FULLY DEPLETED MONOLITHIC ACTIVE CMOS SENSORS

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Raffaele Aaron GIAMPAOLO
Supervisor: Prof. Angelo RIVETTI

Research context and motivation

Research and development on ***Monolithic Active Pixel Sensors*** (MAPS) has lately increased, motivated by a growing interest in the high-energy physics community to use them as radiation imagers for charged particles and X-rays.

- **High energy physics** experiments, e.g. ALPIDE used in ALICE at CERN, are now including intelligent detectors where the sensors and the front-end (FE) act as **one entity**;
- Monolithic active pixel sensors are also used in **consumer applications** and can be found in cameras, biometric sensors etc;
- Furthermore, MAPS can also improve **satellite** particle and photon detectors increasing the **detection yield per mass**. In fact, when comparing a typical detector to a MAPS, lower weight and sizes can be expected.

Addressed research questions/problems

MAPS are divided in two main categories:

- 3D Stacked Hybrid CMOS Image Sensors
- Fully Depleted MAPS (FD-MAPS)

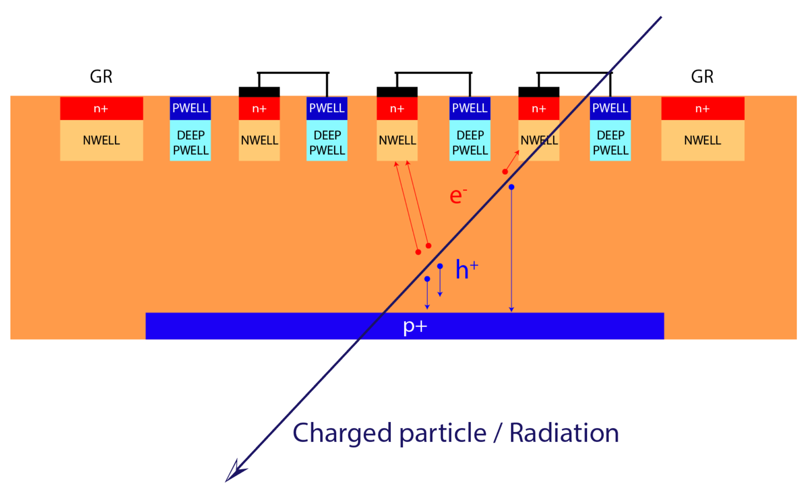
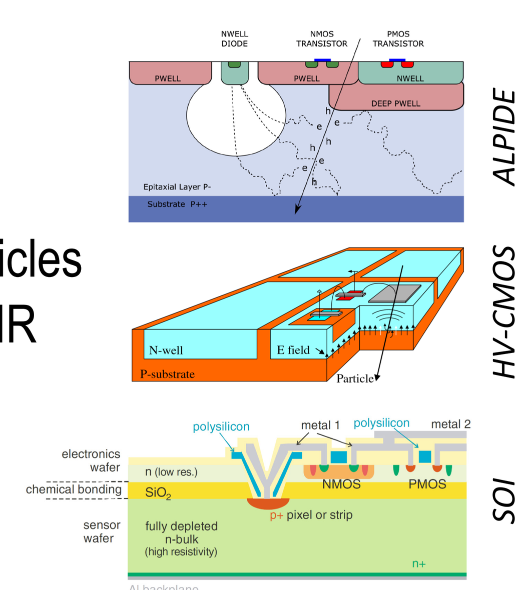


Figure 1 - Simplified scheme of the ARCADIA FD-MAPS

Fully Depleted MAPS (Fig. 1)
Specifications:

- **Fully depleted substrate** → Particles collected by: *DRIFT* → Improves:
  - *Collection speed*
  - *Radiation hardness*
- It's a large *Sensitive volume*
  - → Improves collection efficiency for *X-rays*
  - → Almost *uniform ionization track* left by particles
  - → Lowers *power consumption* for a given SNR



Drawbacks:

- Not always fully depleted (ALPIDE)
- High input capacitance (as in the case of HV-CMOS)
- Usually needs customized CMOS processes (SOI MAPS)

INFN ARCADIA* → CSA front-end adopting CDS
(Figure 1,2)

- → FD-MAPS (up to 300 μm)
- → Designed in commercial CIS 110 nm technology
- → n-type substrate → Increased punch through voltage

