Radiation Hardness of a Large Area CMOS Active Pixel Sensor for Bio-medical applications

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***Index Terms*—Radiation hardness, CMOS, APS, Large area image sensors, semiconductor devices.**

I. INTRODUCTION

IN many biomedical imaging applications there is a strong demand for large area sensors. For the last two decades amorphous Silicon and amorphous Selenium based flat panel imagers (FPI) have represented the detector of choice in digital medical imaging, mainly because they can be easily fabricated on a large area with a relatively low cost technology, derived from the consumer based flat panel display technology [1]. Even so FPIs suffer significant drawbacks, which impact on imaging performance, such as large pixels, high noise (> 1000 e^-), low frame rate and image lag [2]. In this scenario CMOS Active Pixel Sensors (APS) [3] have gained popularity having showed the capability of overcoming such issues, offering a lower noise ($60 - 150\,e^-$), a pixel pitch in the order of $25 - 50\,\mu m$, a high frame based on a true random access via column parallel readout and absence of image artefacts [4], [5]. These advantages, together with low power consumption and potential for a low cost and fast scaling technology (based on standard consumer-based CMOS fabrication), have made CMOS APSs a valuable alternative in the bio-medical imaging field.

Furthermore, recent developments in photo-lithographic techniques [6] have made available the realization of large area devices integrated onto an eight inch silicon wafer to create a contiguous sensor array scalable up to the wafer size, i.e. 13 cm × 13 cm [7].

In order for CMOS APSs to impact upon the medical applications area, then it needs to demonstrate a significant radiation hardness. Several investigations have been carried out to assess the radiation tolerance of CMOS devices [9], [10] and to propose new design techniques to enhance this performance [8].

In this paper we propose a novel wafer scale CMOS APS, developed in the framework of the Multidimensional Integrated Intelligent Imaging Plus (MI-3 Plus) consortium. This detector has been designed for bio-medical applications and offers a high radiation hardness-by-design [8]. The radiation hardness of this detector has been characterized and the results have been compared with a commercial CMOS APS for radiology applications.

II. THE RADIATION HARD DESIGN OF THE DYNAMITE DETECTOR

The APS presented here, named the Dynamic range Adjustable for Medical Imaging Technology or DynAMITe, was constructed in a 0.18 μm CMOS process by reticule stitching technique for a total active area of 12.8 cm × 13.1 cm. A picture of the wafer from which the DynaAMITe sensor will be diced is shown in Fig. 1. The DynAMITe pixel array consists of two different size diodes meshed in the same pixel matrix, thus realizing two imagers in one. The detector consists of fine-pitch grid diodes, offering intrinsic low noise and high spatial resolution, and a large-pitch grid diodes, offering a high dynamic range. Both grids are geometrically superimposed. Thus each cell of the DynAMITe matrix is fitted with multiple diodes: four diodes of small size (50 μm side), named Sub-Pixels, and one diode of large size (100 μm side), named Pixel. The whole matrix comprises 1312 × 1280 Pixels and 2624 × 2560 Sub-Pixels. A more detailed description of the pixel architecture, the read out modalities and electro-optical performance are reported in [5]. The DynAMIte detector has been designed according to the radiation hardness-by-design methodology. In fact all the in-pixel transistors have been designed with source and drain physically enclosed using an Enclosed Layout Geometry (ELG) [8], [11] in order to reduce the edge-leakage, which is generated in the transition area between the thin gate oxide and the thick field oxide, used to produce transistor-by-transistor insulation, after exposure to radiation. P^+ doped guard rings have been added in each pixels to prevent radiation induced inter-device leakage current. Moreover the standard sub-micrometer process used guarantees a thin field oxide, comparable with the tunnelling length for holes in SiO_2. This increases the probability for holes to tunnel out of the gate oxide avoiding the formation of trapped charge at the interface $SiO_2 - Si$, responsible for threshold voltage shift in NMOS transistors exposed to radiation.

III. EVALUATION OF THE RADIATION DAMAGE

The DynAMITe detector, together with a commercial APS designed for bio-medical applications, have been exposed to a X-ray field (W anode, 160 kV, 0.5 mm Cu filtration) up to a dose of 1.2 kGy. Both detectors were provided with a scintillator (140 μm thick Gd_2O_2S:Tb) and a Fiber Optic Plate (3 mm thick for Dynamite, 4 mm for the commercial device).

