A large-area a-IGZO 256x256 imager using a current-mode transimpedance readout for mammography applications

Florian De Roose[16], Sandro Tedde[2], Kris Myny[1], Siavash Ardekani[1], Manoj Nag[1], Marc Ameys[1], Albert van Breemen[3], Jan-Laurens van der Steen[3], Roy Verbeek[3], Hylke Akkerman[3], Gerwin Gelinck[3], Tim Piessens[4], Jan Genoe[15], Wim Dehaene[51], Soeren Steudel[1]
[1]imec, Leuven, Belgium, [2]Siemens Healthcare, Erlangen, Germany,
[3]Holst Centre / TNO, Eindhoven, The Netherlands, [4]ICsense, Leuven, Belgium,
[5]KULeuven, Leuven, Belgium, [6]Florian.DeRoose@imec.be, +32 16 28 31 53

***Abstract*—In this work, we demonstrate for the first time a large-area a-IGZO thin-film imager using current-mode active pixel. It is read out by a custom transimpedance IC, and has 3122e$^-$ noise and 71.4dB dynamic range.**

Since its inception, the mainstream backplane technology for digital radiography is based on a-Si:H TFTs [Str00]. Transistors are used as switches in these passive backplanes, limiting speed and noise performance. Therefore, active pixels using various semiconductors have been researched to improve both speed and noise in literature [Kar03, Ted07], but without industrial traction. The ambition of this work is to demonstrate an industrially-relevant large-area 256x256 imager, based on an amorphous Indium-Gallium-Zinc Oxide (a-IGZO) active pixel backplane and a fully integrated custom readout IC (ROIC).

Figure 1 shows the schematic of the 3T1C active pixel. To achieve high speeds, we selected the current-mode implementation [DeR15]. To maximize gain and minimize the effect of dataline voltage variations, we selected the common-source topology [DeR16]. The readout IC was implemented as a transimpedance amplifier to avoid the integration of large capacitors in the ROIC [DeR16].

We integrated an organic photodiode (OPD) [Bie18] on the backplane to verify the behaviour under visible illumination, as shown in Figure 2. Its external quantum efficiency (EQE) in back-illumination is around 55%.

Figure 3 shows the behaviour of the pixel amplifier measured inside the matrix. The matrix is implemented in L=5µm self-aligned technology with 200nm SiO_2 gate dielectric. Due to the high capacitance of the visible-light photodiode compared to the 300µm thick

