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First reticule size MAPS with digital output and integrated zero suppression for the EUDET-JRA1 beam telescope

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Abstract

A high resolution beam telescope, based on CMOS Monolithic Active Pixel Sensors (MAPS), is being developed within the EUDET collaboration. Mimosas26 is the first pixel sensor covering an active area of $\sim 224 \text{ mm}^2$ with integrated zero suppression for this telescope. A single point resolution better than $4 \mu\text{m}$ is obtained with a pixel pitch of $18.4 \mu\text{m}$. The matrix is organised in 576 rows and 1152 columns. At the bottom of the pixel array, each column is connected to an offset compensated discriminator to perform the analogue to digital conversion. Digital data are then treated by a zero suppression circuit in order to send useful information. This architecture allows a fast readout frequency of $\sim 10 \text{ k frames/s}$. The paper concentrates on the details of the chip design and its main performances. © 2001 Elsevier Science. All rights reserved

Keywords : Monolithic Active Pixel Sensors (MAPS) ; Beam telescope; Correlated Double Sampling (CDS); Analogue to Digital Conversion (ADC); Discriminator; Zero suppression, Fast readout

1. Introduction

EUDET is a coordinated European effort based on research and development for the next generation of

large scale particle detectors at the future International Linear Collider (ILC). The JRA (Joint Research Activity) in which the IRFU-IPHC team is involved, consists in providing a test beam facility with a large bore high field magnet and a high precision, fast beam telescope, by upgrading an

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existing facility in Europe [1]. The telescope will consist of 2 arms of 2x3 MAPS measurement planes (Fig. 1), providing an extrapolated resolution better than $2 \mu\text{m}$.

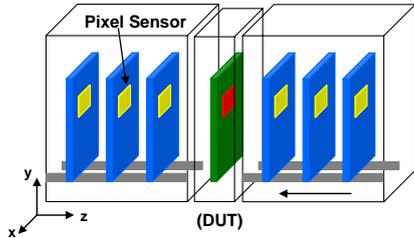


Fig. 1 EUDET beam telescope

In order to minimise the risk, the construction of the telescope was organised in two stages. In the first stage, a demonstrator telescope, exploiting the existing CMOS MAPS sensors with analogue readout (Mimosa17), has been realised. It has been successfully operating since 2007 [2]. In 2009, the final telescope will be equipped with the sensors presented in this paper. The latter named Mimosa26, provides an active surface 4 times larger and a readout time ($\sim 100 \mu\text{s}$) about an order of magnitude faster than Mimosa17 [2].

2. Mimosa26 sensor design

The readout architecture [3] used in the design of Mimosa26 was already validated by two separate prototyping lines: the first Mimosa22 [4, 5], addressing the upstream part of the signal detection and the processing chain; the second SUZE-01 [6], dedicated to data sparsification and formatting. Mimosa22 explores analogue signal processing and analogue to digital conversion. It is composed of 128 columns of 576 pixels, each column ended with a discriminator. The pixel contains a pre-amplifier and a Correlated Double Sampling (CDS) circuitry. The matrix is read out in rolling shutter mode. SUZE-01, the reduced scale prototype sparsification chip, incorporates the zero suppression logic, the memory buffers and the serial transmission. Both chips were fabricated in a CMOS $0.35 \mu\text{m}$ technology.

The tests of Mimosa22, both in the laboratory and with particle beams, show excellent results. The temporal noise of the pixel array associated with the discriminators is about $0.6\text{--}0.7 \text{ mV}$, corresponding to

$\sim 12 e^-$, while the fixed pattern noise (FPN) is $\sim 0.3 \text{ mV}$, corresponding to $\sim 6 e^-$. Figure 2 summarises the beam test results with $\sim 120 \text{ GeV}$ pions at the CERN SPS. The detection efficiency is close to 100% up to a threshold value of the discriminators of 4 mV , corresponding to ~ 6 times the noise standard deviation, with a fake rate below 10^{-4} and a spatial resolution better than $4 \mu\text{m}$ [4, 5].