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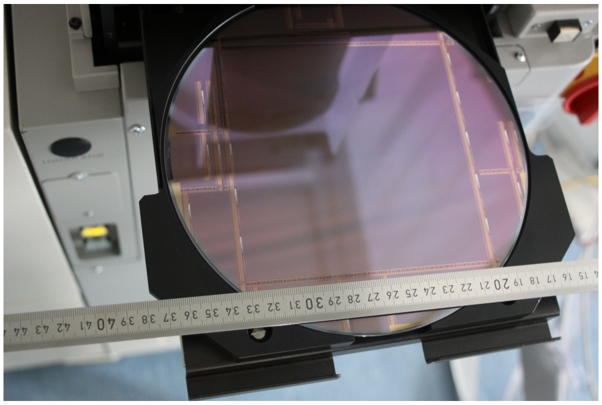

Fig. 1. DynAMITe chip wafer. The boundaries of the chip region are visible with the ruler denoting the 12.8 cm edge dimension.

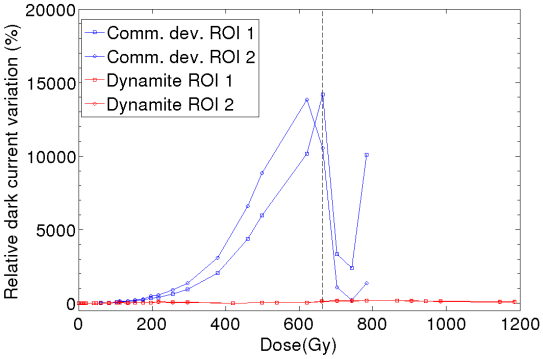

Fig. 2. Relative increase in dark current reported for the DynAMIte detector and a commercial device (*Comm. dev.*) in both the exposed ROIs.

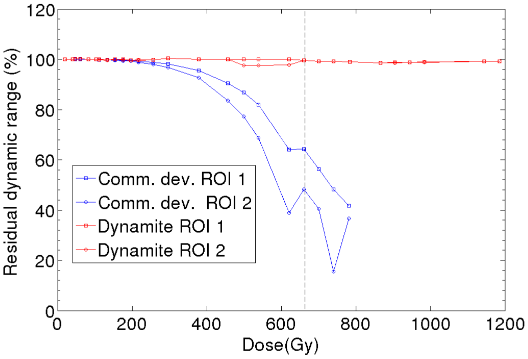

Fig. 3. Residual dynamic range reported for the DynAMIte detector and a commercial device (*Comm. dev.*) in both the exposed ROIs..

An average of 15 hours of exposure per day was performed while detectors were biased. Performance parameters such as dark current, gain, dynamic range, number of outliers and fixed pattern noise (FPN) have been evaluate at each exposure step for two separate region of interest (ROIs).

Figs. 2 and 3 show comparative data for leakage current and dynamic range measured for both detector under analysis. Leakage current increases exponentially for the commercial device (*Comm. dev.*) up to a dose of 700 Gy, where lose of light sensitivity and pixel resolution occurs (dotted line in Fig. 2). At this dose the relative increase in dark current for the DynAMITe detector is lower than 150% (100 times lower than the increase observed int he commercial device) and is almost constant up to maximum dose delivered (1.2kGy). The residual dynamic range, calculated with the respect to the dynamic range of the unexposed sensors, is shown in Fig. 3. The DynAMIte detector exhibits a residual dynamic range of about 99% of the unexposed one up to 1.2 kGy, whereas the commercial device falls below the failure limit of 50% at 650 Gy. This test is still currently in progress for the DynAMITe detector.

IV. CONCLUSIONS AND FUTURE WORK

The DynAMITe detector has been presented as a novel large area APS detector capable of two inherently different resolutions each with different noise and saturation performance in the same pixel array. The radiation hardness-by-design of this detector has been discussed and evaluated through X-ray radiation damage testing. The DynAMITe detector has demonstrated a significant radiation hardness when compared with the commercial device involved in the comparison, showing great potential for use in radiation imaging field. Preliminary results of Monte Carlo simulations will be also reported in the final paper. This will describe the major sources of radiation damage occurring in an APS device, taking into account the contributions to the detector damage from all the steps of the detection chain in a common X-ray imaging set up, i.e. including scintillator and Fiber Optic Plate.

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