Status of the development of MIMOSA CMOS sensors

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This article provides a summary of the R & D activities on MIMOSA Monolithic Active Pixel Sensors. The performances and progress achieved with the fast readout architecture developed for the inner layers of the ILC-vertex detector are reviewed, complemented with a roadmap for the upcoming 2-3 years.

1 Introduction

CMOS sensors are developed for several years in order to achieve high performance in charged particle tracking[1][2]. One will review the main R&D activities driven by the ILC vertex detector (VD) constraints, requiring fast read-out, high granularity, low material budget, good radiation tolerance and moderate power dissipation.

The paper starts with an overview of the VD requirements, reminding that safety factors have to be attached to the simulated beam background rates governing the running conditions in the inner layers. Next, some major established performances of the MIMOSA sensors are recalled. The present R&D activity concentrates on the simultaneous development of fast pixel arrays with discriminated outputs, 4-5 bit ADCs and sparsification micro-circuits. Their status is briefly exposed, followed by their major next steps. The short and mid-term outcomes of this R&D program will meet the requirements of other, less demanding, applications (EUDET telescope[3], STAR HFT[4]), which will provide opportunities to operate large sets of sensors in real experimental conditions. More details on this vast R&D activity may be found in [5].

2 ILC requirements and vertex detector design

The main constraint driving the VD design comes from the beam background (beamstrahlung) which is expected to produce $\simeq 5\ hits/cm^2$/Bunch crossing in the inner most layer, assuming a radius of 1.5 cm and a 4T magnetic field at $\sqrt{s} = 500\ GeV$. Accounting for a safety factor of 3 and a cluster multiplicity of 5-10, a read-out time of $\lesssim 25\ \mu s$ was chosen to keep the occupancy at the per-cent level. This fast read-out time is achieved with sensors organised in short pixel columns perpendicular to the beam axes, read out in parallel. A 4-5 bit ADC integrated at the end of each column encodes the charge. The edge of the sensor hosts sparsification micro-circuits allowing to reduce the data flow. The VD equipped with such sensors will feature 5-6 cylindrical layers, $\sim$300-500 million pixels, covering a total surface of $\sim$ 3000-4000 cm^2. The pixel pitch ranges from 20 to 40 μm, depending on the layer. A first complete ladder prototype is expected by 2010.

3 Review on CMOS sensors performances

Excellent particle tracking performances were repeatedly obtained with numerous small MIMOSA prototypes featuring analog outputs. The best performing fabrication technology found up to now (AMS 0.35 μm-OPTO), allows for a detection efficiency $\gtrsim$ 99.9%, a signal-to-noise ratio (SNR) of $\sim$ 20 − 30 (fig.1) and a fake hit rate of $\lesssim O(10^{-5})$, at an operating temperature of up to 40^oC. These performances were reproduced with real size sensors. One of them, MIMOSA-17 (256 × 256 pixels, 30 μm pitch), equips the demonstator of the EUDET telescope.

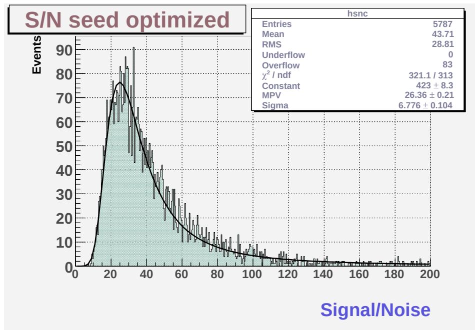

Figure 1: SNR measured at the CERN-SPS with MIMOSA-9, (20 μm pitch) at $T = 20^oC$.

The spatial resolution reaches $\simeq 1.5\mu m$ with a $20\mu m$ pitch and a 12-bit charge encoding (fig.2). The same data were used to show that encoding the charge on a compact 4-5 bit ADC integrated on the sensor edge would still allow for $\simeq 2\mu m$ single point resolution.

