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AIDAinnova

Advancement and Innovation for Detectors at Accelerators

Horizon 2020 Research Infrastructures project AIDAINNOVA

MILESTONE REPORT

RADIATION HARD PROTOTYPE FABRICATION

MILESTONE: MS20

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Abstract:

Within WP5 (Development of Monolithic Active Pixel Sensors) Milestone MS20 contains the fabrication of several prototypes.

This milestone has been successfully achieved and is reported.

For more information on AIDAinnova, its partners and contributors please see http://aidainnova.web.cern.ch/

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Contents

Executive summary

Prototyping of two Depleted Monolithic Active Pixel Sensors (DMAPS) using the LFoundry 150 nm technology has been successfully performed leading to two chips that targeted primarily radiation hardness. The fabrication is successfully completed, and the prototypes now enter their characterization phases.

1. INTRODUCTION

Depleted Monolithic Active Pixel Detectors (DMAPS) are a key technology for the AIDAinnova project as they constitute, according to most detector experts, the most interesting new direction of pixel detector development. Therefore, they are an essential development for pixel detectors at present and planned accelerator experiments.

Within WP5, the development approach branches into two targets, one focusing on high granularity devices, targeting above all small pixel dimensions, the other targeting foremost the radiation hardness of devices, especially for applications at hadron colliders as the LHC. In this Milestone Report, we report on the prototype fabrication of DMAPS devices that target radiation hardness:

(1) LF-Monopix2 sensors in 150 nm CMOS technology: a matured large-size prototype that implements a complete readout architecture.
(2) RD50-MPW2/3 also in 150 nm technology: a more recent development of a more exploratory endeavor.

This milestone report concentrates on the achieved milestones in these two developments.

2. RADIATION HARD DMAPS PROTOTYPE DEVELOPMENT

The development of Depleted Monolithic Active Pixel sensors has followed so far essentially two generally different design approaches (Fig. 2.1): (a) large electrode design and (b) small electrode design. While within AIDAinnova (a) is the prime approach for high radiation hardness, (b) targets primarily high granularity, i.e. small pixels, and low-noise and low-power operation, albeit with good radiation tolerance as well. Development of designs (a) is the theme of this report.

The large electrode design benefits charge collection, making it more radiation hard, which is critical for certain applications, particularly in inner layers of tracking detectors in hadron collider experiments. On the downside, large electrodes result in a larger capacitance at the input of the pre-amplifiers, resulting in larger noise and power consumption. Therefore, the development focuses on achieving radiation-tolerant full charge collection while ensuring a large signal-to-noise ratio for high hit-detection efficiency after irradiation.

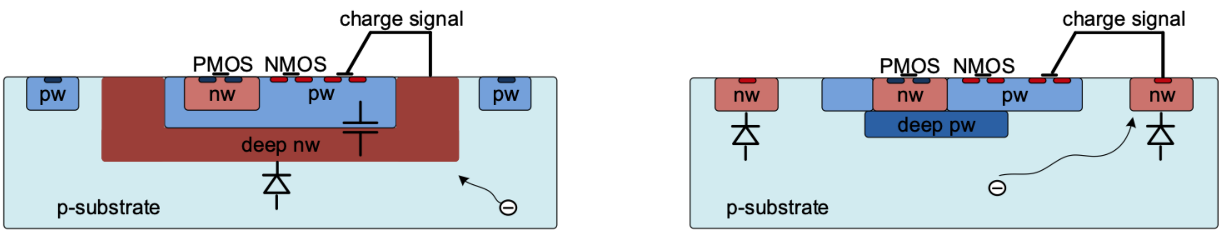

Fig. 2.1 Two approaches for DMAPS: (a) large electrode cell design, (b) small electrode cell design.

2.1. PROTOTYPE LF-MONOPIX2 IN 150 NM TECHNOLOGY

The Monopix chip line includes prototypes in the TowerJazz 180 nm and LFoundry 150 nm technologies. LF-Monopix2 chip has a size of 1 × 2 cm^2 and a pixel pitch of 50 × 150 μm^2, reduced with respect to the previous version (the LF-Monopix1). The pixel matrix takes up 82% of the chip area, the rest is occupied by guard rings, decoupling capacitors and peripheral circuitry at the top and bottom of the chip. Due to the smaller pixel size and hence reduced capacitance (~ 250 − 300 fF) an improved signal to-noise ratio and a better timing performance are expected. The large electrode approach should result in a better performance after irradiation.

The matrix is divided into three main sub-matrices that include different charge sensitive amplifier (CSA) designs. One of the sub-matrices is further subdivided into four regions with different CSA feedback capacitances (1.5 fF or 5.0 fF), local threshold tuning schemes (unidirectional or bidirectional) and pixel-level logic. The pixel design of LF-Monopix2 features rounded corners for reduction of the electric field on the edges, which, together with an optimized guard-ring design, improve the breakdown behavior of the sensor (see Fig. 2.2). Characterization of the LF-Monopix2 is ongoing [1] and will be reported in future reports.

