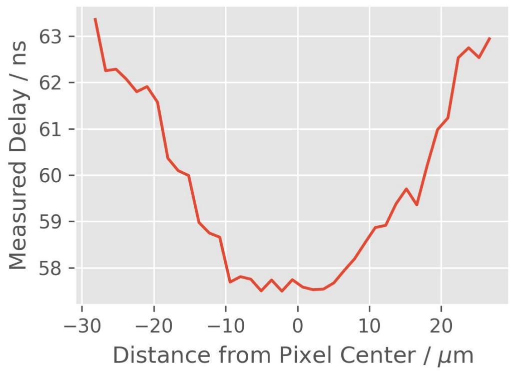


(b)

Figure 2: (a) Residual width as a function of angle of incidence for MoTiC A chips with different active thicknesses and (b) cluster size distribution of aplifier variants of MoTiC A.



(a)



(b)

Figure 3: (a) In-pixel hit time measurement with MoTiC A and (b) its diagonal cross section.

with the sample with 200 μm active thickness at the optimal angle for 2-pixel clusters. Due to the high charge sharing mentioned above, the optimal angle is 8° which differs from expected $\tan^{-1}(50/200) \approx 14°$. The measurements were taken at a bias voltage of 60 V. The high charge sharing is due to low field regions below the pixel edges as demonstrated by simulations in [2].

2.3 Timing Resolution

Every four pixels of MoTiC share a TDC. The TDC unit measures time of a hit using a combination of a coarse digital and a fine analog measurement. Calibration measurements demonstrated that the TDC unit has a timing resolution better than 40 ps. Hit time measurements with particle beams was performed using the hit as the start signal for time measurement and a signal from a dedicated trigger system as the stop. Fig. 3 shows in-pixel coarse digital time measurement. Hits in the central region of the pixel have shorter drift time owing to the higher electric field. Fine analog timing was not available due to technical reasons. A coarse timing resolution better than 1.2 ns was achieved.

3. Conclusions

MoTiC, a new fully depleted monolithic pixel chip capable of timing measurements, has been developed and characterized with particle beams. The chip has reached an hit detection efficiency in excess of 99.8 % before irradiation. A hit resolution of 4.8 µm is obtained at an optimal angle for 2-pixel clusters. The in-pixel TDC has reached a fine timing resolution better than 40 ps when characterized with test pulses while only coarse timing measurement was charactrized with particle beams and reached a timing resolution better than 1.2 ns.

Acknowledgments

The authors would like to express their gratitude to the ARCADIA collaboration for their offering to participate in their engineering runs and for their input during the design phase. The development of the process modification and sensor nodes has been performed in the framework of the INFN CSN5 Call ARCADIA. The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF). Finally, the authors thank the developers of Corryvreckan for their efforts to develop the beam test data analysis framework. Individuals have received support from the European Unions Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant105 agreement No 884104 (PSI-FELLOW-III-3i) and the Swiss National Science Foundation.

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