Radiation Hard High Speed Camera System for Accelerator Beam Diagnostics

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Abstract:
This poster describes a radiation-tolerant, triggerable, high speed imaging chip and a complete camera system for investigating rapidly occurring phenomena in radiation environments. The imaging chip that has been designed and taped out in the Phase II program is sensitive to optical wavelengths and it has 1 megapixel resolution, 10 kfps (kiloframes per second) frame rate and 300krad(Si) total ionizing dose tolerance. One of the main applications is beam monitoring in particle accelerator facilities. The camera provides critical information for monitoring fast transient, time-dependent behavior and events in accelerator beams. The camera is under development through a Sequential Phase IIA grant from the Department of Energy SBIR topic 24h.

Advantages:
- High-speed camera that provides very high frame rate with user-selectable modes in which the resolution can be traded off with frame rate.
- The image sensor designed and fabricated in Phase II has high sensitivity originating from the use of a Pinned Photodiode (PPD) pixel architecture, large light-sensitive collection area and low-noise readout electronics.
- The industry's first radiation-hard high-speed camera, it is a critically needed solution for many applications, such as nuclear physics, high-energy physics, space, defense and nuclear energy applications.
- The fastest radiation-tolerant camera currently available commercially has 60Hz frame rate and VGA resolution. At VGA resolution, Alphacore's camera will have 570x higher frame rate than the closest competitor.
- High-speed, radiation hard camera that is inexpensive– Radiation tolerance makes the camera an industry-first. Non-rad-hard cameras with comparable specs (such as the top-of-the-line Vision Research Phantom cameras) cost as much as $200k. Alphacore's camera will cost only $20k, enabling wide use in scientific experiments that often have limited budgets. This price is truly remarkable, knowing that radiation tolerant components are usually at least five times as expensive as their standard counterparts.

Project Genesis and Problem Description`

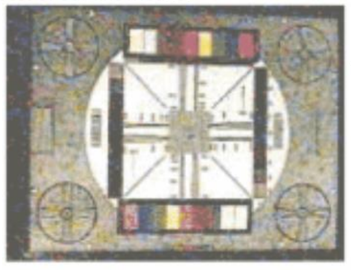
Alphacore has communicated with researchers from Thomas Jefferson National Accelerator Facility (TJNAF) who have requested the development of the fast framing, radiation-hard imaging systems.

TJNAF researchers have an immediate need to use this type of camera in both Hall A and Hall C polarization experiments where beam helicity flips must be monitored.

Non-hardened image sensors and cameras typically do not operate beyond few tens of kilorads

Hardened sensors and cameras typically target nuclear plant monitoring applications and have low frame rates (30fps)

High-speed rad-hard image sensors and cameras do not exist (to the best of our knowledge)



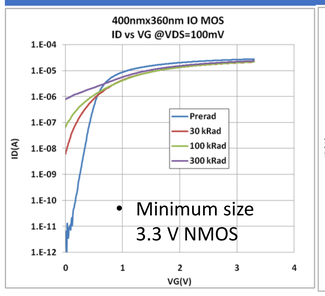
- Image sensor test pattern before irradiation

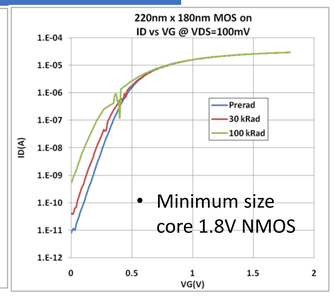
- Same test pattern after 10 krad exposure

[Courtesy: Vision System Design]

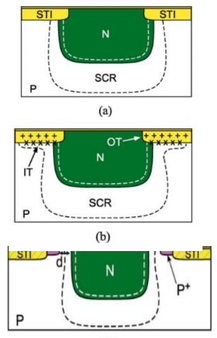
The requested camera would provide critical information during helicity flips in polarization experiments. TJNAF also needs this camera for monitoring off-normal, time-dependent behavior related to unwanted trip events in the accelerator beams.

TID Effects in CMOS Transistors and Pixels

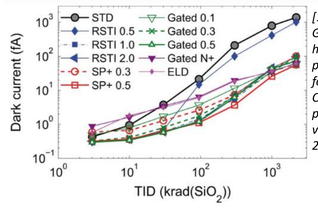




Based on Co-60 tests, thick oxide NMOS has 100x higher leakage than core NMOS. The Alphacore image sensor uses core transistors for all supporting circuits outside the pixel array.

