Enhanced X-RAY CMOS sensor panel for Radio and Fluoro application using a low noise charge amplifier pixel with a Partially Pinned PD

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Si flat panel X-ray sensors are taking an ever growing part of the X-ray sensors due to their superior performance by means of signal to noise ratio, speed and other special features. These sensors are commonly using a scintillator to convert the X-ray photons into visible photons which in turn are sensed by the flat panel photodiodes. The scintillator has an inherent gain, such that the number of visible photons per pixel per one X-ray photons ranges between 200 to 1000 [1,2]. The number of X-ray photons depends on the dose which can vary between a few nGray per frame in “fluoro mode” (video) to μGray and more for “Radio” (still) mode. This order of magnitude in the dose implies orders of magnitude change for the collection charge capacity in the pixel. Previously we have shown that a charge amplifier (CA) pixel allows switching between radio and flouro modes using analog binning of four buried PD. This architecture was realized into a large-format medical X-Ray CMOS image Sensor for high frame rate applications [3]. In this paper we will show major performance improvement using a Partially Pinned Photo Diode (PPPD).

The PPPD was designed that most of its area is fully depleted in the reset phase of operation. Figure 1 shows x-section of the PPPD where only a small region in the vicinity of the TG is heavily doped. When diode is brought to its reset voltage, most of the potential drops on the heavily doped region while the low doped region is fully depleted (Figure 2). During integration electrons are collected at the low potential low doped regions and diffuses to the high doped high potential regions. As long as the voltage near the TG does not fall below VPINN the low doped region is fully depleted and the associated diode capacitance is low. Typical C-V curves of a PPD are shown in Figure 3.

A CA pixel is schematically drawn on Figure 4. During reset the TG is activated and the diode voltage is set to VREF, charge stored on the diode will move to the integration capacitor C_f . The noise measured on pixel output associated with RESET operation

$$Noise(V) = \frac{\sqrt{KTC_{DIODE}(VREF)}}{C_f} \quad (1)$$

Where $C_{DIODE}(VREF)$ is the diode capacitance at VREF. Since diode is PPPD, $C_{DIODE}(VREF)$ is relatively small and the pixel noise floor can be arbitrary small. Practically the feedback capacitance for “fluoro mode” is order of magnitude smaller the feedback capacitor for “radio mode”, thus resulted pixel noise floor is often irrelevant in radio mode which is limited by output chain. On Figure 5 a schematics a dual gain CA pixel is shown, since the diode is a PPPD it has charge capacity which is suitable for radio mode however the charge can be translated to voltage using the high gain feed-back capacitor. The noise in this case is optimized to be less the read noise. Finally on Table 1 we compared the performance of a 6”x5” sensor which fabricated using with a STD buried PD versus the partially pinned version.