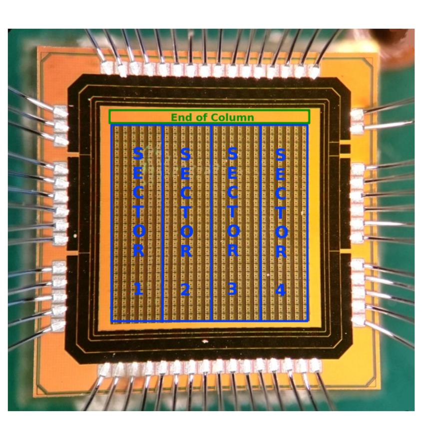
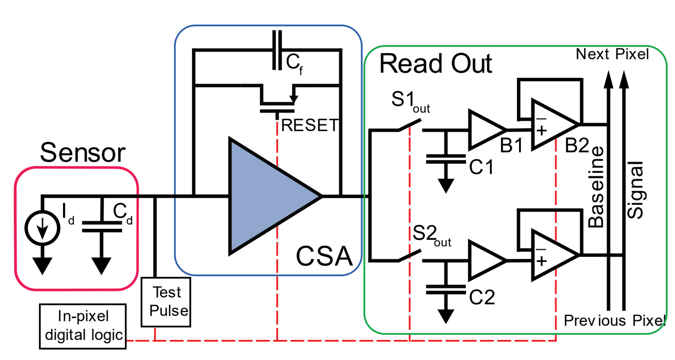


Figure 2 – Top view of the complete prototype



* Advanced Readout CMOS Architectures with Depleted Integrated sensor Arrays

Novel contributions - ARCADIA

- Extensive tests on the novel FD-MAPS produced by INFN.
- Design of a MATLAB based software enabling quick and precise values extraction from acquired CCE maps.
- Construction of a customized LASER test setup.

List of attended classes

- 01QTEIU – Data mining concepts and algorithms (11/01/19, 4 CFU, Merit)
- 01LCPRV – Experimental modeling: costruzione di modelli da dati sperimentali (11/01/19, 6 CFU, Pass)
- 01QRHRV – Microelectronics for radiation detection II (03/06/19, 4 CFU, Merit)
- 01UGERO – Materials by design - How structure meets function (03/07/19, 3 CFU, Merit)
- 01SAYRV – Self Management: techniques for work environment (14/05/19, 2 CFU, Pass)
- 01SFURV – Programmazione scientifica avanzata in MATLAB (15/5/2019, 4 CFU, Pass)
- VIII International Course "Detectors and Electronics for High Energy Physics, Astrophysics, Space Applications and Medical Physics", INFN LNL, Legnaro (1/4/19, 30 h)

Adopted methodologies

Tests to improve next generation sensors included:

- **Electrical test** and verification on test structures developed to fully characterize the sensor properties. The tests included IV Curves (Fig. 3d) to measure the punch through voltage of the sensors.
- **LASER beam tests**, through transient current techniques (TCT), revealed no anisotropies in the charge collection efficiency (CCE) except for a signal degradation over metal lines.
- 2 MeV **Proton beam tests** (Fig. 3c) done at the *Ruđer Bošković Institute* on the test-structures corroborated the LASER tests demonstrating the high CCE and low signal degradation over metal lines when the sensor is used for particle detection.

