Lateral Drift-Field Photodetector Based on a Non-Uniform Lateral Doping Profile Photodiode for Time-Of-Flight Imaging

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Introduction

The maturity of CMOS technology based imagers enabled their application in optical range measurements and 3D imaging based on the *time-of-flight* (ToF) measuring principle. In our ToF measurement approach [1], the sensor system emits a widened light beam and a photodetector array provided to be part of the sensor system receives the radiation reflected from a 3-D scene. The distance information is included in the time delay T_d elapsed between the emission of the light and its return to the photodetector after the light has traveled the distance of *2d*. A pulsed NIR (near infrared) laser diode emitting radiation at 905nm wavelength is used with pulse widths ranging from 30ns up to 60ns. The maximum measurable distance d_{max} is limited to the pulse width (T_{pulse}) of the laser pulse. To achieve milimetric accuracies, the ToF systems based on pulse modulation must have picosecond time discrimination capability, high detection speed, low noise, and high signal-to-noise ratio (SNR). The problem of so short time scales are the short integration times of photogenerated current and problems regarding its proper readout. So, to achieve an acceptable SNR, a special effort should be invested into reduction of the amount of noise present in the pixel and provide a proper charge-transfer speed. In the following we investigate two possible pixel configurations: photogate-based pixel [1], and a novel structure based on a lateral drift-field photodetector.

Photogate Active Pixel Configurations

For the analysis of the speed performance of PG-based pixel structures (Fig. 1), two types of currents must be taken into account: the *drift* and the *diffusion* currents induced during transfer of the photogenerated charge from the MOS capacitor based photogate (PG) to the n^+ "floating" diffusion (FD) across the MOS capacitor based transfer-gate (TG), all depicted in Fig. 1. A really fast transfer of collected photogenerated charge carriers can be only enabled if there is an electrostatic potential gradient beneath the PG and the TG which generates a drift field in that area. For longer PGs (e.g., 15µm), the electrostatic potential beneath the PG remains constant, which means that the minority carriers collected beneath the PG can only be transported toward the FD by thermal diffusion. For PG active pixels fabricated in the 0.35µm CMOS process available at the Fraunhofer IMS, for several laser pulse widths, the collected photocharge transfer time from the PG to the FD via the TG was varied. As expected, for T_{TX} of 30ns only around 20% of signal charge reaches FD, as it can be observed in Fig. 2 in terms of the FD output voltage measured after the SF buffering stage in the pixel. If the transfer time is extended to 60ns, the transfer loss is reduced to 50%.

Lateral Drift-Field Photodetector (LDP)

A novel approach is here introduced, based on a lateral drift-field generated in the photoactive area of the pixel by a concentration gradient formed by a non-uniform lateral doping profile of an extra designed *n*-well to be fabricated in the commercially used 0.35µm CMOS process. Thus, we obtain a *lateral drift-field photodetector* (LDP), a layout of which can be observed in Fig. 3. The proposed pixel consists of a specially designed *n*-well with a non-uniform lateral doping profile that follows a square-root spatial dependence, a single "extra" mask for which was designed following the analysis performed in [2] and is shown in Fig. 4. "Buried" MOS capacitor-based collection-gate (CG), a transfer-gate (TG), and an n^+ floating-diffusion (FD) used as a non-destructive readout node, fabricated on the mentioned *n*-well also form part of this extreme low-noise photodetector. The pixel readout is performed using a *source-follower* in-pixel buffer configuration, and a correlated double-sampling (CDS) approach. The lateral drift-field induced (see Fig. 5) in the pixel solves the transfer-speed and image-lag issues normally present in standard photogate or *pinned* photodiode based active pixels. Fig. 6 shows the electrostatic potential simulation results for the CG and two TGs and FDs, respectively, where the photogenerated charge induced by the first half of the incoming reflected laser pulse should be transferred to FD1 and the second half to the FD2. According to the simulation results presented, charge-transfer times of less than 4ns are to be expected.

Reference

[1] A. Spickermann *et al.*, "Pulsed Time-of-Flight 3D-CMOs Imaging Using Photogate-Based Active Pixel Sensors", published in this conference.