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Figures

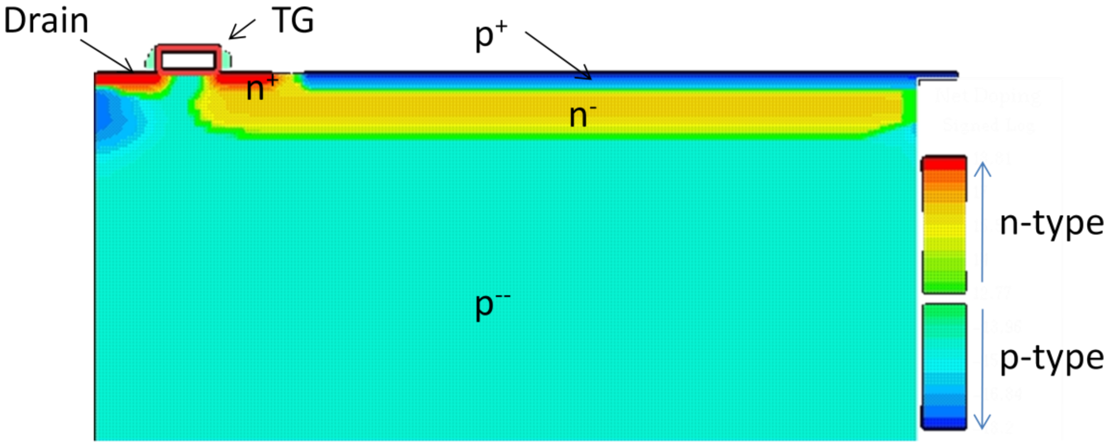

Figure 1: X-section of a partially pinned PD

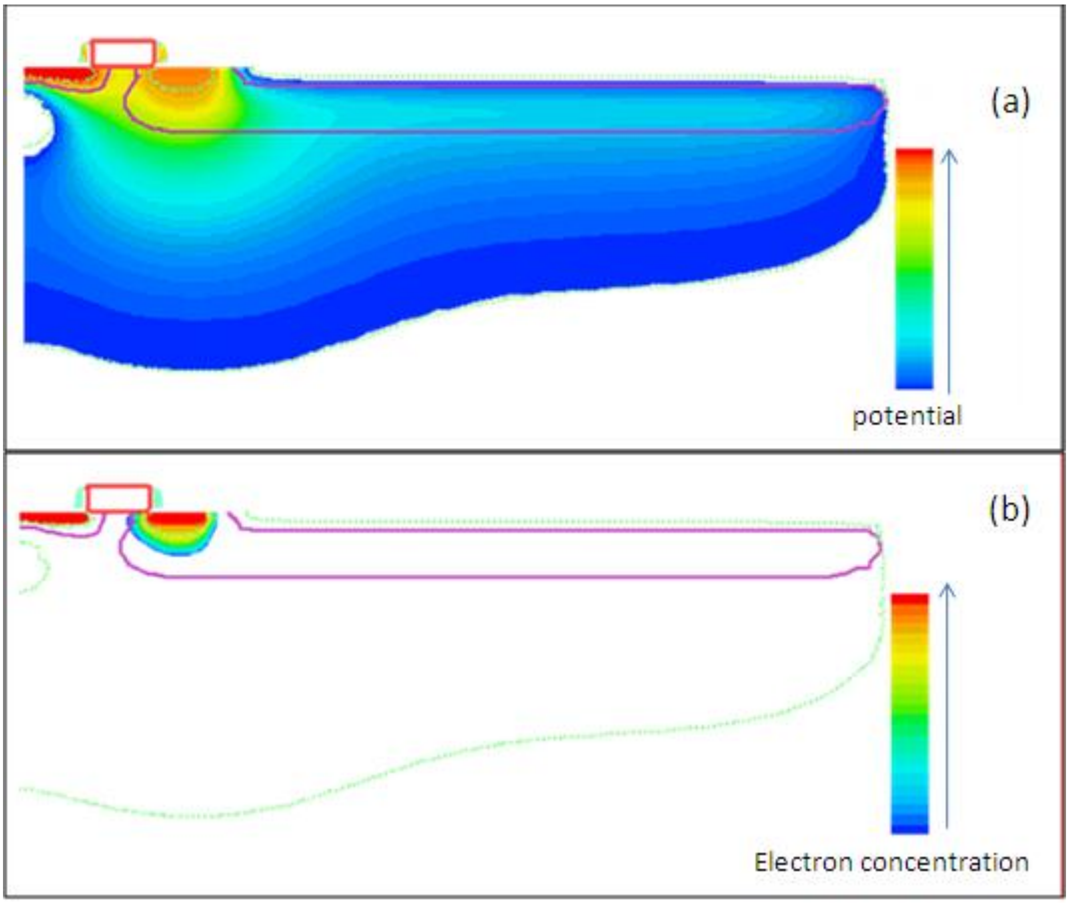

Figure 2: (a)- 2D diagram of the potential when diode is at start of integration (reset phase). The potential is high only in the vicinity of Transfer gate. (b)- 2D diagram of electron concentration in reset phase, most of the area of the diode is fully depleted and does not contribute to diode capacitance

