Radiation Effects on Active Pixel Sensors (APS).

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An active pixel sensor is defined as a detector array that has at least one or more active transistors integrated into the pixel [1]. So an APS is constituted by two elements, one composed by the pixel area for detection signal and signal storage, the other constituted by the active transistor(s) to amplify the signal and then to allow semi-random access to the pixel *(fig.1)* and random read out of the signal. Thus, due to its structure, APS is a potential candidate to the CCD's succession.

I.INTRODUCTION

Charge coupled devices (CCDs) are currently the dominant technology for image sensors. The most important features of CCDs are their high sensitivity, their high quantum efficiency of the order of 40% and their high fill factor of pixel (80%-100%). However, CCD are unhardened due to their structure and well known for their sensitivity to radiation encountered in space. These applications need a high degree of electronic integration on the chip to allow miniaturisation of instruments systems and to simplify system interfaces. Indeed, CCD's cannot be easily integrated with CMOS circuits due to the additional fabrication complexity and increased cost. Moreover, CCDs need at least 2 voltage levels to achieve charge transfer. On the other hand, CCDs suffer from ionising damage which leads to flatband voltage shifts [2] and from displacement damage which introduces a loss in charge transfer efficiency [3]. Moreover, both of these radiation effects increase dark current and constitute a significant source of noise [4]. The radiation tolerance of a CCD gets worse as the sensor format gets larger since more charge transfers are required to deliver the signal electrons to the output amplifier and since a dead pixel in a CCD stops a transfer of an entire column.

Thus, APS sensors offer a good alternative for space applications due to the fact that CMOS sensors provide the advantage to combine complex analog and digital components on the same chip [5]. APS structure eliminates signal degradation due to charge transfer inefficiency in CCDs and APS only needs of one voltage to function which reduce considerably current consumption. Nevertheless, APSs suffer from noise due to the readout circuit and from dark current.

This paper will present irradiation results on one type of Active Pixel Sensor (APS) for future space applications.

II APS PHOTOMOS and PHOTODIODE OPERATION

This detector contains two Active Pixel Sensors (APS), one photodiode and one photoMos, with 32*32 pixels sized at 50×50 μm² . The fill factor is 75% for the photodiode and 57% for the photoMos. This circuit has been developed by SUPAERO [6] using a standard CMOS Double Layer Polysilicon / Double Layer Metal 1.2μm process line from Austria Micro System (AMS). Imagers include, as well, 5-bit X-Y address decoders, correlated double-sampling (CDS) readout electronics to reduce kTC noise, 1/f noise and pixel pattern noise from the pixel and double-delta sampling circuit to diminish column-to-column fixed pattern noise *(fig. 2)*.

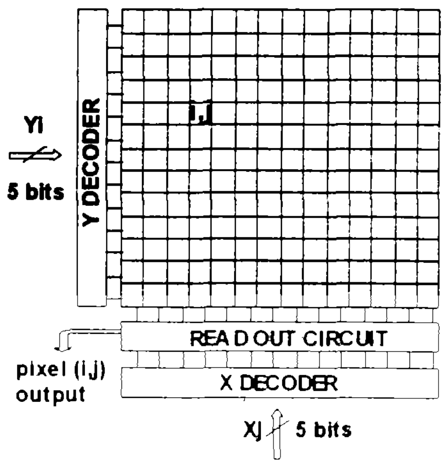

Figure 1: APS random access circuit.

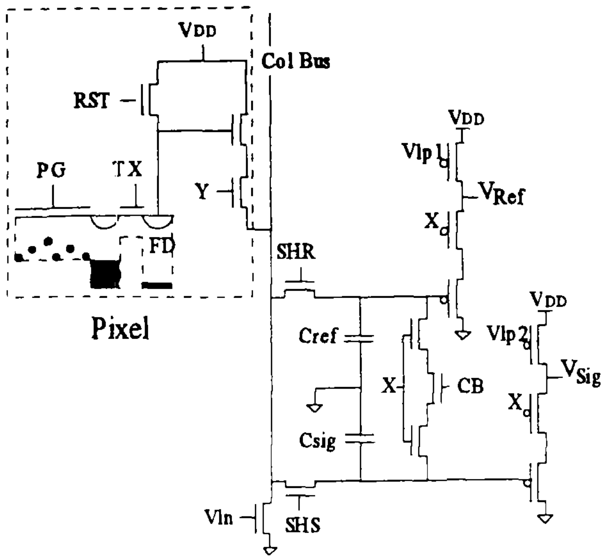

Figure 2 : APS photoMos pixel and readout circuit.

In the photoMos device, charge is integrated under the photoMos PG and prior to readout, the floating diffusion node, FD, is reset using the in-pixel reset transistor RST. Then the photosignal is transferred from PG into the floating diffusion node and [7].

In the photodiode device, the charge are integrated into a depleted N^{+}/P junction. At the end of the integration time, the charge signal is read out. Then the junction is reset .