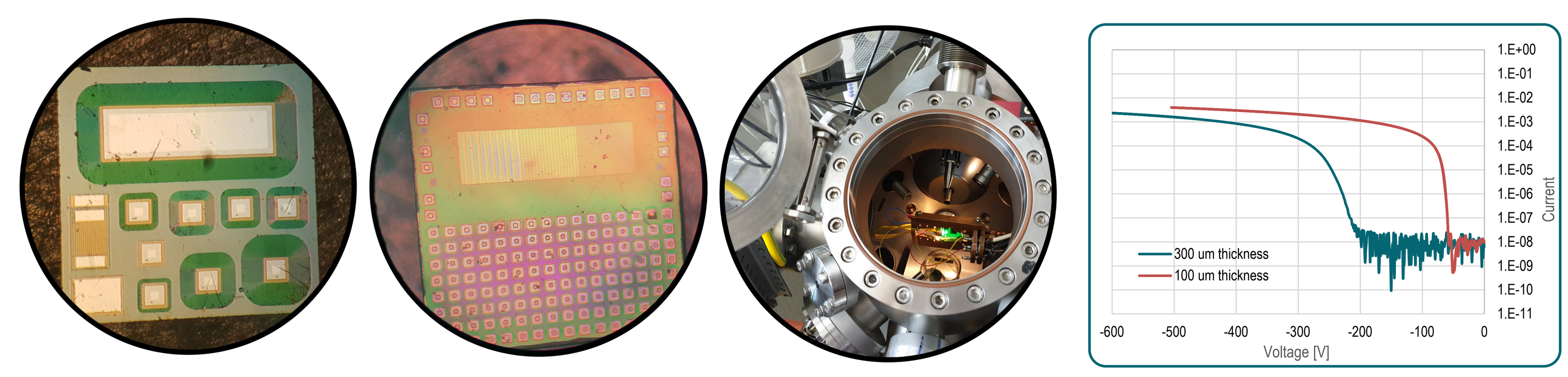
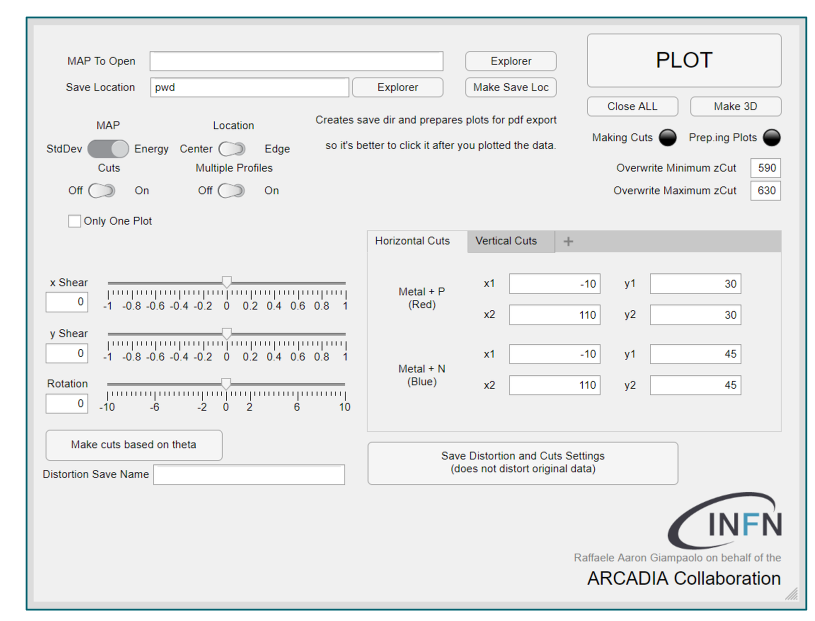


Figure 3 – Sensor Back Side — *Sensor Front Side* — *Sensor in vacuum chamber* — *IV Curves*

Proton beam and laser tests required a unified analysis platform distributed among INFN institutions; thus a **MAP Evaluator MATLAB app** (Fig. 4a) has been created.
Using this app a **high CCE uniformity** has been demonstrated and the **electric field edge** of the ARCADIA prototypes can be studied (Fig. 4b-c).