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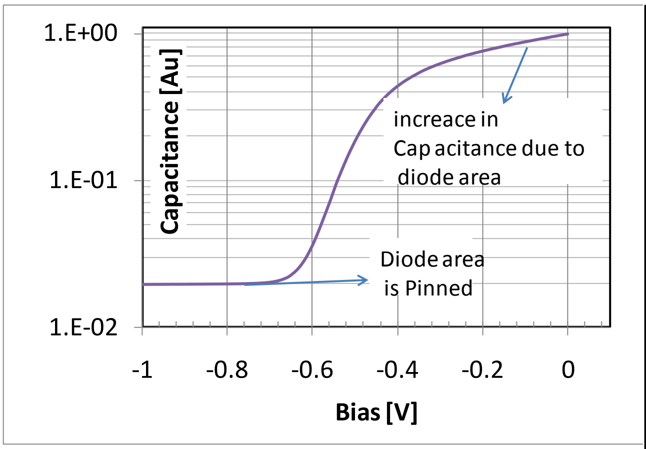

Figure 3: Typical CV curves of a partially pinned PD. The Capacitance is extremely non-linear function of the voltage. Above VPINN the contribution comes from link region near TG, At low enough voltage (above VPINN) diode capacitance changes roughly as square root of voltage. The transition between the voltage where capacitance dominated by diode area and the voltage where capacitance dominated by the link region is engineered to be below 200mV.

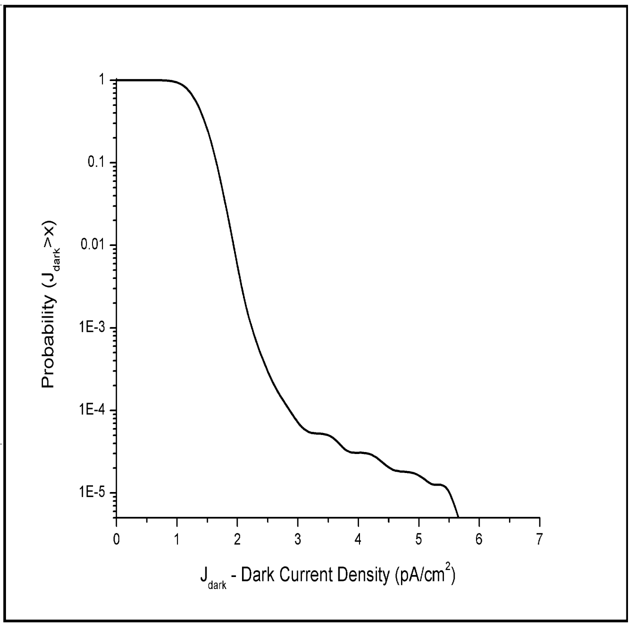

Figure 4: DC distribution extracted from 1die per wafer product with 964 x 786 150um pixels.

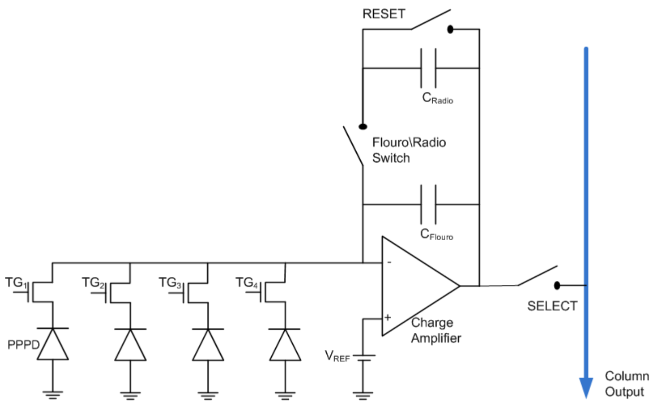

Figure 5: Partially Pinned PD allows using a pixel with dual gain where small integration capacitor is used for fluro mode.

Parameter	Unit	STD diode	Partially Pinned Diode
Sensitivity	GL/nGy	1.2	1.1
Max Dose at saturation	µGy	3.4	3.8
Noise Floor	GL	1.05	0.56
SNR @ 3µGy	dB	38	38
DR	dB	72	78

T=30°C, RQA5, 1GL~366uV (PGA9)

Table 1: summary of parameters Improvement in 5x6" medical x-ray product when moving from the std buried PD to the partially pinned PD.

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