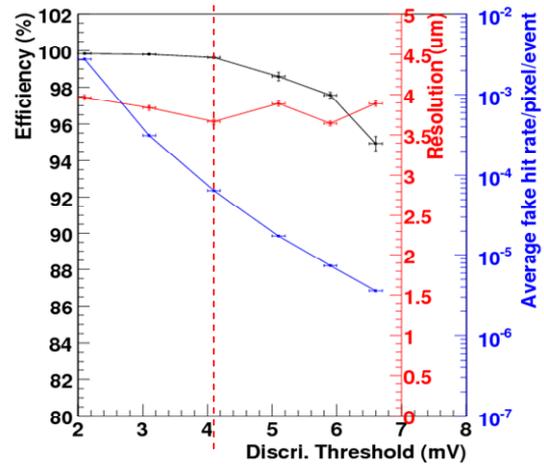


Fig. 2 Mimosa22 sensor performance

Figure 3 shows the block diagram of Mimosa26, which is based on a pixel array covering 224 mm^2 . The rolling shutter read-out mode is steered through a row selector & pixel sequencer located on the left side. The voltage signal induced by the charges collected through an Nwell/P-epi diode is amplified in each pixel by a preamplification stage [4]. The information from two successive frames is subtracted by the clamping technique in order to perform in-pixel CDS. The 1152 pixel signals of the selected row are transmitted to the bottom of the pixel array where 1152 column-level, offset compensated discriminators ensure the analogue to digital conversion. A second double sampling, implemented in each discriminator stage, removes pixel to pixel offsets introduced by each in-pixel buffer [7]. This allows using a common threshold for all discriminators. The discriminator outputs are connected to a zero suppression circuitry, organised in pipeline mode, which scans the sparse data of the current row. It skips non hit pixels and identifies contiguous pixels (string) having their signals above the threshold. The length and addresses of the strings beginning are stored in one of the two SRAM

allowing a continuous read-out. A data compression factor ranging from 10 to 1000, depending on the hit density per frame, can be obtained. The collection of sparsified data for a frame is then sent out during the acquisition of the next frame via one or two 100 Mbits/s LVDS transmitters. An optional PLL module is allowing a high frequency clock generation based on a low frequency reference input clock. The on-chip programmable biases, voltage references and the selection of the test mode are set via a JTAG controller.

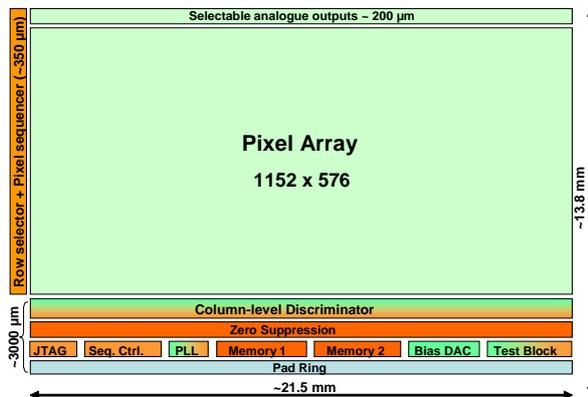


Fig. 3 Mimosa26 block diagram

The possibility to test each block (pixels, discriminators, zero suppression circuit and data transmission) increases the testability. This is implemented in the Mimosa26 design.

3. Mimosa26 sensor test and evaluation

Mimosa26 returned from foundry on February 2009. Extensive tests are going on in the laboratory. Preliminary results indicate that Mimosa26 should meet the requirements of the EUDET telescope specifications. Figure 4 shows a measured temporal noise of 0.64 mV and a FPN of 0.29 mV for one quarter of the pixel array with its associated discriminators. These values are equivalent to those obtained with Mimosa22. The remaining three quarters of the matrix exhibit similar performances showing a good uniformity of the whole 576 x 1152 pixels with the 1152 discriminators. The characterization of Mimosa26 will be completed by the beam tests planned in Summer 2009.

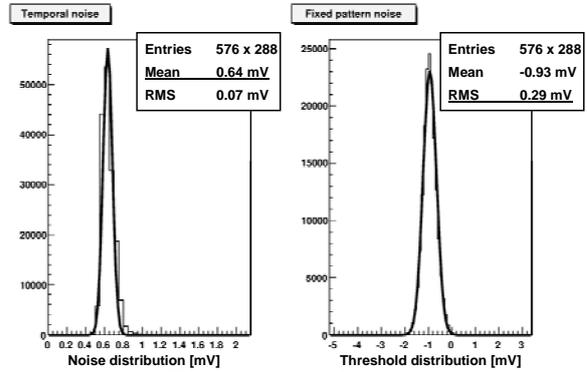


Fig. 4 pixels + discriminators

4. Conclusion

Mimosa26 is the first reticule size, fast readout MAPS which integrates on-chip data sparsification for the EUDET telescope. Its design will serve as a base line for vertex detectors of several experiments, such as the STAR Heavy Flavor Tracker (HFT) upgrade. It will also be extended to the CBM Micro Vertex Detector (MVD) (SIS-100) and is proposed for the ILC vertex detector.

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