**COLOR CMOS-BASED MICROCAMERA FOR SPACE EXPLORATION.** C. Virmontois[1], O. Gasnault[2], S. Maurice[2], M. Dupieux[2], A. Toulemont[1], O. Gilard[1], A. Bardoux[1], P. Bernardi[3], N. Perrot[4], C. Sellier[4] and D. Gambart[4], [1]Centre National d'Etudes Spatiales (CNES), Toulouse, France, cedric.virmontois@cnes.fr, [2]IRAP, Toulouse, France, [3]LESIA, Observatoire de Paris, France, [4]3D PLUS, Buc, France.

**Introduction:** Space exploration missions require compact imaging systems that are able to provide high quality images in harsh environments. In the framework of R&D activities, The Centre National d'Etudes Spatiales (CNES), also called French space agency, lead the developpement of an advanced camera, named CASPEX for Color CMOS Camera for Space Exploration, see Fig. 1. This instrument is integrated using 3Dplus technology [1] in order to be as compact as possible. It was particularly designed to insure good radiation tolerances and to cover a wide range of scientific and technical applications that require highly integrated instruments, such as planetary missions, nanosatellites, platform and launcher monitoring, or star trackers. This system has been chosen to be the Remote Micro-Imager (RMI) of the SuperCam instrument lead by IRAP and LANL for the next martian NASA rover: MARS 2020.

CASPEX will be used for the first time on SuperCam to provide high-resolution and high-quality colored images. CASPEX is based on the last generation of CMOS image sensors (CIS), using microlenses and color filter array (CFA). Moreover, a dedicated high dynamic range (HDR) method will be applied to reach pixel full wells comparable to Charge Coupled Devices (CCDs) and to provide good radiometric results.

**Camera architecture:** CAPSEX devices are stacked in 4 levels to obtain a 3D cube with a reduce volume of 35x35x27 mm$^3$. The top level contains the CMOS image sensor which is the key element of the camera. The CMOS technology was choosen for the high level integration, the low power consumption and the interesting behavior against the space radiations, which has been studied since the last decade. The selected CIS is constituted by 2048 x 2048, 5.5µm pitch pixels. Each pixel is based on pinned photodiode architecture [2] with several transistors, see Fig. 1. This architecture reduces the noise using correlated double sampling, reduces the dark current around 125 $e^-$/s at 35°C, and improves the radiation tolerance of the device against cumulative doses [3]. This CIS is fully digital, it contains on-chip microcontrollers, registers, per column ADCs (2048), and can be read using 16 Low Voltage Differential Signaling (LVDS) outputs. The behavior of the digital part of the sensor against single event effects (SEE) has been evaluated by CNES [4] and shows low upset and very low latchup events. Red, green or blue color filters are introduced in the optical stack above each pixel using a Bayer array distribution. Microlenses are deposited on the top of each pixel at the end of the image sensor process, see Fig. 3. This optical element focus the incident light in the pixel to improve the pixel quantum efficiency.

The Field Programmable Gate Array (FPGA) is located on the second camera level interfacing the CIS with the instrument system. The FPGA can store the image in a volatile memory on the same level and perform preliminary image processing, such as averaging, adding, subframing, etc… On the same level, an oscillator provide the clock signal to the FPGA. Non-volatile memories are also implemented in the second level to load register states of the CIS and star catalogue in case of star tracking applications. The fourth level of the cube is dedicated to biasing. Anti-latchup system are integrated to prevent from CIS latchup.

The rear of the camera contain an PGA array where a flex can be connected to insure the link to the system. The PGA array is established to cover a wide range of connections, from LVDS to SpaceWire depending the FPGA code. The link was tested with a length longer than 50 cm using LVDS at 50 MHz.

**Camera performances:** Specific demosaicing algorithms exist to obtain full resolution color images [5]. However, the available red, green and blue filters present an increase of their transmission in the near infrared domain (above 700 nm). This characteristic induces radiometric error and false colors on the image as can be seen in Fig. 5. To avoid this artefact, it is important to use an infrared cut-off filter in front of the camera. This filter is ajusted to 650 nm for SuperCam and the result is presented in Fig. 5.

The SuperCam RMI camera is mounted behind a 10-cm diameter telescope, colaligned with 3 other subsystems that measure the elemental, mineraological, and organic contents of distant targets [Maurice et al., LPSC abstract 2015]. The RMI goal is to provide colored high-resoltuion context images of these targets. The signal-to-noise ratio (SNR) must be higher than 200 at half-dynamic to obtain useful information. To reach this performance, two HDR methods can be applied for SuperCam: piecewise and multi-frame summations. The piecewise method is based on the leak of the transfer gate during integration time to reach 50 k$e^-$ full well instead of the basic full well of 10 k$e^-$. The second method provides an equivalent full well of 200 ke$^-$ which is above the specification requirements. Fig. 6 & Fig. 7 show these results.