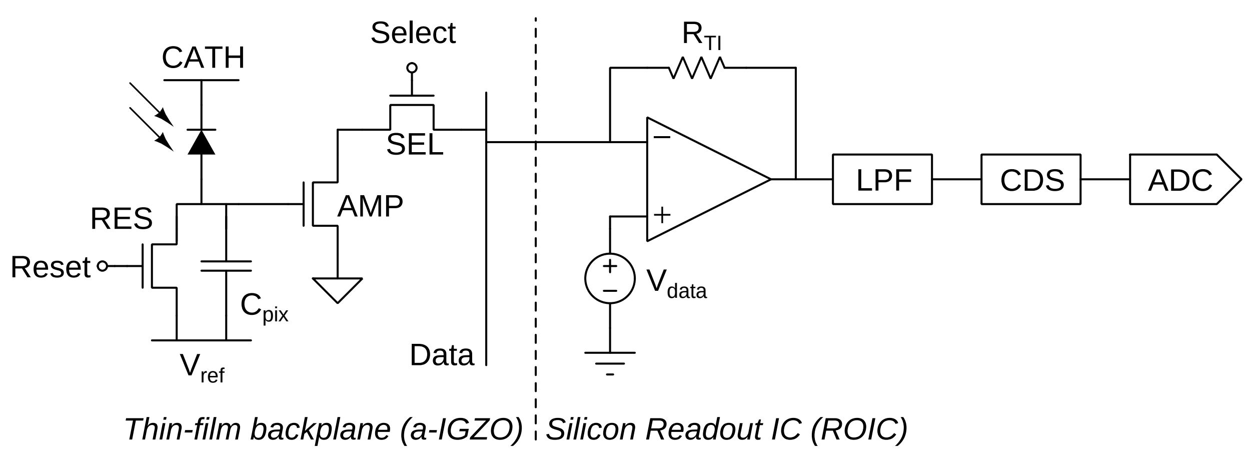


Fig. 1: Schematic of the readout concept. The current-mode common-source active pixel allows for high-speed readout with maximum gain. The transimpedance digitization stages avoids the integration of large capacitors in the readout IC.

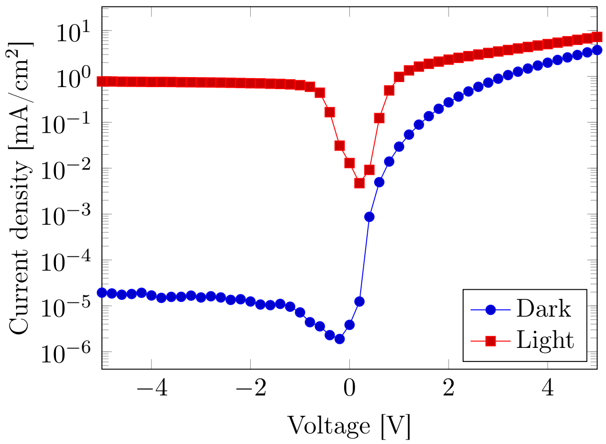


Fig. 2: Characteristic of the organic photodiode in dark and under illumination (3mW/cm^2, 523nm)

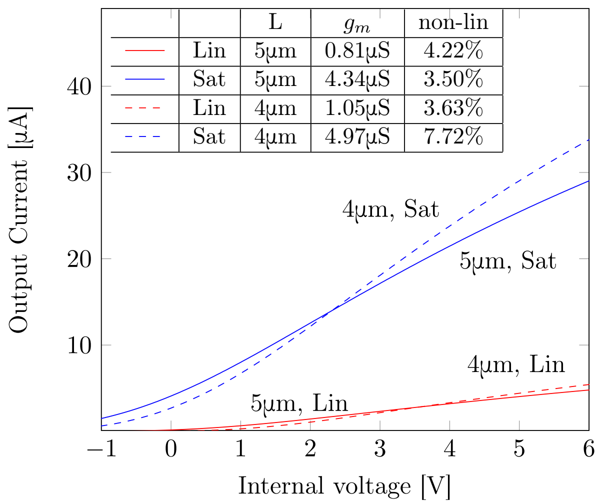


Fig. 3: Amplifier characteristics. Operating the transistor in saturation mode yields much higher transconductance

