Cosmos sensor 10um 64Mpixel Low Noise and high dynamic range image sensor for space and scientific applications

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Abstract A wafer scale 8k x 8k CMOS image sensor with low noise and high dynamic performances is presented in this paper. The Cosmos sensor is using a column-parallel two-stage oversampled analog-to-digital converter with dual gain conversion feature able to resolve up to 100Ke with sub-electron dark noise. The sensor has been integrated in a deeply cooled CMOS camera for ground-based astronomy and scientific applications.

Keywords: Large Format, HDR, ADC, back thinned, dark current, low noise.

1. Introduction

CMOS image sensors are being progressing with relevant advances in low noise applications based on enhanced pixels [1] and readouts, including very specific techniques to reduce dark noise[2][3]. Besides scientific and astronomy applications require very large full well capacity (FWC) in order to capture in the same scene elements with substantial different illumination across different pixels. Large pixels are eventually needed to increase pixel sensitivity, a key parameter in astronomy and science, along with large format resolution result in very large dimensions sensors.

Some applications are still using CCD as spectroscopy, where they offer high quantum efficiency, low dark current and relative low noise. However, current CMOS technology offers similar high quantum efficiency in back side illuminated (BSI) sensors and very low dark noise.

This paper presents a wafer scale (one die per 200 mm wafer) >64Mpixel 10um x 10um pixel back illuminated CMOS sensor with sub-electron readout noise and large full capacity >80Ke. The sensor is incorporated into a camera with sealed light-weighted high vacuum chamber allowing for < -25oC TEC cooling achieving record dark current levels.

2. Large format low noise image sensor

The COSMOS sensor utilizes a 5T pinned-photodiode dual conversion gain 10um x 10um pixel fabricated on high resistivity Si with a 10um epi layer thickness. Back thinned, it provides greater than 90% peak quantum efficiency. The sensor is a stitched device that can be produced in tile sizes of 1620 x 1620 pixels. A 5 x 5 array of tiles is used to fabricate the >64Mpixel sensor yielding 8100 x 8100 active columns and rows (Figure 1). Other sensor formats can be available based on different stitched array configuration.

The 5T pixel utilizes two floating diffusion (FD) nodes for achieving high and los conversion gain. In low conversion gain capacitance in both nodes are connected increasing the full well capacity. For low light signals, high conversion is used where only one small capacitance is present in the floating diffusion node.

Cosmos sensor digitalizes pixel signals with a novel two-stage ADC architecture, based on Sigma-Delta (SD) and Single-Slope integrator topology [4][5]. This architecture is depicted in figure2, it allows programming the required bit resolution and conversion time, affecting the ADC noise and frame rate respectively. The first stage ADC is a SD integrator which resolves the MSB bits of the digital word, D1, and can be programmed to resolve 4, 5 or 6 bits, while the second stage ADC is a SS ADC which resolves the 10 LSB bits (N2=10) of the word, D2.

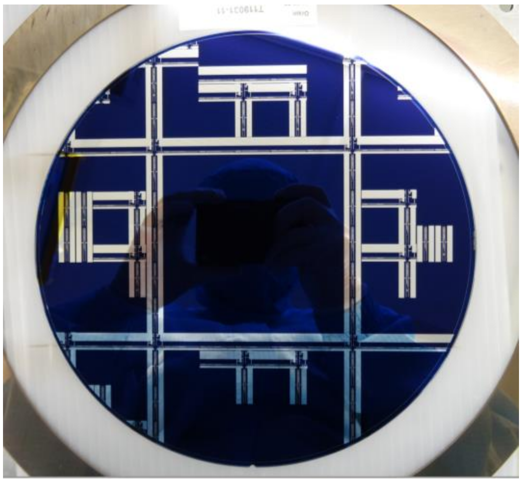

Fig. 1. Wafer scale 8k x 8k 10um image sensor

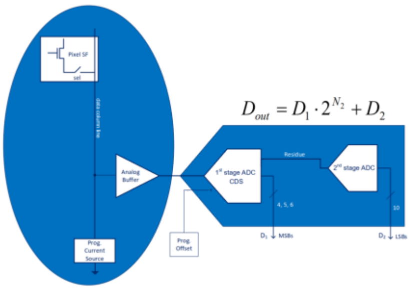

Fig. 2. Two-stage ADC showing the split sigma-delta / single-slope architecture.

In HDR mode, the COSMOS sensor operates in 14-bit High Gain plus 10-bit Low Gain conversion is done performing the correlated double sampled (CDS) in analog domain sequentially. It optimizes the trade-off power, timing and noise performances, since large signals level, where low gain applies, are dominated by shot noise. In addition, external CDS with multi-sampling (CMS) further is available to reduce temporal noise to sub-electron levels and when combined with dual conversion gain HDR readout, dynamic range of over 100dB is realized in a single exposure.

