Vertically Integrated CMOS Active Pixel Sensors for Tracking Applications in HEP Experiments

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Introduction

- ✓ In this work we propose an innovative all-in-one detector featuring multiple, stacked, fully-functional CMOS Active Pixel Sensor layers, aiming at:
  - momentum measurement (impact point and trajectory) with a single detector;
  - low material detector (reduced multiple scattering issues).
- ✓ Perspective advantages for particle tracking / vertex detectors:
  - high granularity – high spatial resolution;
  - separation of sensor, analog read-out electronics, A/D conversion layers (increased fill-factor, performance).
- ✓ A first chip prototype has been fabricated within a multi-project run using a 130nm CMOS 3D Chartered/Tezzaron technology, featuring two layers bonded face-to-face.

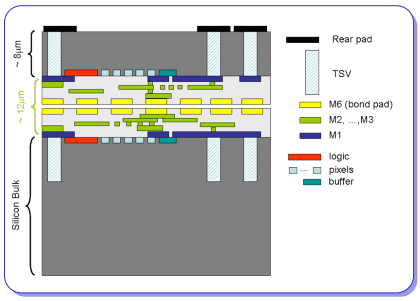


Fig. 1: Schematic cross-section of a front-to-front two chip bonding (thinned top tier). Both tiers feature few test structure, as well as fully-functional 16x16 pixel matrices with small and large photodiodes.

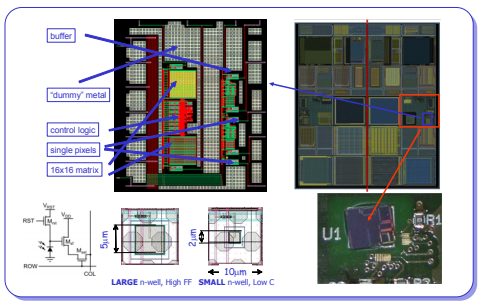
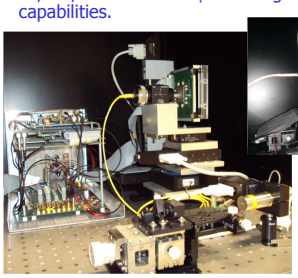
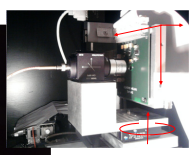


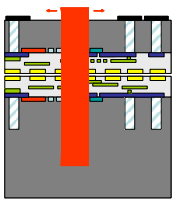
Fig. 2: The RAPS04 3D structures. The chip has been fabricated within the 3D-IC consortium (3dic.fnal.gov) – CMOS 3D Tezzaron/Chartered 130nm technology.

Optical Workbench – Characterization with Laser

- ✓ IR, UV, VIS laser with µ-focusing and µ-positioning capabilities.







Significantly different responses for spots that hit the pixel sensitive area with respect to spots crossing in between pixels - potential warning for effective fill-factor / efficiency.

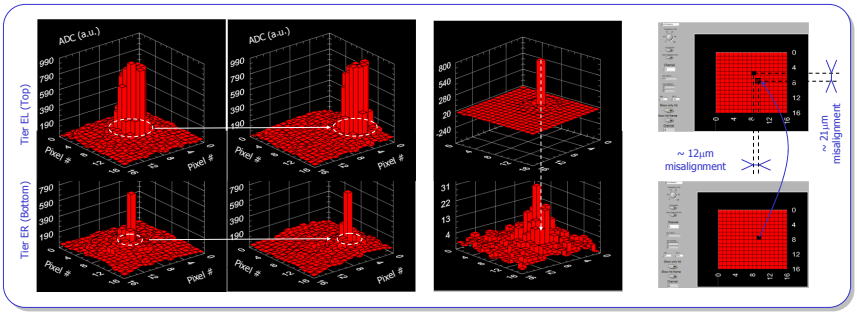
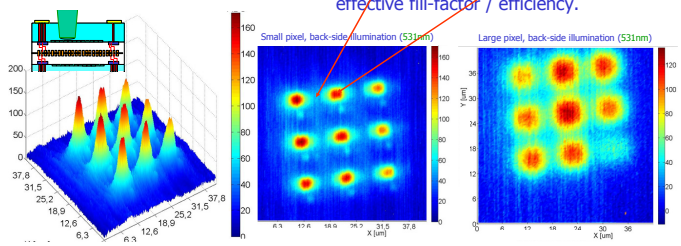


