CMOS sensor as charged particles and ionizing radiation detector

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Abstract. This paper reports results of CMOS sensor suitable for use as charged particles and ionizing radiation detector. The CMOS sensor with 640x480 pixels area has been integrated into an electronic circuit for detection of ionizing radiation and it was exposed to alpha particle (Am-241, U nat), beta (Sr-90), and gamma photons (Cs-137). Results show after long period of time (168 h) irradiation the sensor had not loss of functionality and also the energy of the charge particles and photons were very well obtained.

1. Introduction
Recently, the CMOS active pixel sensors have been tested for several applications and thus have increased the demand for improving the performance thereof [1]. This type of sensors has an APS (Active Pixel Sensor) architecture, which is formed by an integrated circuit with a matrix of pixels where each pixel itself contains a photodetector [2,3]. At present, the pixel size is less than 2 micrometers which is possible thanks to microelectronics. In addition to imaging applications, new perspectives in various research areas could be opened by a different type of devices such as CMOS sensors. As an example, these devices could be used for detection of ionizing radiation with the possibility of a submicrometer measurement. In this work we have investigated the possibility of using a CMOS sensor with an area of 640x480 pixels, which previously has been integrated into an electronic circuit (figure 1) for detection of ionizing radiation and charged particles testing from radioactive sources, such as: Am-241, Natural Uranium (U-234, U-235 and U-238), Sr-90, and Cs-137.

1.1 CMOS sensor operation.
The operation of the CMOS sensor is characterized by its APS architecture, which is sensitive to the incidence of visible or infrared light, this way the polarized inversely occurs a certain circulation of current when pixel is excite by light generates a current power in each of the pixels, which varies with the intensity of light received.
In turn is incorporated an amplifier for electrical signal at each photo site where the device must send the electrical signal produced by each photosite sensor out of it and amplify on the PC.
1.2 Signal generation for the sensor CMOS.
According to the linear energy transfer (LET) [4], the load generated from several heavy ions is usually assumed to be proportional. Indeed for in situ particles in the surface area of the sensor, linear energy transfer remains constant, where the concept has worked well for older devices, and continues to have a reasonable approach to alpha particles. In this work the system has been exposed to alpha particles by Am-241 and natural uranium. Considering

\[ \Delta F = -\nabla \Delta E \]

where \( \Delta E \) is the energy loss of the charged particle due to electronic collisions while across a distance \( dx \), excluding all secondary electrons with kinetic energies larger than \( E_0 \) from the count. For beta radiation, electrons will have an electric current proportional to the decay energy, which is produced in each of the pixels, provided by the Sr-90 and Cs-137,

\[ E_{e^-} = I \]

Finally for gamma radiation, whose photon will impact in the surface of the sensor that is exciting each pixel sensor according to the photoelectric effect through the Cs-137,

\[ hf = \phi + E_k \]

In this way, the energy that is incident on each of the pixels is directly proportional to the radiation from each radiation source.

2. Experimental part

2.1 System Calibration
The radioactive source of Americium-241 was characterized by constant emit alpha radiation, which has been used for the calibration of various sensors. From a sample of 0.2g and by mass-energy relation was calibrated system:

\[ E_{Am-241} = (1.00495275 \times 10^{-39} \text{ kg})(2.997 \times 10^8 \text{ m/s})^2 \]

\[ E_{Am-241} = 5.63451604 \text{ MeV} \]
2.2 Electrical response from CMOS sensor
The response of the sensor in the absence of radiation has been studied, for each of the pixels is taken the information from them; where the distribution was possible represent a Gaussian as shown in figure 2.

This means that the sensor could withstand the variation of current produced by different radioactive sources, which shows that for small variations of electric currents, the critical detection point will be through $2.7 \times 10^3$ photosites found in the pixels of the sensor and to larger variations will only need 27 to 270 photosites due to digitization of the signal.

3. Results

3.1 Sensor Response to Alpha radiations
The sensor was exposed to ionizing radiation at the Nuclear Sciences Institute (UNAM) of México. Figure 3 shows the impact of $^4$He atoms on the sensor surface, and the total energy of the source (Am-241) was about 5.0 MeV where the peaks represent the total energy.

For the composition of Natural Uranium, was obtained a maximum energy of 4.0 MeV and minimum around 2.5 MeV as shown in figure 4. That behavior is due to the composition of the radioactive source which is composed of $^{235}$U, $^{238}$U, and $^{238}$U. One influence is the types of nuclear decays occurring in it due to fluctuation of the energy that arrived to CMOS sensor.

3.2 Sensor response to Beta and Gamma radiations.
Sensor response to beta radiation was obtained by a strontium-90 source, as shown in figure 5, this source had magnitude of about 0.8 MeV of energy.

![Figure 2. Distribution of digitization in the CMOS sensor pixel represented by a Gaussian.](image-url)
Figure 3. Alpha radiation detection from Am-241 on the sensor area.

Figure 4. Natural Uranium radiations on the sensor area.

Figure 5. Beta radiation energy from Sr-90 on the sensor area.

Figure 6. Photons from Cs-137 incidents on the sensor area.

Finally, the Cesium 137 source was used for testing CMOS sensor. Figure 6 shows beta and gamma radiation energy incidents on the sensor. It is important to mention that the gamma rays do not affect the functionality of the sensor and the energy recorded was 1.6 MeV.

3.3 Activity frequency.
Frequency of activity (hits per second) of the sources was carried out during 30 s irradiation and in this period of time the impacts or hits on the sensor were recorded (table 1). This readout was repeated for five times for each source.
Table 1. Activity frequency.

| Sources | Hits/s    |
|---------|----------|
| Am-241  | $1.295 \times 10^4$ |
| U nat   | $1.244 \times 10^6$ |
| Sr-90   | $5.12 \times 10^9$  |
| Cs-137  | $3.15 \times 10^{11}$ |

4. Discussion and conclusion
The CMOS sensor response was appropriated in each variations of energy from the radioactive sources. The graph in the figures shows the area and positions of the sensor surface where the impacted particles and gamma rays. The higher peaks show each energy type from radiation source. The frequency of activity of the sources was very well determined. Due to the composition within the pixels by the photosites, exposure of the sources was in the absence of external light in order to avoid the outer photons excite each of the photosites. When the CMOS sensor was tested under continuous irradiation for a long period of 168 hours (1 week) using the largest energy source (Am-241), the sensor had not loss of functionality.

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