3D monolithic-sensor approach to particle detection

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Abstract

In this paper we suggest a novel approach to particle track reconstruction in vertex detectors. Vertical scale integration (3D) technology for the fabrication of CMOS VLSI circuits has been used to devise a low-material monolithic stack of sensitive pixellated layers connected through silicon vias (TSV) connections. The structure has been extensively simulated, has been designed in a conventional VLSI design flow and is currently under production: first prototypes will be available at the beginning of 2010.

Key words: monolithic detector, 3D, vertical integration

1. Introduction

The usual approach of 3D integration in a vertex detector framework could be described as heterogeneous integration in the sense that it devotes different tiers to the sensing layer, and to the analog and digital circuitry. Such an approach has certainly some advanages as it guarantee a 100% fill-factor of the detecting area while at the same time allowing for some on-chip signal processing.

On the other hand such an archiecture cannot be strictly considered "monolithical".

The need for several superposed detectors (in order to have an estimation of the incidence angle) results in a somewhat bulky structure which has to be crossed by the oncoming particles, with a non-negligible probability of scattering.

In this work we suggest a novel approach: identical fully-functional pixel layers (each including both sensing area and control/signal elaboration circuitry), have been stacked in a monolithic device through silicon vias (TSV) connections. Each sensing layer can be independently read out, thanks to presence on each tier of the dedicated selection and output circuitry, thus improving detection accuracy.

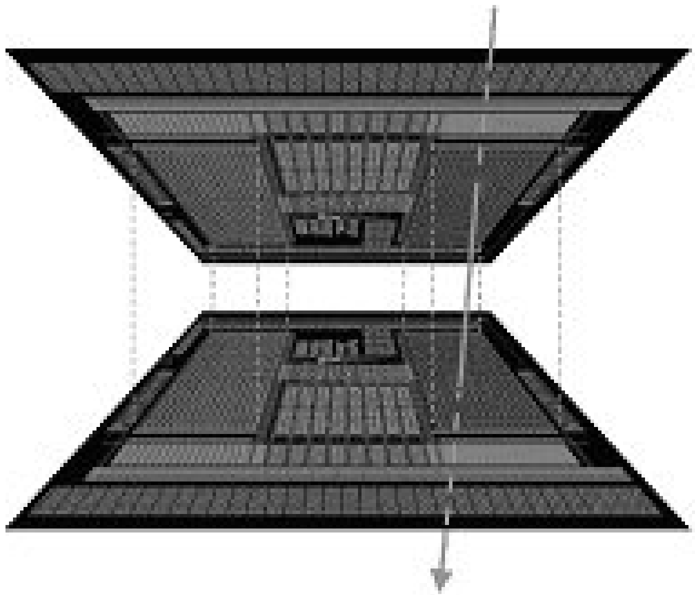

Figure 1: Principle of detection.

2. Prototypes

Identical fully-functional pixel layers, each including both sensing area and control/signal elaboration circuitry, have been stacked in a monolithic device through silicon vias (TSV) connections. Each planar (2D) structure has been derived from already fabricated and tested CMOS Active Pixel Sensors detectors [1] . Each sensing layer can be independently read out, thanks to presence on each tier of the dedicated selection and output circuitry.

The main advantage of such an architecture is that the information multiplicity coming from thinned, spatially close stacked layers could be usefully exploited to extend the detection capability of the monolithic sensor: in principle, such a detector would be capable of giving accurate estimation not only of the impact point of a ionizing particle (with spatial resolution in the micrometers range), but also of his incidence angle (with angular precision around 1) thus realizing a single detector allowing for particle momentum measurement, at the same time being a low material detector. Negligible multiple scattering effects are expected with respect to conventional bump-bonded structures, since incoming particles have to cross only few micrometers of bulk silicon [2].

This detector has been designed in a conventional VLSI design flow using a 130nm Chartered/Tezzaron CMOS technology, and is currently under production: first prototypes will be available at the beginning of 2010. Eventually, Fig. 2 illustrates the devised layout: several matrices of active pixel sensors with high fill factor, featuring a 10 μm pitch have been included, along with some test structures. A more complete prototype, featuring a 10mm^2 detection area is being designed and will be submitted later this year (Fig. 3).

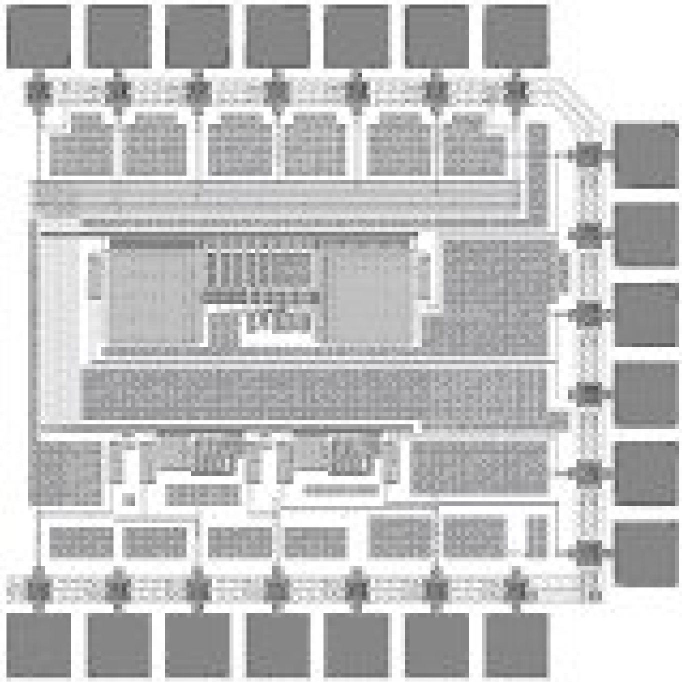

Figure 2: First Prototype structure layout.