Additionally, the COSMOS sensor incorporates a low power mode that can be activated to reduce power when the frame rate is low enough. When active, the sensor enters low power mode for long exposure integrations. This function allows the camera to reduce the sensor temperature bellow -25ºC.

3. COSMOS Camera

The sensor has been installed inside the COSMOS camera showed in figure 3. The COSMOS camera is designed to function over a wide range of environmental operating conditions suitable for astronomical ground based imaging application. The COSMOS camera utilizes a 4-lane CoaXPress link operating at up to 12.5 Gbit/s to the host PC via quad-channel PCIe frame grabber.

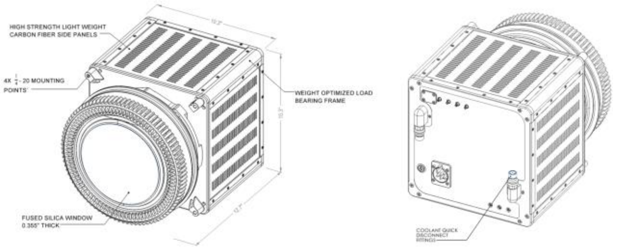

Fig. 3 Front/Exterior and back of the COSMOS camera.

3. Measurement results

Electro-optical performances have been measured for 14bit resolution rolling shutter mode for high and low gain modes when working at 22 fps frame rate with a conversion time of 5.4usec. When the sensor operates at 16bit resolution the frame rate is 7.4fps. Table 1 shows the main electro optical measurements. The lower noise when going from 14bits to 16bits is a remarkable result along with higher FWC than 100Ke, while at 14bits high gain the dark noise below 1.6eRMS.

Table 1. EO measures 4b RS high/low gain and 16b low gain.

EO Parameter	14b High Gain RS	14b Low Gain RS	16b Low Gain RS
DSNU	1.91 e-	19.3 e-	18 e-
PRNU	0.37 %	0.14 %	0.47 %
FWC	>12,000 e-	>100,000 e-	>100,000 e-
Dark Noise	1.53 e- rms	12 e- rms	6.5 e- rms

Figure 4 is showing dark images after DSNU correction for high and low gain modes respectively.

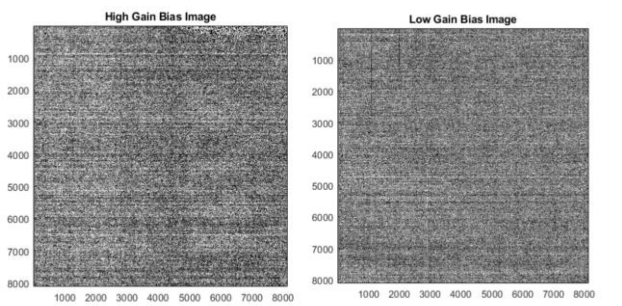

Fig. 4 High gain and low gain bias images.

Figure 5 depicts the dark noise distribution for 14bits high and low gain modes. It is showing very low noise tail thanks to the very low random telegraph noise (RTN) which results in outstanding feature compare with other low noise image sensors [6].

Figure 6 shows the quantum efficiency, where the peak QE is 94% at 550nm, with quite good performance at NIR wavelengths: 53% at 850nm and 35% at 925nm.

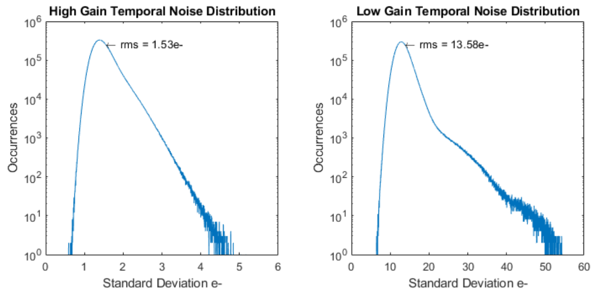

Fig 5. High and low gain dark noise distributions in 14 bit RS.

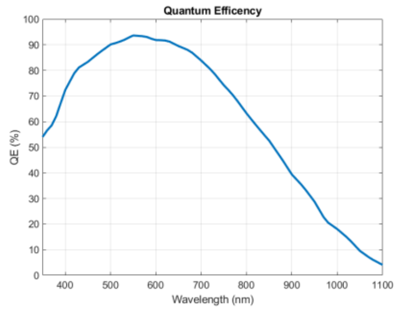

Fig. 6. Quantum efficiency measured from 350 to 1100 nm.

The measured dark current is 0.08 e/p/s at junction temperature of -17.3 ºC, while the doubling coefficient is 6.4 ºC.

4. Conclusion

This paper is presenting a large format 8k x 8k low noise image sensor with dark noise less than 1.6eRMS at 22fps, very low RTN, dark current of 0.08 e/p/s at -17.3 oC and high QE >94% at 550nm.

References

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