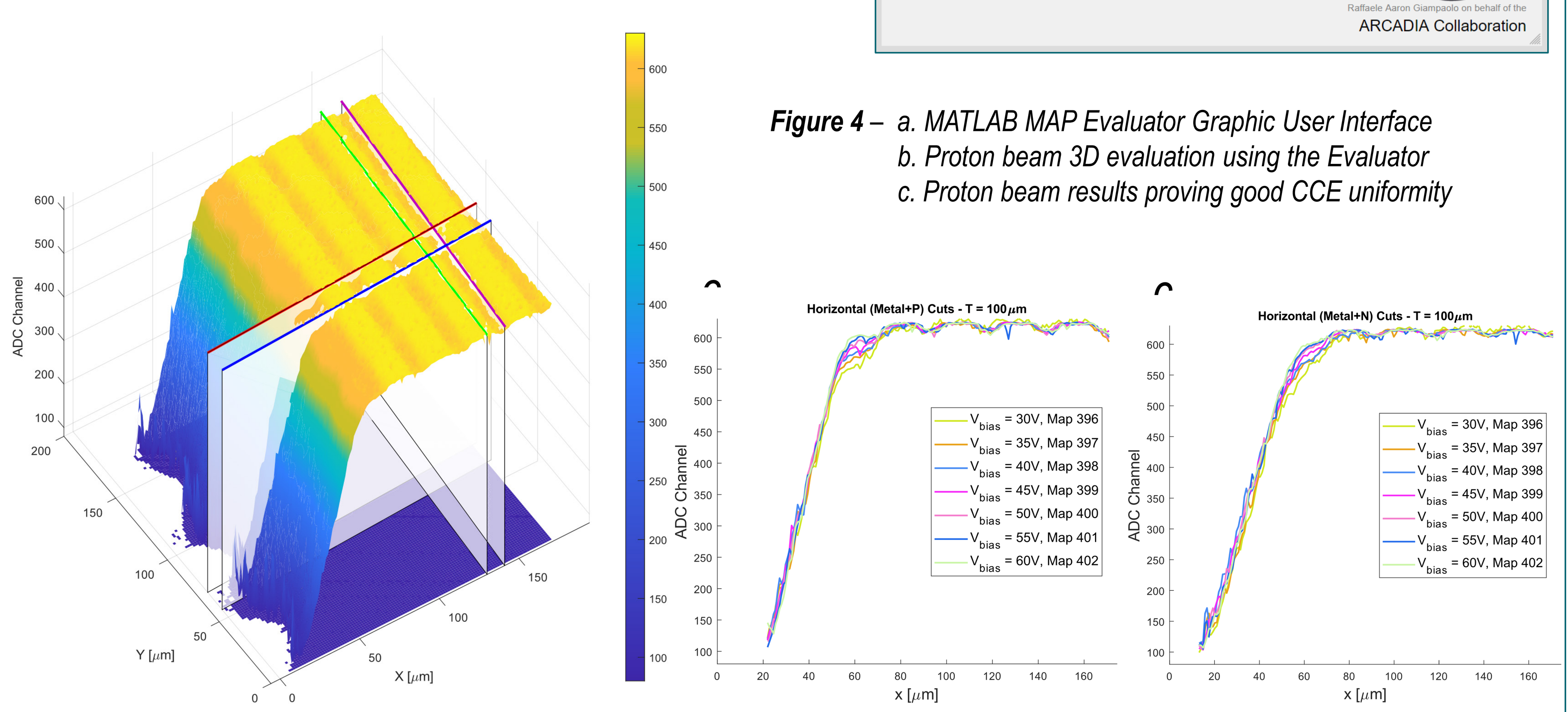


Figure 4 – a. MATLAB MAP Evaluator Graphic User Interface
b. Proton beam 3D evaluation using the Evaluator
c. Proton beam results proving good CCE uniformity

Future work

1. Further tests and improvements of the ARCADIA front-end for extremely low power applications.
2. Research and development of **3D Stacked Hybrid CMOS Image Sensors** (Fig. 5).

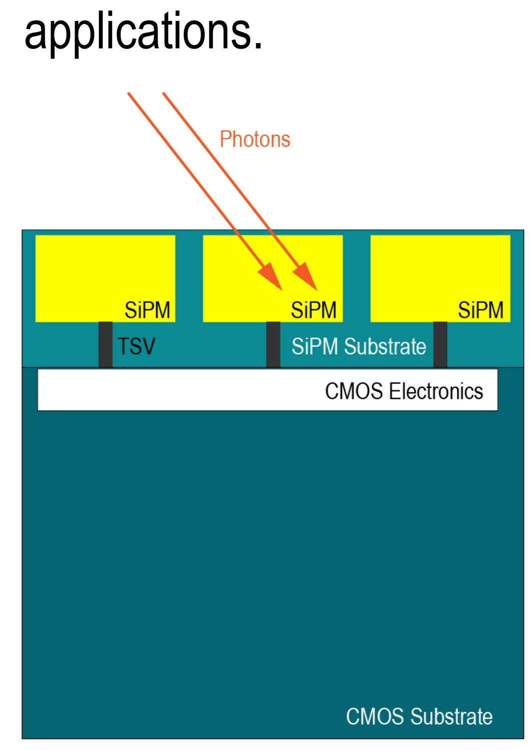


Figure 5 - Simplified scheme of a 3D SiPM scalable sensor

In these devices the sensors and the electronics are built on different wafers and then bonded either through bump bondings or through silicon vias (TSV). Differently from FD-MAPS, these devices are mainly suitable for **photon sensing**. The physics and engineering communities, are now starting to embrace the capabilities of such technologies in order to **maximize the SNR**, **the granularity of detectors** and the **production rate** in case of large area detectors.
The perfect experimental physics candidate is the DarkSide collaboration. In this framework, a scalable 3D Hybrid CIS would render single-photon counting and digitization of large area silicon photo-multipliers in cryogenic temperatures possible.

Submitted and published works

Giampaolo, R. A. et alia, "*Depleted MAPS on a 110 nm CMOS CIS Technology*", 26th IEEE International Conference on Electronics Circuits and Systems, Genova, November 2019, Accepted