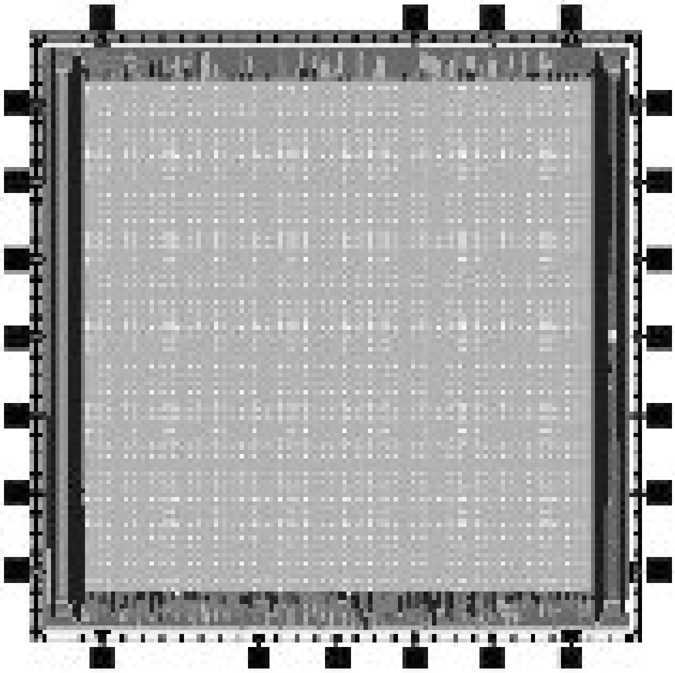

Figure 3: Second Prototype structure layout.

3. Simulations

This detector configuration has been extensively simulated by means of physics and device level TCAD tools (GEANT4, Synopsys Sentaurs). Device-level simulation results of multiple layers (up to four layers) are reported in Fig. 4 , Fig. 5, in terms of estimation accuracy of the crossing point and of the incidence angle as a function of different impact position of a single ionizing particle.

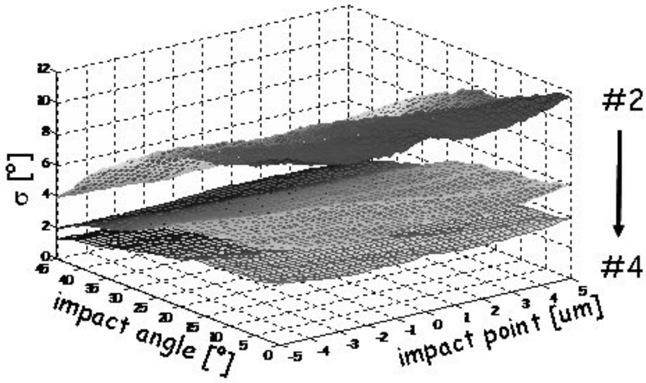

Figure 4: error on impact point estimation.

4. Conclusion

A monolithically stacked array of Active pixel layers has been devised as a low-material momentum detector for HEP applications. Simulations has been performed and the layout has been submitted to be manufactured on commercial 130nm technology. First prototypes will be available at the beginning of 2010

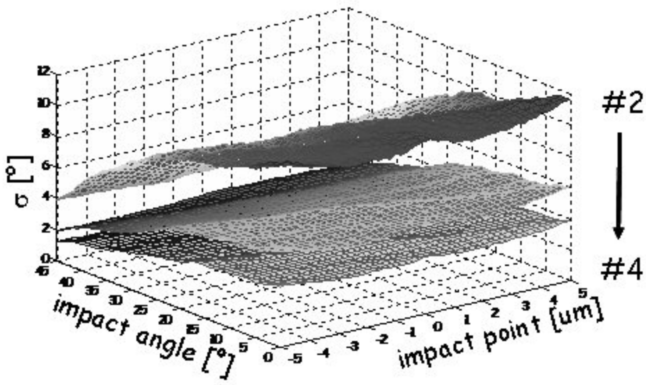

Figure 5: error on impact angle estimation.

References

[1] D. Passeri et al., Characterization of CMOS Active Pixel Sensors for particle detection: beam test of the four sensors RAPS03 stacked systemNuclear Instr. and Meth. A, (2009).

[2] D. Passeri et al., Analysis of 3D stacked fully functional CMOS Active Pixel Sensor detectors, (2009) Journal of Instrumentation 4 P04009.