IMPLEMENTING GLOBAL SHUTTER IN A 4T PIXEL

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A global shutter pixel in CMOS sensors does not scale as well as a rolling shutter pixel. The smallest global shutter pixel reported was of 4.4um size and had 5 transistors in the pixel [1].

If a small shutter pixel is needed, one can try a 4T architecture. This pixel was long time thought to have a global shutter functionality. One may realize a full frame shutter by integrating the photo-charge in the photodiode (PD) in parallel to the readout of the charge from floating diffusion (FD) or one may realize a sequential shutter, when exposure and transfer are done during the blanking interval between the readouts. Although 4T pixel does not have the flexibility of the 5T shutter pixel in terms of the shutter control and, it can not maximize the frame rate because of the need for blanking, it can satisfy the needs of many motion analysis applications by combining the full frame shutter, the sequential shutter, and an automatic gain control compensating for a jumping exposure.

However, the conventional 4T pixel manufactured through the standard CMOS sensor process exhibited an unwanted leakage from photodiode into the pixel memory node so it was not recommended for practical usage by [2] and other publications.

The leakage into the pixel memory may occur in two ways: a) under TX gate, because this MOSFET is either depletion-mode or buried-channel and so often referred to as "leaky", or b) as a direct diffusion from the bulk facilitated by a build-up of photo-EMF. The latter always presents in the bulk of illuminated silicon, but if the photodiode is saturated, then it is lost as a drain for excessive electrons. Then, the concentration of photoelectrons in the epi-substrate grows up (and so the photo-EMF), so, finally, the excessive carriers break through the P-well barrier surrounding depleted areas around FD and VDD diffusions. In one way or the other, the shuttered signal charges stored for readout get contaminated with the leakage charges coming in a rolling shutter fashion, and the pixel shutter operation is compromised. The idea of the 4T shutter is particularly bad when trying to operate with an intense light > 10X of saturation and short exposures (say, < 1/10 of frame time).

For the answer how to fix the 4T shutter problem we can look into how the CCD tackled the excessive charge by introducing horizontal and then vertical antiblooming (AB) techniques.

This paper presents preliminary results of on-going horizontal AB development in a 4T pinned photodiode pixel. As a test device we took a 16Mpix 120 Fps image sensor we developed for motion analysis application, with 3.9um 4T pixel manufactured in a 0.18um CMOS sensor process. We extended active area from PD to a nearby source follower VDD diffusion (Fig.1.). Field implant, p-well implant, buried n- implant and surface pinning implant masks were changed accordingly, and the mask defining the implant in the channel area was added. We manufactured 10 wafers, and one variable was the n- doze in the AB channel. The dose was varying from 0 to the maximum, which in our case was the dose of the PD buried implant.

Sensors from two wafers showed satisfactory 4T shutter functionality. The samples from wafer #8 with the highest n- doze in the antiblooming channel P-80K3E12 (same as in the PD) showed perfect "cut-off" of the background non-shuttered light, however demonstrated only ½ of the charge handling capacity of the pixel w/o antiblooming channel. The samples from wafer #6 with lower dose (P-80K2E12) in AB channel (PD implant was P-80K3.5E12) could only turn off the shutter leakage by biasing TX to a negative -0.45V voltage. The charge capacity did not suffer noticeably.

The pictures of a rotating fan (Fig.2) visually demonstrate the effect of removing the leakage in 4T global shutter pixel with AB channel. Sensor of wafer #6 was used with higher full well but requiring negative TX for operation. Figure 2a shows the picture (window, ~1/2 full size) taken with Vtx_low=0V, while picture 2b was taken from the same imager with Vtx_low=-0.45V. All other measurement parameters were exactly the same. The exposure time was 0.5ms and the frame time was 11ms.

The image in 2a shows two artifacts of the conventional 4T shutter pixel with leakage. 1) area with high illumination collects additional background light; 2) the dynamic image in high illumination area shows an additional rolling shutter blur and the leak from dc image:

As a supplementary material, we present the specification table for the 16Mpix sensor used in this experiment. This design is a 4X scaled up version of the 4Mpix sensor we presented to this forum before [3]. The data was obtained from the sensor operating in a full frame shutter mode where the shutter leakage was not an issue.

Conclusions

A horizontal anti-blooming channel was added to a 3.9um 4T pixel to enhance its global shutter functionality, and several flavors of a 16Mpix sensor were manufactured, differing by the buried n- implant dose in the AB channel.

Sensors from 2 wafer splits out of 10 demonstrated the capability to block the leakage into pixel storage nodes and showed the true global shutter performance. A fine-tune of the doses is yet needed to optimize the full well and to get the shutter operating with zero TX bias.

1. I. Takayanagi et. al., A 600x600 Pixel, 500 fps CMOS Image Sensor with a 4.4um Pinned Photodiode 5-Transistor Global Shutter Pixel. International Image Sensor Workshop, Ogunquit, 2007 pp.287-290.
2. G. Meynants, Increasing Dynamic Range in CMOS image sensors. InterTech Pira conference on image sensors, London, March 2008.
3. A. Krymski, A High Speed 4 Megapixel Digital CMOS Sensor. International Image Sensor Workshop, Ogunquit, 2007 pp.78-81.

