Characterization of CMOS Active Pixel Sensors for particle detection: beam test of the four sensors RAPS03 stacked system.

D. Passeri(1,2), D. Biagetti(1,2), L. Servoli(1), S. Meroli(1)

1) Istituto Nazionale di Fisica Nucleare, via Pascoli 1, 06123 Perugia, Italy,
2) Università di Perugia, via Duranti 93, 06125 Perugia, Italy,

Introduction

- Following the mainstream of microelectronics CMOS bulk technology, a third generation of monolithic Active Pixel Sensors for particle detection purposes (called RAPS03) has been fabricated in 0.18μm CMOS 1P6M technology and tested. Beside electrical characterization and particle detection principle validation, an extensive detector functional test has been carried out. Actually, single chips have been already characterized in terms of response to X-ray photons and β particles.
- In this work, in order to check their suitability for vertexing/tracking applications, four stacked CMOS APS sensors featuring 256×256 pixels with 10μm×10μm pixel size have been tested at the INFN Beam Test Facility (BFT), Frascati (Rome), Italy. To this purpose, a dedicated mechanical and electrical set-up has been devised and implemented, allowing for the simultaneous read-out of four sensors arranged in a stacked structure. This work has been carried out within the framework of the SHARPS experiment, supported by I.N.F.N.

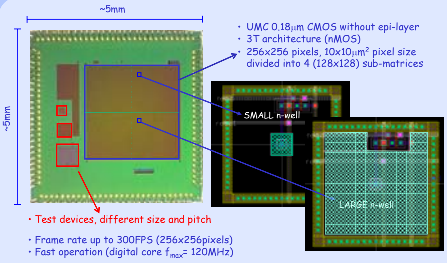

Fig. 1: The RAPS03 sensor laoyut, featuring 256×256 pixels with 10μm×10μm pixel size, and both small and large n-well diodes.

The Experimental Set-up

The DAQ system allows for the read-out of four matrices simultaneously, and performs the A/D conversion of pixel voltage outputs. The maximum operating frequency was set to 64MHz, allowing for the read-out of the 128 × 128 sub-matrix in less than 1msec. A dedicated software control was implemented on a FPGA, allowing for ADCs and sensors control (read-out frequency, integration time), as well as for some elaboration, e.g. pedestal subtraction, bad pixel masking. Trigger strategies allow for variable thresholds setting and different trigger mode (internal/external, AND/OR between different layers).

Fig. 2: The four RAPS03 sensor stacked system.

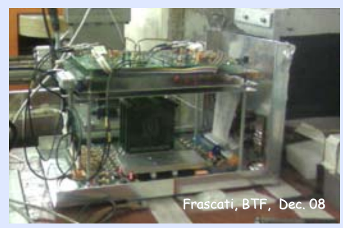

Fig. 3: The tracking system installed at the INFN Beam Test Facility in Frascati (Rome), Italy.

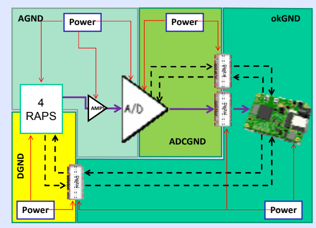

Fig. 4: The read-out system block diagram.

Experimental Results

The characterization has been carried out using the Beam Test Facilities at the INFN LNF, Frascati (Rome), Italy. An electron beam featuring energies up to 500MeV has been used. A typical response of the four sensors is illustrated in Fig. 5. The tracking system exploits a self-trigger, using layer I and layer IV as telescope.

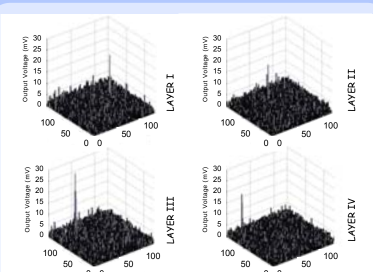

Fig. 5: Response of the four layers to a particle hit.