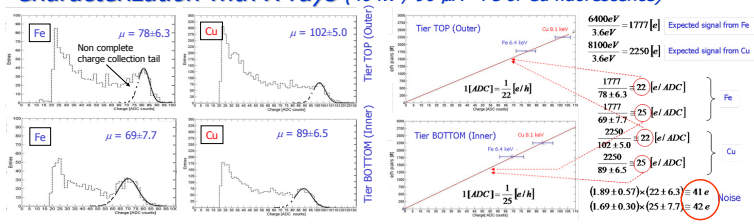
Fig. 3: Top & Bottom tier responses (X-Y scan) with 780nm red laser (16x16 matrix) - clear coincidence between outer and inner tier responses.

Fig. 4: Top & Bottom tier misalignments has been found. Chip functionality has not been compromised, due to redundant bondpoint scheme at the chip pads.

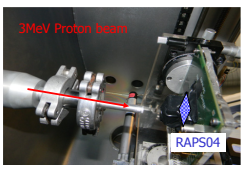


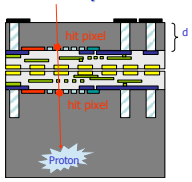
Back-side illumination (no metal-shield) regular pattern (small vs. large photodiodes).

Characterization with X-rays (40 kV / 90 µA - Fe or Cu fluorescence)

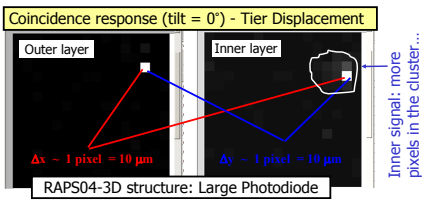


Characterization with 3MeV proton beam





3 MeV protons test facilities @ INFN LABEC (Florence, Italy).



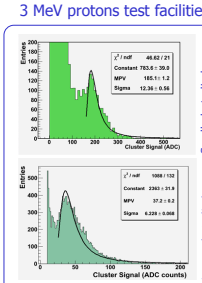
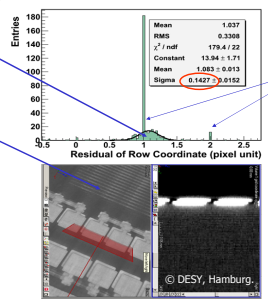


Fig. 6: Small & Large photodiode signal distribution.

Row coordinates residuals between inner and outer layer misalignment measurement – A 1.083 pixel size -> 10.83µm misalignment has been found, being the spatial resolution 0.1427 pixel size -> 1.4µm.

A tier misalignment in the order of 10µm has been found by means of chip CT (courtesy of DESY, Hamburg). The misalignments of the PAD region is clearly visible.

These results confirm the capability of the two tier systems to evaluate the particle track with micrometer resolution, thus allowing even tilted track reconstruction.



Conclusions

- ✓ First functional characterization of 3D monolithically stacked Active Pixel Sensors layers fabricated in Chartered/ Tezzaron 130nm 3D technology for particle tracking purposes.
- ✓ Good communications between bottom and top tiers (contacts only at the periphery – PADs; redundant bondpoints scheme).
- ✓ Both tiers are fully functional – different test structures and matrix structures (5x5, 16x16, small vs. large photodiode) have been characterized with focused laser.
- ✓ Noise analysis and X-rays calibrations with Fe and Cu fluorescence.
- ✓ Charged particle characterization with 3 MeV proton beam to estimate charge collection region thickness
- ✓ Coincidence responses between bottom and top matrices have been obtained with laser stimuli and 3 MeV proton beams.
- ✓ Misalignment between top and bottom tiers has been found in both cases and it is compatible with CT chip measurements.