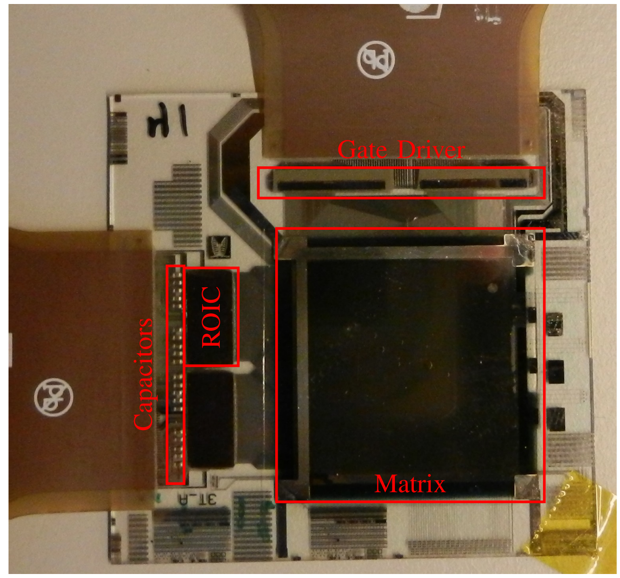


Fig. 4: Photograph of the imager sample

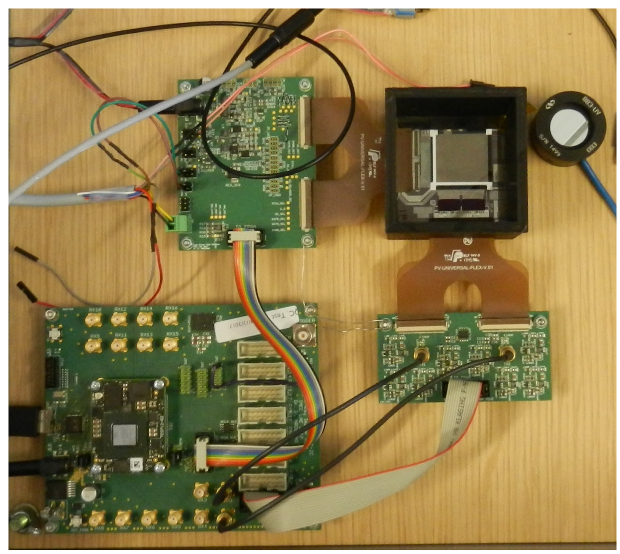


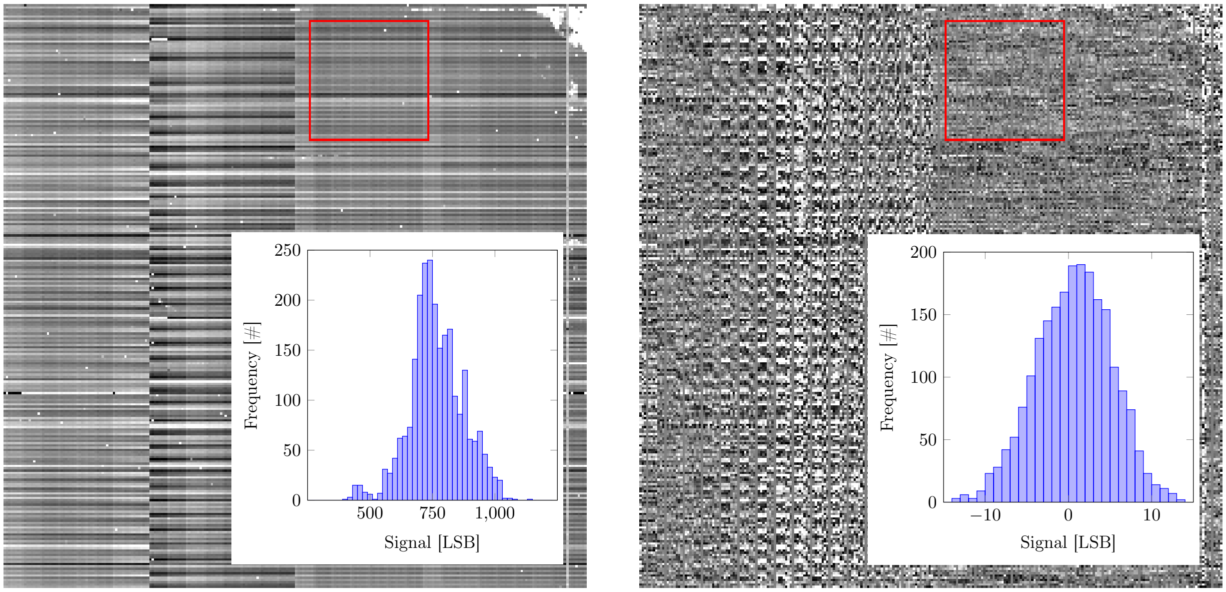
Fig. 5: Photograph of the setup with the sample

direct-conversion X-ray materials [Büc15], the charge-to-current gain is 3.54µA/pC. Figure 4 and 5 show the sample and the readout setup respectively. We measured the system with a 160kΩ transimpedance resistor. The low-pass filter was set at 200kHz. The readout time per line is 47µs, which is limited by the ADC timing in the ROIC.