Radiation hardness has also been studied extensively. In particular, the MIMOSA-15 prototype, wich features radiation tolerant pixels, was irradiated with 1 MeV neutrons and 10 keV X-rays. Both for a fluence of $\sim 10^{12} n_{eq}/cm^2$ and for an integrated dose of 1 Mrad, a SNR $\gtrsim$ 20 and an efficiency $\gtrsim$ 99.5% were observed at -20^oC. Irradiation tests were also performed with 10 MeV e^- which are still to be completed. As a preliminary conclusion, at least 3 years of ILC running should be viable close at room temperature[6]. Performances of sensors featuring integrated single processing remain however to be evaluated.

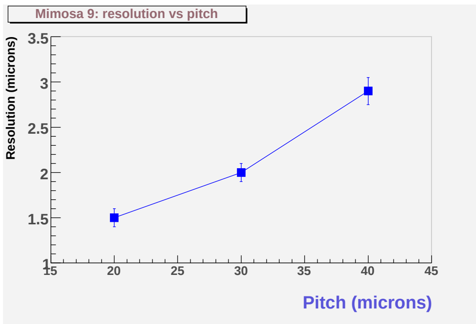

Figure 2: Single point resolution measured at the CERN-SPS with MIMOSA-9 (three pitch values: 20, 30 and 40 μm)

4 Fast read-out architectures and integrated ADC

The MIMOSA-8 prototype[7], which features pixels with integrated CDS, organized in parallel columns ended with discriminators, has allowed to validate the fast architecture needed for the inner layers. A satisfactory charged particle detection was observed despite the thin epitaxial layer of the fabrication technology (TSMC 0.25 μm), leading to a modest SNR.

The MIMOSA-8 architecture was translated in AMS 0.35 μm-OPTO technology, which features a thicker epitaxial layer. The sensor, called MIMOSA-16, was tested at the CERN-SPS. Preliminary results show a detection efficiency of $\gtrsim 99.8 \pm 0.2\%$ for a fake rate of $\lesssim 10^{-5}$ and a spatial resolution of $\sim 5 - 6\mu m$ despite the $25\mu m$ pitch. In parallel, the first zero suppression prototype (SUZE-1), foreseen to complement the MIMOSA-16 architecture, has been designed and will come back from foundry in October 2007. Finally, several laboratories are developing various 4-5 bits ADC architectures (semi-flash, flash, SAR, Wilkinson). Based on the results obtained with the prototypes tested up to now, a first mature ADC design is expected in 2008.

5 Roadmap

Here is a summary of the different prototypes foreseen in the period $\sim$ 2007-2009:

-SUZE-01: zero suppression micro-circuit, back from foundry in October 2007;

-MIMOSA-22: extension of MIMOSA-16, 18.4 μm pitch, (128+8) $\times$ 576 pixels, submission in October 2007,

-PHASE-1: extension of MIMOSA-22 with 640 $\times$ 640 pixels, 30 μm pitch, 2×2 cm^2, for STAR HFT, submission in June 2008;

-ADC: integrated on pixel matrix, submission by Summer 2008;

-MIMOSA-22+: combination of MIMOSA-22 and SUZE-01, 1088 $\times$ 544/576 pixels, 1×2 cm^2, final chip for EUDET telescope project, submission by Autumn 2008;

-ADC and zero suppression micro-circuit in the single chip : 2009.

6 Conclusion

MIMOSA sensors offer very attractive performances in terms of SNR, detection efficiency, spatial resolution and radiation tolerance for their application at the ILC vertex detector. They are however not yet adapted to the read-out speed required to cope with the expected beam background. Intense R&D is thus invested in achieving fast sensors with integrated analog-to-digital conversion and data sparsification. Encourageing results were obtained with a prototype composed of columns read out in parallel and ended with integrated discriminators. The development of ADCs foreseen to replace the discriminators and of zero suppression micro-circuits are also progessing well.

In the mid-term, sensors developed for the VD will equip less demanding devices (EUDET beam telescope, STAR HFT), which will allow to investigate how large sets of sensors can be operated in real experimental conditions and which added value they bring to charmed meson reconstruction.

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