The readout circuit includes two sample-and-hold circuits for storing and reading out differentially the signal and the reset levels. Once the reset and signal levels are read out differentially ($\Delta 1$), the crowbar (CB) is pulsed, thereby shorting the two sample-and-hold capacitors in the column addressed. The outputs of the reset and signal branches are again read out differentially, thereby generating a voltage which is proportional to the threshold voltage difference between the two adjacent p-channel transistors ($\Delta 2$). The voltage proportional to the photosignal is obtained by subtracting this offset level from the first reading. $\Delta' = \Delta 1 - \Delta 2$.

III. Experimental Conditions and Results.

The Schlumberger ITS9000MX tester is used to generate the required control signals to the APS and to measure output signals. This tester offers the possibility to develop software programs to extract dark noise, fixed pattern noise, read noise and as well, conversion gain and dark current.

Irradiations were performed at room temperature under static bias using the Co^{60} gamma ray source (Shepherd 2500 Ci) at a dose rate of 150 Gy[Si]/h (1Gy = 100 rad).

APS devices were characterised at room temperature (21°C) prior to exposure to provide a complete pretest baseline. The saturation signal level for the photodiode is 1360 mV and 1400 mV for the photoMos. The readout rate is 1 us per pixel for the photoMos and 1.5 us per pixel for the photodiode.

For a short integration time (5us), the output dark voltage in the photoMos (~25mV) is four times higher than in the photodiode (~7mV).

The dark voltage was measured as a function of the integration time *(fig. 3).*

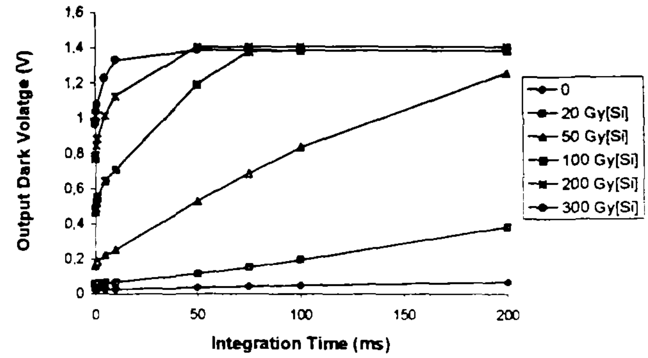

Figure 3: PhotoMos Dark Voltage.

The slope of the curves of figure 3 is proportional to the dark current in the detector (1).

$$I_{dark}(A/cm^2) = \frac{q}{A}\cdot\frac{dV'_{dark}}{dt}\cdot\frac{1}{\alpha}$$

(1)

where A is the detector area, α is the conversion gain (μV/e-) and q the electronic charge.

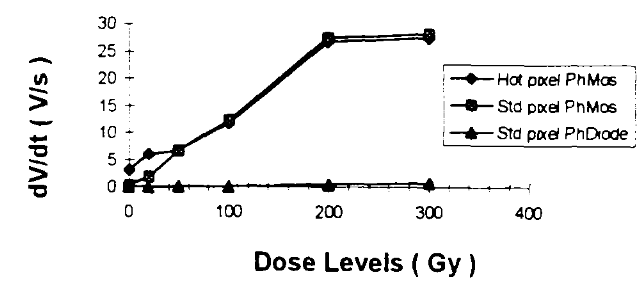

Figure 4: Dose Level Effects on Dark Current for the PhotoMos and the Photodiode.

A "hot" pixel has an initial dark current rate, so an output dark voltage, much larger than the typical value.

For the photoMos, the dark current increases dramatically with dose level *(fig 4)*. Dark currents on photodiode appeared at 200 Gy[Si]. At this dose level, the readout circuit is damaged as well.

As photodiode output dark voltage remained at 7mV during irradiation, no dose level effect appeared on these structures.

For the photoMos, the output dark voltage level increased of a factor of about 40 at 300 Gy[Si] (~960mV) *(fig. 5)*.

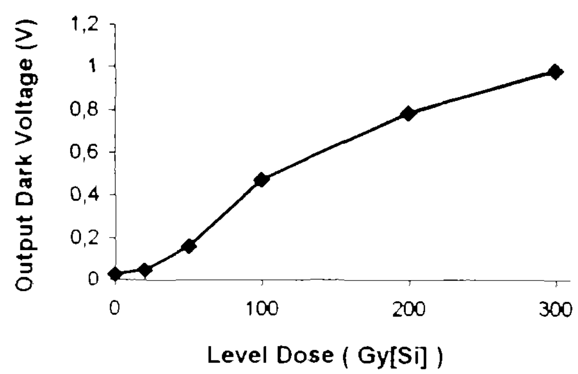

Figure 5: Dose Levels effects on PhotoMOS dark signal.

IV. PERSPECTIVES.

PhotoMos is more sensitive to radiation effects than the photodiode. Important parameters of image sensors like dark currents increase severely with dose levels. Nevertheless, photodiode sensitivity is one hundred time lower than photoMOS sensitivity.

In the final paper, we will expose more precise characterisations (noise, conversion gain) and analyse the APS's working degradation process under Co^{60} and protons exposures.

This primarily work will provide elements to compare APSs and CCDs when exposed to radiation environments.

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