The resulting dark image can be seen in Figure 6a. The red square defines a region of interest (ROI), with a limited number of defects. We also rejected the broken pixels from the ROI. After removing the fixed offset from the dark image, the noise in the ROI is 101 LSBs. However, the temporal noise is mainly dominated by a common component per row. By using a local reference, e.g. every 1 in 8 pixels, this noise can be reduced to 5.06 LSBs, as shown in Figure 6b.

The sensitivity of the sensor was determined by illuminating the imager with a green LED. Using optical power measurements and the EQE of the photodiode, we estimate the collected electrons. Figure 7 shows the relationship between collected electrons and the digital output. The highest sensitivity was 617e$^-$/LSB, so the noise performance is 3122e$^-$, close to the performance of the typical passive imagers.

Figure 8 shows an image captured using a transparency slide. Table I details the measured specifications of the imager. This is the first full-matrix thin-film imager with current-mode active pixels,



(a) Before correction (b) After correction

Fig. 6: Dark image before and after correction by local reference. The histogram is for the region of interest, indicated by the red box. The standard deviation before correction is 330, after correction this becomes 5.06.

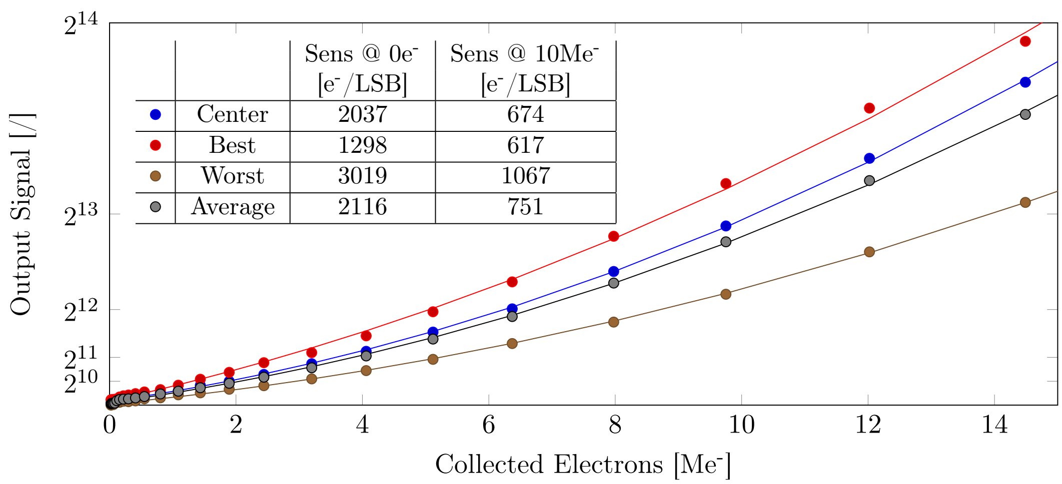


Fig. 7: Input-output relationship of the imager for non-defective pixels within the ROI

integrated with a custom readout IC. The imager has a dynamic range of 71.4dB, and can be read out at 83.1fps. This design clearly shows the high speed and noise performance of active imagers in thin-film technologies.

References

[Bie18] M. Biele *et al.*, "Spray-coated organic photodetectors and image sensors with silicon-like performance," *Advanced Materials Technologies*, 2018