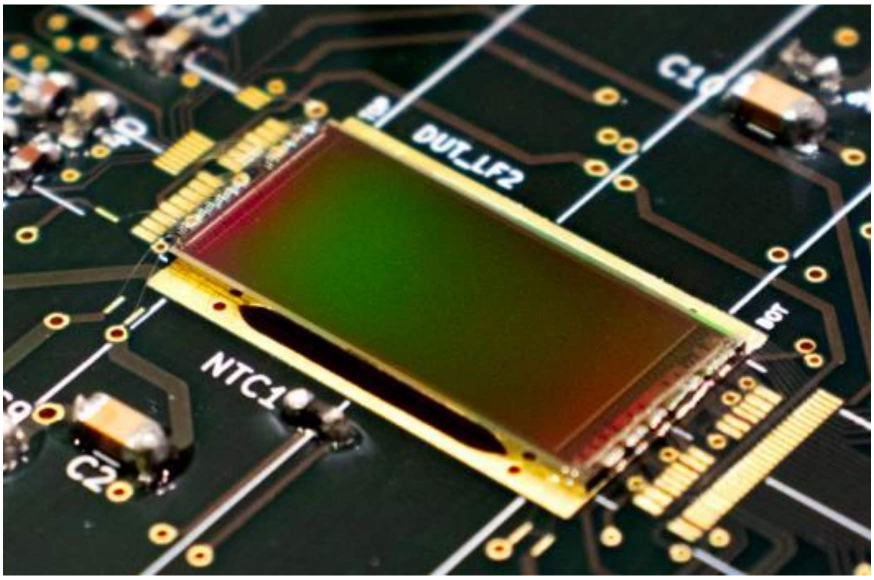

Fig. 2.2: Photographs of successfully produced LF-Monopix2 mounted on a readout board.

2.2. PROTOTYPE RD50-MPW2 AND 3 IN 150 NM TECHNOLOGY

A second effort to develop radiation hard devices was launched after the LF-Monopix approach. The RD50-MPW2 chip [2], fabricated in the framework of AIDAinnova, followed the MPW1 chip, which suffered from a large leakage current. In an effort to understand the high current, the MPW2 chip implements a smaller, very simple, chip structure with a guard ring frame at the edge. The chip avoided certain post-processing filling layers that involve conductive material. The chip has 8 rows x 8 columns of 60 μm x 60 μm pixels with analogue readout only (see Fig. 2.3).

The RD50-MPW2 has several design limitations, such as the small number of rows and columns of the pixel matrix, the lack of digital readout electronics to identify events and a very simple peripheral readout that makes certain types of measurements too slow or not possible. Thus, the MPW2 chip was closely followed by the RD50-MPW3, which overcomes the limitations of its predecessor by extending the number of pixels in the matrix (64 columns x 64 rows), incorporating in the pixel area digital readout electronics based on the column drain architecture, and adding optimized peripheral readout electronics for effective pixel configuration. The MPW3 chip is currently being tested and tests after irradiation are expected later this year.

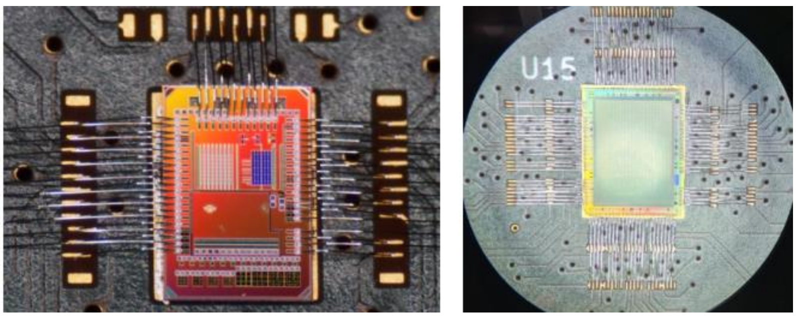

Fig. 2.3: Photograph of successfully produced RD50-MPW2 (left) amd RD50-MPW3 (right) chips mounted on boards for testing.

3. CONCLUSIONS

The planning envisaged for the DMAPS high radiation tolerance approach employing the 150 nm CMOS technology and different architectures was executed as planned initially, leading to the following:

- A large prototype matrix LF-Monopix2 with full readout architecture (column-drain) which has been irradiated to 10^{15} n_{eq}/cm^2 and is currently being thoroughly tested.
- A first small size prototype investigator, also in 150 nm technology (RD50-MPW2), followed up with a new version (RD50-MPW3) that implements a larger matrix with column drain readout. The devices are also being tested.

The devices have been made available to the groups participating in the work package and their performance will be evaluated before and after irradiation. We conclude that with these successful chip submissions, milestone M20 was fully met and can be considered to be accomplished.

4. REFERENCES

[1] J. Dingfelder et al., “Progress in DMAPS developments and first tests of the Monopix2 chips in 150 nm LFoundry and 180 nm TowerJazz technology”, NIMA Vol 10341 (2022), 166747. doi:10.1016/j.nima.2022.166747

[2] E. Vilella et al., “Development of high voltage-CMOS sensors within the CERN-RD50 collaboration”, Vol 1034 (2022), 166826. doi:10.1016/j.nima.2022.166826

ANNEX: GLOSSARY

Acronym	**Definition**
DMAPS	Depleted Monolithic Active Pixel Sensors