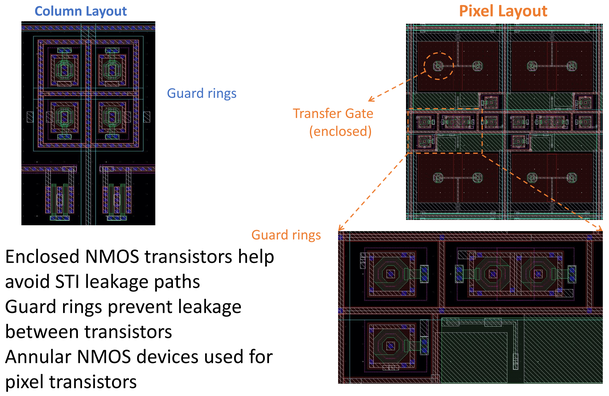


The dark current increase is due to interface trap (IT) and oxide trapped charge (OT) formation along the PD/STI perimeter. Different PD Layouts can be used to keep the SCR away from the STI



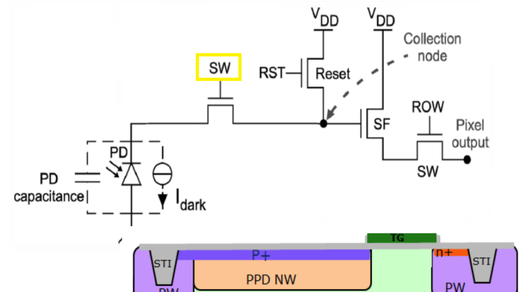
[1] V. Goiffon et al, Generic radiation hardened photodiode layouts for deep submicron CMOS image sensor processes, IEEE TNS vol. 58, n 6, Dec. 2011

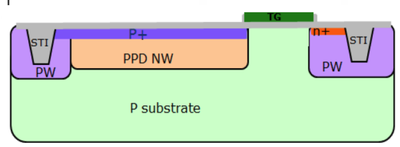
Radiation Tolerant Image Sensor Design



- Enclosed NMOS transistors help avoid STI leakage paths
- Guard rings prevent leakage between transistors
- Annular NMOS devices used for pixel transistors

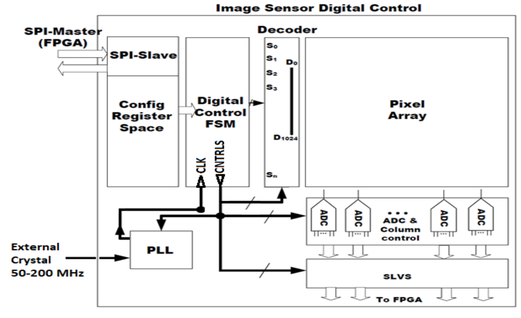
High-Gain, Low Noise 4T Pixel





- 1 Megapixel sensor uses 4T pixel topology, Pinned Photodiode (PPD) light-sensitive element
- The pinned photodiode structure uses a shallow p+ layer on top of an n-well layer of a traditional pn junction photodiode. The n well is "sandwiched" between the p+ layer on top and the p epi layer underneath
- A transfer gate is shown as an additional switch (SW), and the collection node is an n+ in p-well floating diffusion
- The PPD is ideal for low light or high-speed applications, such as this DOE program
- Advantages of the PPD and 4T pixel include inherent noiseless gain from PD to the floating diffusion, fast integration and readout times, reduced dark current, lower noise, and increased quantum efficiency

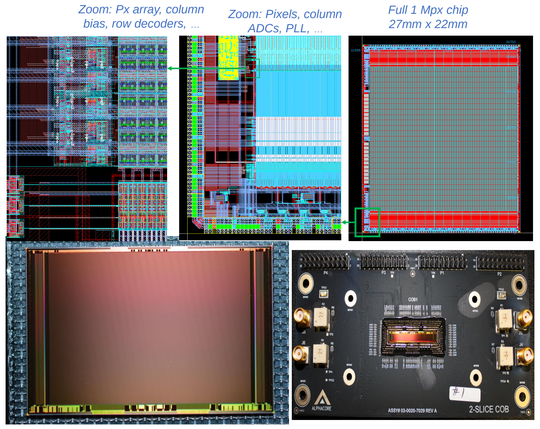
High Speed Image Sensor Architecture



- High-speed 1 Gbps readout architecture
- Pixel values sampled onto PGA
- A to D conversion starts while next pixels are sampled
- Parallel A to D result is shifted out at 1Gbps DDR
- 500 MHz clock generated with on-chip PLL

Project Status

10,000-pixel image sensor and camera has been designed, built and evaluated. It operates up to 20,000 fps



1024 x 768 10,000fps image sensor has been designed, fabricated, packaged and is currently under test.

Camera system electronics prototypes are currently being tested at TJNAF and at Alphacore

Acknowledgements

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