Scintillator based color X-ray photon counting imager

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With the ubiquitus usage of radiography in many medical diagnosis, the urge to achieve the lowest possible radiation dose is a driving force for the X-ray image sensor community. The ultimate signal to noise ratio that one can theoretically achieve is the quantum limit, where each and every photon reaching the imager is counted. Additionally, photon counting comes with abenefit: the possibility to sort incoming X-ray photons based on their energy, thus achieving "color X-ray", a real added value for the diagnostician. As shown in [1], from electronics standpoint state-of-the-art photon counting pixels [2,3,4] use direct detection, whereby the X-ray to charge conversion happens by the photo-electric effect in a high-Z semiconductor photoconductor or photodiode.

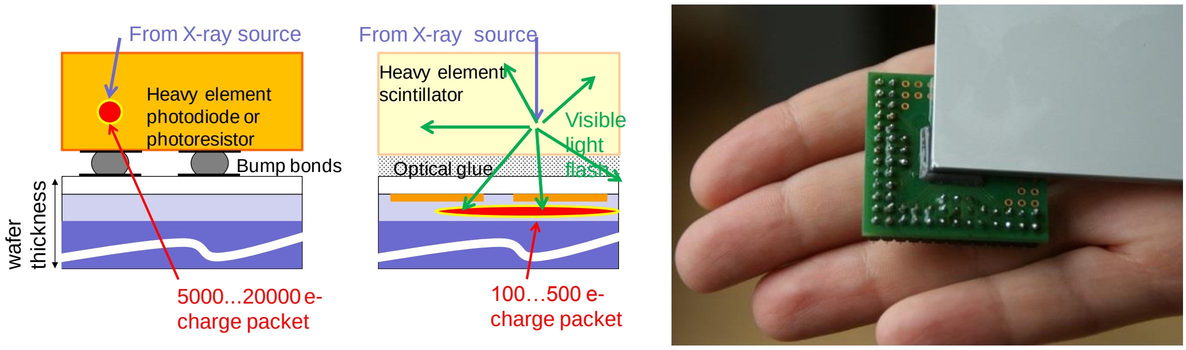

Figure 1 Direct (left) vs indirect (center) X-photon detection technics, detector prototype(right)

In direct detection material, an X-ray photon with a typical energy for medical imaging produces about 5000 to 20000 electrons. Photon counting imagers based on direct detection materials have been used in scientific and medical imagers. However manufacturing of such detector in large scale, compatible with applications such as Chest Xray or Mammography faces several challenges. High-Z material substrates come usually in limited area. Furthermore, hybridization in large scale is a difficult task and present as well certain risk. To overcome these limitations, Caeleste proposes a CMOS photon counting circuit based on indirect detection materials, such as CsI or GadOx, materials that are available and widely used in medical Xray equipment.

In this paper we present the design, manufacturing and test of a second generation photon counting prototype with the following specifications. The aim of this development is to demonstrate the possibility to do photon counting and color Xray in an industrially affordable scheme. As a consequence, this development makes use of standard CIS foundry, off the shelf scintillators. The sensor is designed for yield, with low amount of transistor per pixel thanks to a novel approach in analog counting, enabling sensor sizes up to wafer scale. Based on this sensor, a demonstration imaging system was built. The device operates correctly as an image sensor. Measurements were done at room temperature, with X-ray illumination in the 40 to 80kVp range. We used GdOS or CsI scintillators, whereby CsI gave significantly better results [5], as with the GdOS fluorescence time constants in the order of 0.1 to 10 ms were observed, whereas in the CsI, the observed (pulse shaper speed limited) time constants where in the range 10 to 30 µs.

item	specification
Technology	0.18um standard CIS CMOS
Color Xray	Dual channel Photon counting with a scintillator
Scintillator type	CsI or GadOx
Pixel size pitch (µm)	100µm
Transistor count per pixel	45 T
Array size	92 x 90 pixels
IC size	1x1cm
Full readout frame rate	30fps
Photon detection noise threshold, [e-]	100e-
Electrical color separation noise [e-]	$15e\text{-}_{RMS}$
Q_N [e^-_{RMS}]	$15e\text{-}_{RMS}$
Maximum count rate (separating two pulses)	> 300kHz
Thresholds of comparators	Programmable
Power supply	Standard 3.3V
Power consumption	<3uW / pixel