**References:**


[1] P. Ramm et al. (2010) *Proc. ESSCIRC.*
[2] P. Lee et al. (1995) *Proc. IEEE Worshop CCDs Adv.Image Sens.*
[3] V. Goiffon et al. (2011) *IEEE Trans. Nucl. Sci.*
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**Fig 1:** The microcamera CASPEX top and profile views.

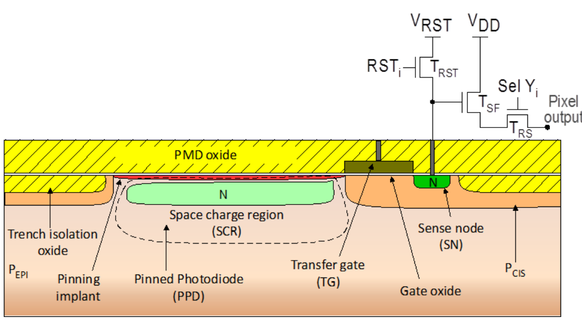


**Fig 2:** Cross section of the pinned photodiode. The space charge region appears as a buried bubble. The transistors is used to read the photodiode.

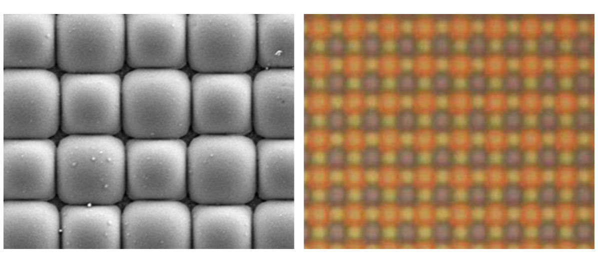

**Fig 3:** SEM images of the Microlense (left) and optical image of the color filter array (right). Microlenses are single layer polymer and less than 1µm thickness. Pixel pitch is 5.5µm.

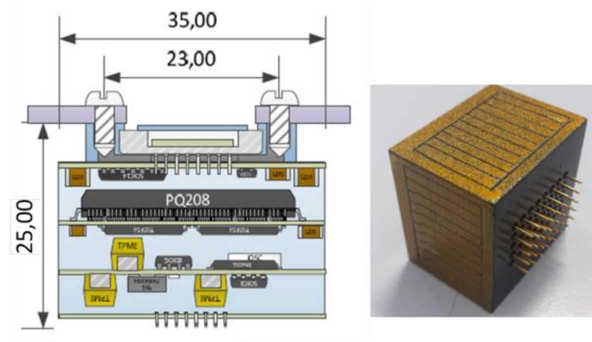


**Fig 4:** CASPEX cross section (left), volume is in mm. The PGA is presented on the rear view (right).

**Fig 5:** Color image from CASPEX without (left) and with (right) additional cut-off filter (650 nm).

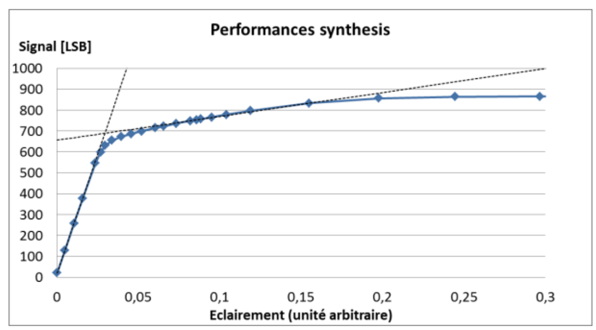


**Fig 6:** HDR piecewise performances. The equivalent full well reaches 50 ke$^-$.

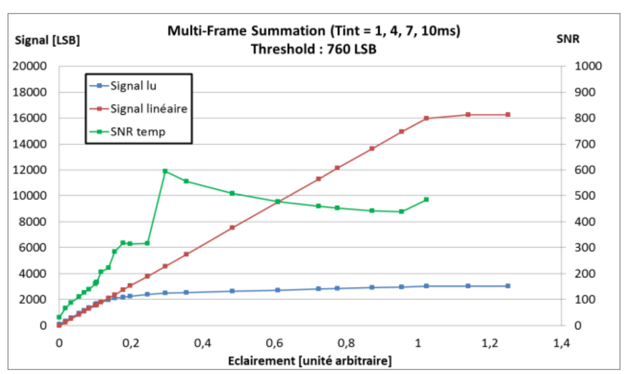


**Fig 7:** HDR multi frame performances. The equivalent full well reaches 200 ke$^-$.