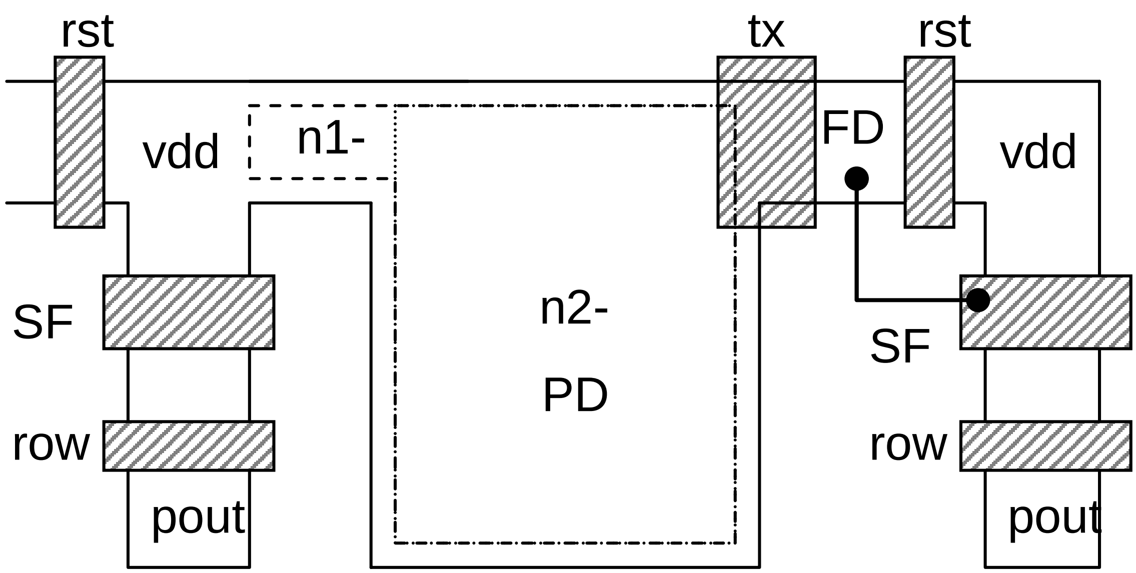

Fig.1. Simplified drawing of the 4T pixel with horizontal AB channel

Technology	0.18um CMOS Sensor
Pixel	3.9um ; 4T shutter
Format	4736x3456
Frame rate	>120 Fps
Noise	26e-
Saturation	8400 e-
Conversion gain	100 uV/e-
DSNU	<0.5 % of sat, rms
PRNU	<1.5% rms
White spots > 1/4 saturation	< 20 /sensor @ 60C
Responsivity	2 V/Lux*s @550 nm
Output	10b x 16 ports

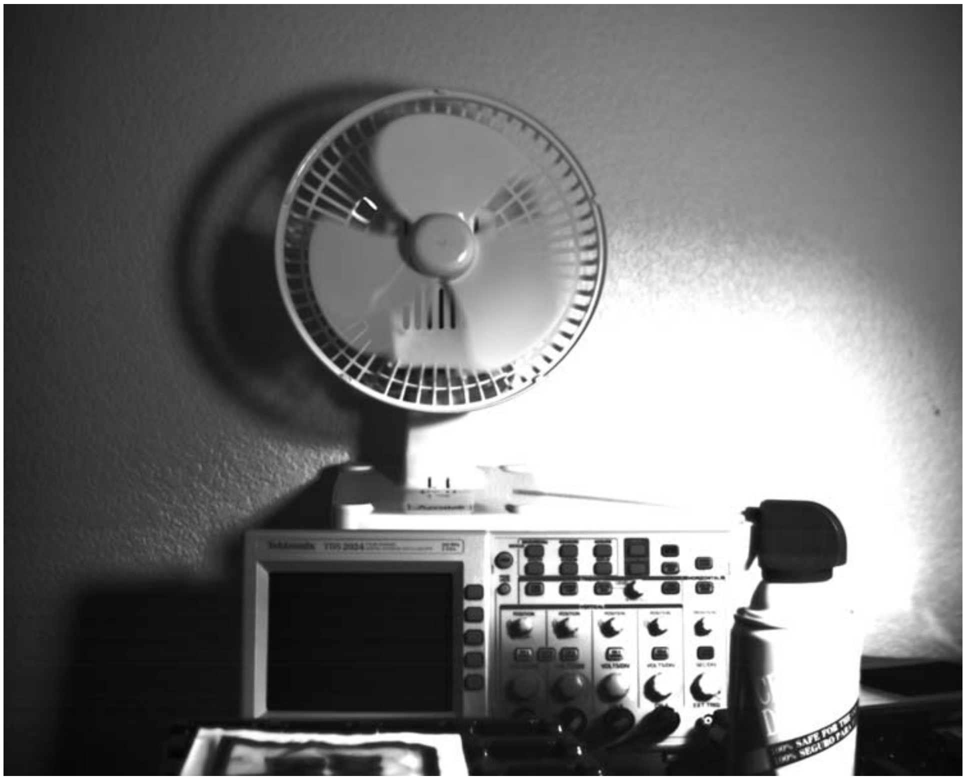

Fig 2a. Image taken using leaky 4T shutter pixels (AB turned OFF).

Fig.2b. Image taken using 4T shutter pixels with AB channel turned ON.