The electrical crosstalk between pixels was expected to be most critical due to the digital switching in one pixel feeding through to the sense nodes of other pixels sharing the same common row or column lines, or the substrate. However, resolution target shows a quite decent color separation at maximum resolution:

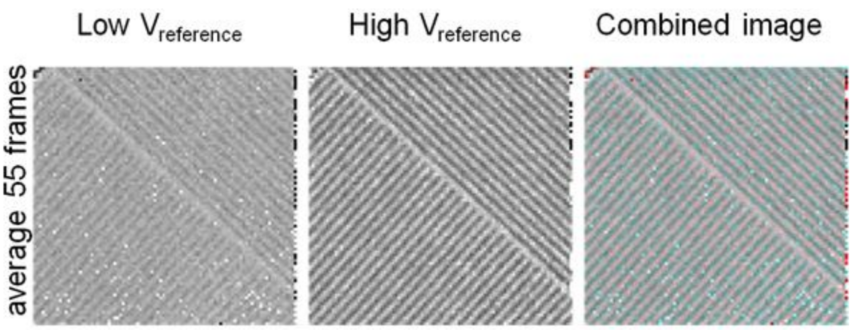

Figure 2: color imaging under Xray illumination, resolution chart

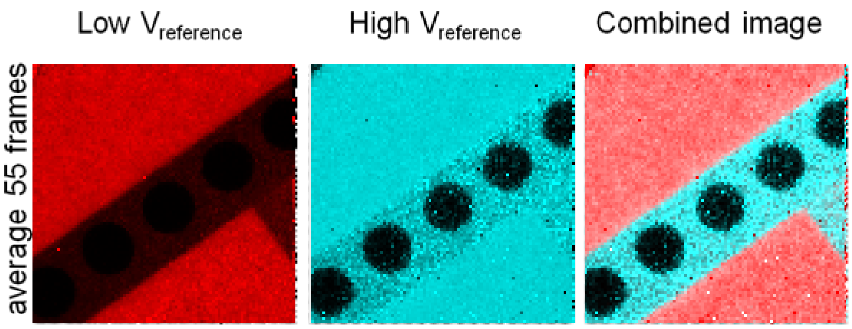

Figure 3: color imaging under Xray illumination, electrical socket

We designed and demonstrated a true, two channels, photon counting indirect detection X-ray image sensor of 1cm^2 or 90x92 pixels. To overcome the yield burden of transistor-heavy pixels, we reduce the number of transistors per pixel to an overall 45 MOSFETs. Each pixel has two comparators and counters, which allows counting against two pulse amplitude thresholds or two X-ray “colors”. The device is manufactured in 0.18 µm CMOS technology. Very low dose X-ray images are taken and color-processed. While the test of this prototype will continue in the next months, the current results are encouraging enabling the development of a wafer scale version of this sensor.

References:

[1] B. Dierickx et. al, “Indirect X-ray Photon-Counting Image Sensor with 27T Pixel and $15e^{-}_{rms}$ Accurate Threshold,” , ISSCC Dig. Tech Papers, 6.6, 2011.
[2] R. Ballabriga et. al., “The Medipix3 Prototype, a Pixel Readout Chip Working in Single Photon Counting Mode With Improved Spectrometric Performance”, IEEE Trans Nuclear Science, vol.54, no.5, 2007 , and references therein
[3] W. Barber et. al., “Large Area Photon Counting X-Ray Imaging Arrays for Clinical Dual-Energy Applications”, NSS-MIC, Oct 30, 2009
[4] J. Iwanczyk et. al., “Photon Counting Energy Dispersive Detecotr Arrays for X-ray Imaging”, IEEE Trans Nuclear Science, vol.56, no.3, p.535, June 2009
[5] B. Dierickx, B.Dupont, A.Defernez, N.Ahmed, “Color X-ray photon counting image sensing”, IISW, Hakodate Japan, June 2011