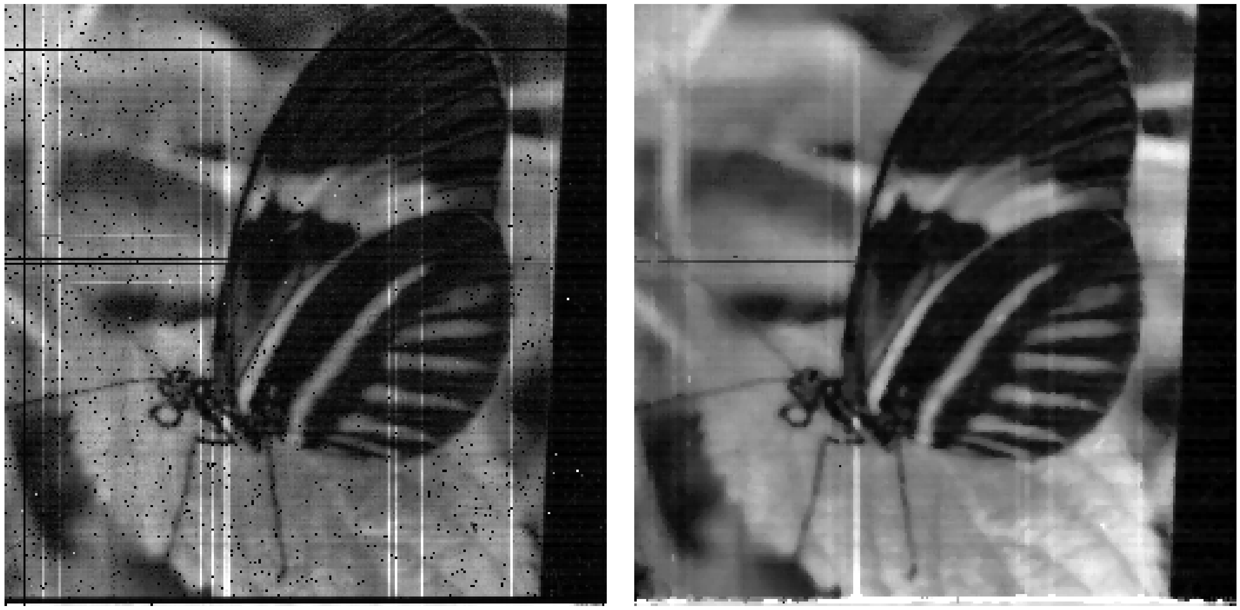
[Büc15] P. Büchele *et al.*, "X-ray imaging with scintillator-sensitized hybrid organic photodetectors," *Nature Photonics*, 2015

[DeR15] F. De Roose *et al.*, "Active pixel concepts for high-resolution large area imagers," *IISW2015*, 2015

[DeR16] F. De Roose *et al.*, "A flexible thin-film pixel array with a charge-to-curretn gain of 59uA/pC and 0.33% non-linearity and a cost effective readout circuit for large-area X-ray imaging," *ISSCC2016*, 2016

[Kar03] K. Karim *et al.*, "Amorphous silicon active pixel sensor readout circuit for digital imaging," *IEEE EDL*, 2003

[Str00] R. Street, *Technology and application of*



(a) Without flatfielding (b) With flatfielding

Fig. 8: Image captured with a transparency slide under green light

Frontplane tech	OPD [Bie18]
Backplane tech	a-IGZO,5µm
Pixel pitch	100µm
Refresh rate	83.1fps
Sensor EQE	≈55%
Conversion gain	617e⁻/LSB
Noise level	5.06 LSB
	3122e⁻
Amplifier Gain	4.34µS
CtC gain	3.54µA/pC
Full-well cap	11.6Me⁻
Dynamic range	71.4dB

TABLE I: Specifications

Amorphous Silicon, Springer, Germany, 2000
[Ted07] S. Tedde *et al.*, "Active Pixel Concept Combined With Organice Photodiode for Imaging Devices," *IEEE EDL*, 2017

ACKNOWLEDGEMENTS

F. De Roose thanks the Agency for Innovation by Science and Technology in Flanders (IWT-Vlaanderen) for financial support. The research leading to these results has received funding from the European Community's Horizon 2020 Program H2020-ICT-2014-1 under Grant Agreement No. 643920 of the DiCoMo project.