Geant4 Simulations vs. Experimental Results

Geant4 simulations have been performed in order to evaluate the effect of multiple scattering on track reconstruction. Four sensors featuring 280μm thick silicon substrate and 1mm thick Al_2O_3 ceramic packaging have been considered, and equally spaced by 1.8mm on air, thus reproducing the experimental conditions. Measurements (Fig. 7) are in very good agreement with simulation results (Fig. 8). Actually, wider contributions in Fig. 7 are related to uncorrelated hits between different layers and the narrow peak only has to be used for spatial resolution measurement. The poor resolution obtained at such e^- energies are a clear evidence that the multiple scattering (e.g. the relatively high material) dominates the tracking performance. A simple estimation of the spatial resolution when no package material is considered (e.g. by using chip dies only) is reported in Fig. 9.

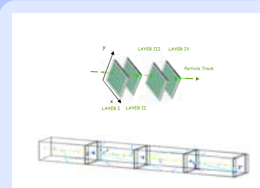

Fig. 6: Geant4 simulated structure.

A significant improvement of the spatial resolution has been obtained, thus confirming that the performance of the detection system, at least for this range of energy (e^- up to 500MeV) is limited by material issues.

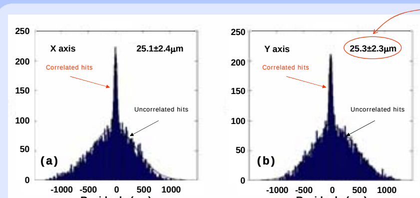

Fig. 7: Measured spatial resolution (491 MeV): (a) x-direction and (b) y-direction.

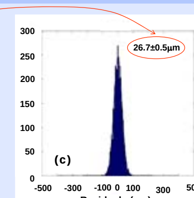

Fig. 8: Simulated spatial resolution (491 MeV).

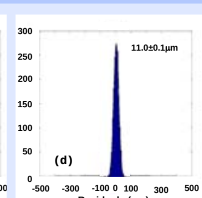

Fig. 9: Simulated spatial resolution (chip dies only).

Signal to Noise and Spatial Resolution

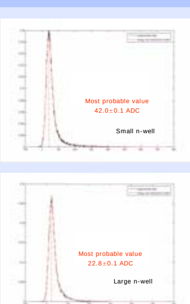

Fig. 11: 5x5 cluster signal distributions: small n-well (top) and large n-well (bottom) diode (465MeV e-).

The signal distributions within the cluster are represented in Fig. 10. The Landau signal distributions for a 5x5 pixels cluster are reported in Figs. 11 in terms of ADC counts (1 ADC = 0.62mV). The single pixel noise is 1.67ADC (small n-well) and 1.05ADC (large n-well).

From the generalized η-function distribution [1], the deviation from the "ideal" case of charge division among adjacent pixels can be estimated (assuming that η-functions along x-axis and y-axis are uncorrelated), thus estimating a theoretical spatial resolution limit for particle trajectory of about 0.37μm (Fig. 13).

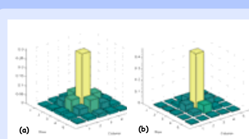

Fig. 10: Cluster signal distribution (small n-well (a) and large n-well (b)).

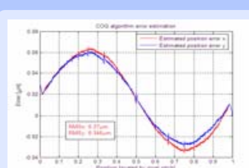

Fig. 13: Estimated theoretical spatial resolution limits.

Conclusions

- CMOS Active Pixel Sensors can be proficiently adopted for tracking/triggering purposes in High Energy Physics experiments.
- A compact tracking system featuring four CMOS APS layers has been fully tested at INFN BTF (Frascati), and will be further tested in a high momentum beam.
- Multiple scattering (e.g. material issues) seems to be critical for its specific applications, fostering the adoption of "ad hoc" low-material monolithic 3D tracking solutions allowing for impact point and incidence angle reconstruction [2] (see also INFN VIPIX experiment).

References

[1] G. Landi, "Properties of the center of gravity: an algorithm for position measurements", NIMA 485, (2002), pp. 698-719.
[2] D. Passeri et al., "Multilayer CMOS APS sensors integrated in CMOS vertical scale technology (3D) for particle detection" at last 7th International Meeting on Front-End Electronics, 18-21 May 2009, Montauk, New York (USA).