Large-Format Medical X-Ray CMOS Image Sensor for High Resolution High Frame Rate Applications

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In recent years there is an increase demand for large-format x-ray imagers capable of real-time imaging of medical procedures. Such imagers are commonly using amorphous Silicon (a-Si) Thin Film Transistors (TFT) and Photo Diodes (PD) [1]. The x-ray radiation photons transforms to a visible range radiation using a state of the art CsI screens couplers. A major challenge for real-time x-ray imaging system is to reduce as much as possible the radiation dose needed during the medical procedure while producing images of acceptable quality. This allows numerous emerging medical procedures where the physician is standing near the patient without endangering himself. Nevertheless, in any given point during the procedure the physician may need a single shot of high resolution quality picture by increasing the x-ray dose by many orders of magnitude. This unique set of requirements together with inherent high dynamic range scenario calls naturally for high performance CMOS Image Sensor (CIS) system on a chip.

In this paper we will present our latest developments of a large format high frame rate CIS. Figure1a shows a single 5"x6" sensor located on a 200mm wafer. The single chip sensor is three sides buttable which enables tiling of a large format sensor. An illustration of a 10''x12'' x-ray panel with 2x2 sensor arrangement is shown in Figure1b. The chip is manufactured on 0.18 CIS process. Chip of this size is produced using conventional wafer stepper equipment using the so called stitching technique [2]. Stitching is usually done by cutting the whole sensor into smaller pieces taking advantage of the natural symmetry of CIS designs (example is shown in Figure 2). The symmetry of this chip was highly increased during the design process and mask re-arrangement thus ensuring minimum manufacturing cost and maximum yield. A special challenge for the stitching was imposed by the need to put both the readout and the row drivers circuitry on the same edge of the chip to allow butting from three sides of the chip. This was realized by a novel, though surprisingly simple, solution.

The maximum resolution is *964 x 786* with pixel size of 150um. The sensor can be switched to a high sensitivity mode with *482x393* through pixel level charge binning on an internal Charge Amplifier (CA). The Photo diodes are carefully optimized using a buried implant scheme to minimize dark current and dark current degradation of the chip due to radiation damage.

The design is based on a 12bit column parallel single slope ADC presenting low noise and high linearity [3]. The ADC schematic is presented in Figure3. The column parallel ADCs are spread over one side of the entire wafer, each consisting of a linear slope and a dummy slope deriving a fully differential architecture. The linear slope is generated using a current steering 12bit DAC. Figure4 shows an x-ray image taken in high sensitivity mode using 160 nGy. Figure5 shows an x-ray image taken in high resolution mode using 5 μGy. Finally, Table1 summarizes the sensor performance in visible light and Table 2 summarizes the system specification.

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References

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[2] A. Shacham, "Method of forming reticle from larger size reticle information", **US 6,194,105**, 2001

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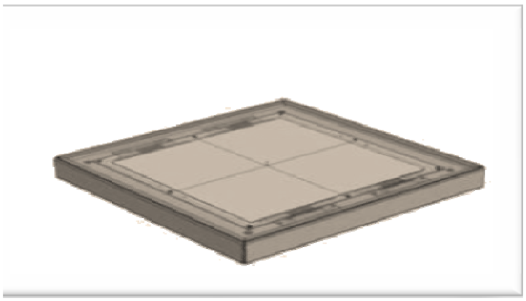
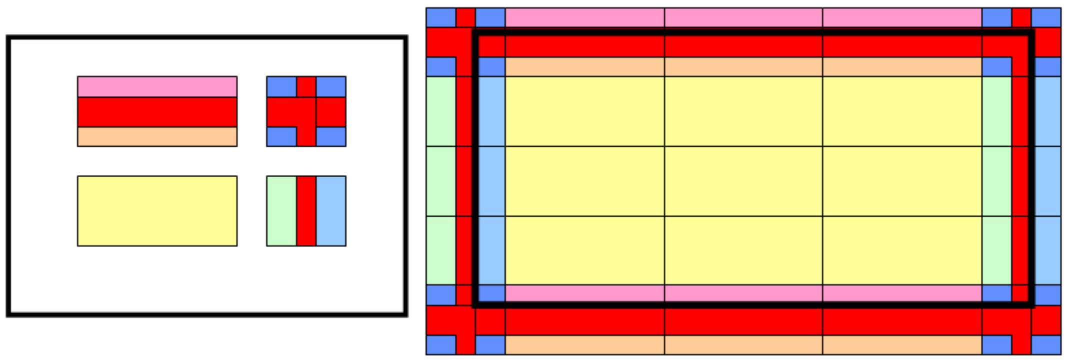
Figures

