ISAE-SUPAERO / CNES / NASA GSFC
PhD thesis position

PARTICLE FLUX DEPENDENCE OF SPACE RADIATION EFFECTS IN IMAGE SENSORS

Duration : 3 years

Location : 50% at ISAE-SUPAERO and CNES, Toulouse, **France** / **50%** at NASA Goddard Space Flight Center, Greenbelt, MD, **USA**

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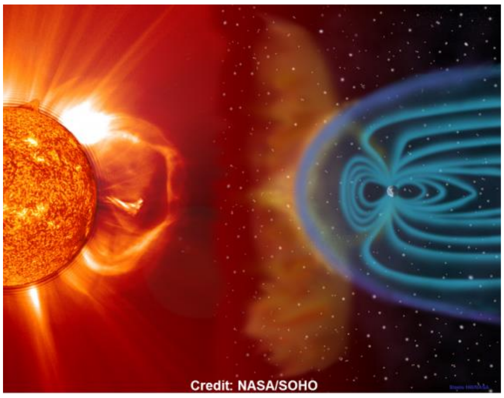
Scientific Domain: Image Sensors, Detectors, Pixel Arrays, Nano/Microelectronics, Solid State Physics, Semiconductor Device Physics, Particle/Matter Interactions, Radiation Effects on Electronics

Keywords: CMOS Image Sensors (CIS), Single Photon Avalance Diodes (SPADs), Charge Coupled Devices (CCDs), Silicon, Space Radiation Environment, Radiation Effects, Displacement Damage, Space Instrumentation, Remote Sensing, Navigation and Orientation, Planetary observation and Astronomy.

Context: Space missions rely on image sensors for critical applications such as navigation and orientation, planetary observation, and astronomy. Mission success depends in part on the image sensor performance withstanding the space radiation environment (illustrated in Figure 1). The main energetic particles encountered by space systems are high energy protons, electrons and heavy ions.



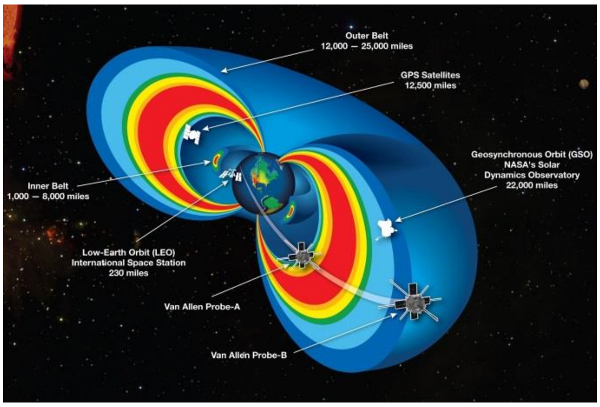


Figure 1 : Illustration of space radiation environment (Credits NASA).

Image sensors or imagers, such as Charge Coupled Devices and CMOS Image Sensors, are silicon integrated circuits that detect visible light to make an image. Such electronic image sensors are used in camera phones, in digital cameras, as well as in optical space instruments.

As illustrated in Figure 2, an electronic image sensor consists of a pixel array to collect light and peripheral analog and digital electronic functions to readout the pixels. Pixels are usually constituted of a photodiode and a few Metal Oxide Semiconductor Field Effect Transistors (MOSFETs) to access the useful photogenerated signal.

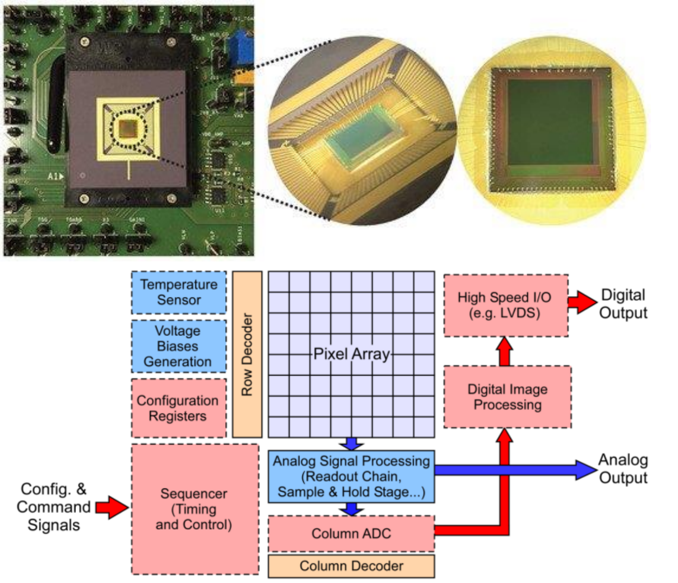


Figure 2: Photograph on an image sensor silicon chip mounted inside a ceramic package (top). Typical architecture of a CMOS image sensor (bottom).

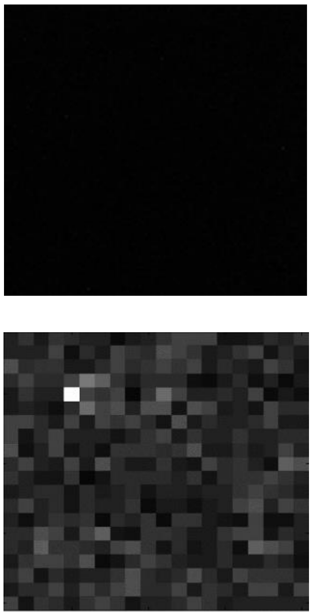


Figure 3: Illustration of the effects of the space radiation environment on a dark image captured by an image sensor before (top) and after (bottom) exposure to particle radiation.