(a)



(b)

Figure1: (a) – Sensor fabricated on wafer. (b) Illustration of 2x2 tiling of sensor. The result is 12''x10'' x-ray panel



(a) (b)

Figure2: (a) – Illustration of mask arrangement for a typical stitched product using design fragmentation of repeating parts (both on the optical array the circuit periphery) and the non-repeating parts. (b) Illustration of full chip using multiple exposures of different fragmentations

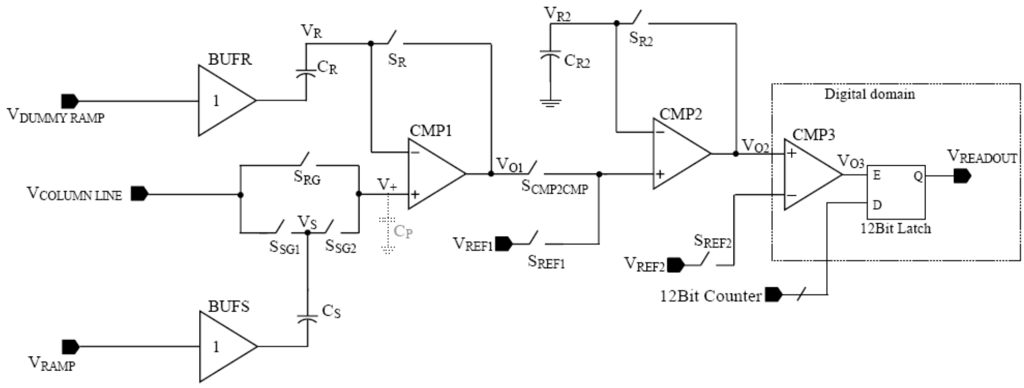


Figure3: Schematics of the column parallel ADC

Figure4: X-ray image of a human hand taken with 160nGy in high sensitivity mode

Figure5 X-ray image of human hand taken with 5µGy in full resolution mode

Tables

	Value	Unit	Comment
QExFF	>55	%	illumination @ 523nm
Sensitivity	12	V/lux/sec	
Full Well	8	Me^-	
Dynamic Range	76	dB	1x1 pixel
RMS random noise	250	µV	entire system noise (pixel and ADC)
Vertical FPN	2	LSB	
ADC INL	0.1	%	

Table1: Performance summary (for visible light)

Image Characteristics	
Pixel Pitch	150 µm
Image Size	964 x 786 pixels (full resolution)
Active Image Area	120 x 150 mm
A/D Conversion	12 bits
Image Performances (full resolution)	
Dynamic Range	76 dB
Image Lag	< 0.3% after first frame @ 30fps
Signal to Noise	43 dB @ RQA5 4µG
Modulation Transfer Function	61% @ 1 lp/mm (RQA5 terms)
Detective Quantum Efficiency	73% @ 0 lp/mm (RQA5 terms)
Operating Modes	
Capture Modes	Pulsed,Continuous
Image Resolution Modes	Non-Binned (full resolution), 2x2 Binning
Frame Rate	Up to 30fps @ pulsed mode (non-binned) Up to 60fps @ continuous mode (binned)
Flexible Region of Interest	
Transition Time between Radio/Fluoro Modes	< 300ms
Transition Time between Magnification Modes	< 300ms
Operational Conditions	
X-ray Maximal Linear Dose	40µGy/frame
Lifetime Dose	100Gy

Table2: Sensor specification (coupled with column grown CsI Scintillator)