Both commercial and science-grade image sensors suffer image degradation (as depicted in Figure 3) due to displacement damage to the crystal lattice (Figure 4 and 5) of the semiconductor from space energetic particle interaction with the material Radiation hardness assurance of these image sensors relies in part on terrestrial radiation testing performed at particle accelerator facilities. During this terrestrial test the total radiation dose representative of that expected during the several year lifetime of the space mission is typically delivered to the sensor in multiple exposures lasting minutes, over a period of a single day or up to several days if extensive characterizations are performed between exposures. Accelerator facility availability and cost, as well as flight project schedule and labor costs, drive the acceleration of the dose rate for these tests whereas in the real mission, the same radiation dose is deposited over several years of operation.

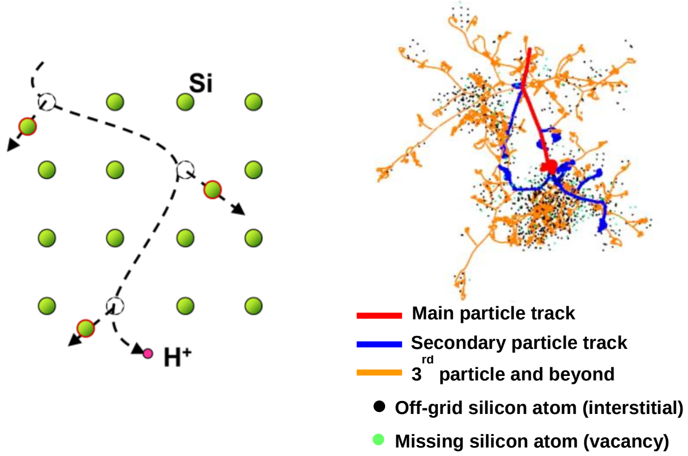


Figure 4 : Illustration of the damage cascade caused by an energetic particle from the space radiation environment in a silicon microvolume

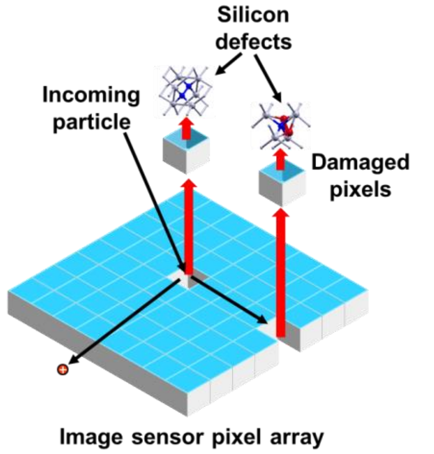


Figure 5 : Illustration of the effects of the space radiation environment on pixel array performance : energetic particles can damage a pixel if they hit a silicon atom inside the its sensitive volume

Prompt annealing of defects due to thermal activation is known to take place over a period of seconds to minutes in silicon at room temperature. Although damage to the lattice is introduced on the order of picoseconds, flux (non-ionizing dose rate) effects are not considered to be significant at the recommended proton test flux of 10^7 to 10^8 cm^{-2} s^{-1}. Studies cited typically utilized very low (a few MeV) energy particles at room temperature, and at fluxes ≥ 10^7 cm^{-2} s^{-1}. In contrast, on orbit the long-term flux of protons is several orders of magnitude lower, peaking at energies of 50-70 MeV for shielding levels typical for image sensors. CCDs and other sensors are often cooled to reduce dark current. The application conditions therefore slow the annealing and enable rarer large-cluster damage formation. In addition, cases of terrestrial testing that over-predicted image sensor degradation have been reported privately and in the literature. Importantly, overly-conservative terrestrial test results can increase mass penalties from unnecessary shielding and remove from consideration scientifically desirable imagers.

Thesis Objectives: This Ph.D. thesis topic will center on the design and execution of a well-controlled set of experiments under typical on-orbit conditions using relevant modern silicon image sensor technologies to evaluate the effects of particle flux on displacement damage effects. Recently, extensive modeling of displacement damage mechanisms in silicon, including use of a novel kinetic Activation Relaxation Technique (k-ART), has enabled insight into the size and evolution of particle-induced damage sites over time scales meaningful for correlation with experiments. Modeling to guide test conditions and understand experimental results will strengthen the impact of this topic.

Work to be performed: The doctoral student will:

- Perform a literature review concerning:
  - temperature, flux, and energy effects on displacement damage induced degradation of silicon devices in general and image sensors specifically.
  - state-of-the-art (SOA) CCD, CIS, and other silicon image sensor technologies.
  - discrepancies in terrestrial test and on-orbit sensor performance.
- Develop hypotheses of flux effects on SOA silicon image sensors.
- Design a concise set of particle-accelerator experiments to test hypotheses.
- Perform molecular dynamic and k-ART modeling of hypotheses to predict test outcomes and optimize design of experiments.
- Conduct particle-accelerator experiments to test hypotheses and fidelity of model predictions, iterating with modeling work as needed to explain findings.
- Propose appropriate test guidelines based on findings.
- Predict extensibility of findings and guidelines to other sensor materials and technologies.

Required competences: Master Degree addressing one or several of the following themes :

- Solid State Physics / Semiconductor Physics / Semiconductor Device Physics
- Nano-Microelectronics / Optoelectronics
- Aerospace Engineering
- Particle/matter interactions / Radiation Effects on materials or electronic circuits
- Nuclear Physics

How to apply?

Send an email to vincent.goiffon@isae-supaero.fr with a CV and a cover letter presenting the motivations for this position.

Apply also on the CNES website to be registered by the CNES HR department:

https://recrutement.cnes.fr/en/annonce/892093-148-particle-flux-dependence-of-displacement-damage-effects-in-image-sensors-31400-toulouse

The targeted period to start this PhD project is: September 2020 to April 2021.