[2] S. Merchant, "Arbitrary Lateral Diffusion Profiles", IEEE Trans. On Electron. Devices, Vol. 42, No. 12, Dec. 1995, pp. 2226-2230

Figures

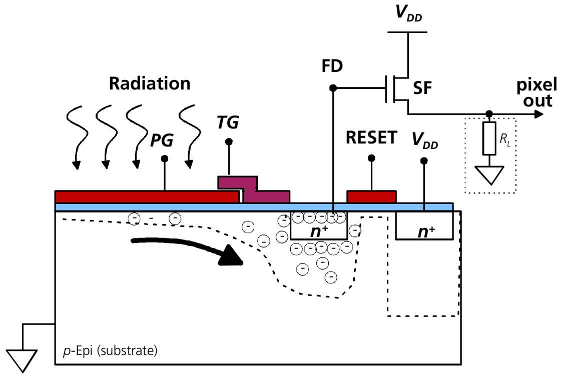


Fig. 1 – Schematic representation of a PG active pixel in the charge transfer phase.

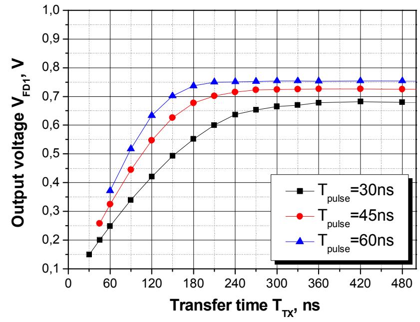


Fig. 2. Output voltage measured at the FD for different transfer times and laser pulse widths.

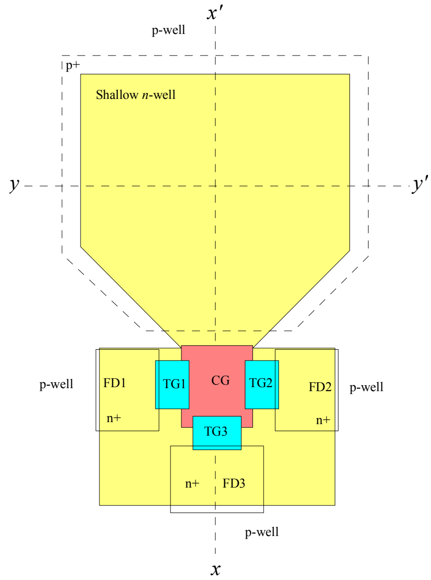
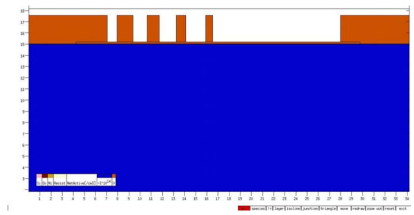
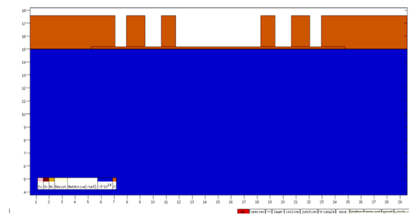


Fig. 3 – Layout presentation of the lateral drift-field photodetector (LDP) proposed for ToF 3D imaging applications.



(a)



(b)

Fig. 4 – The "extra" mask used for the TCAD simulation of the extra *n*-well implantation in the 0.35µm CMOS, following the x-x' plane (Fig. 3); (c) the mask used for the *n*-well implantation following the y-y' plane shown in Fig. 3.

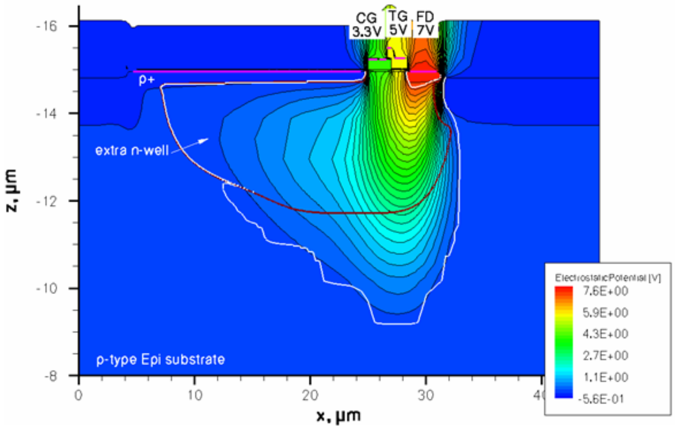


Fig. 5 - Lateral Drift-Field Photodetector (LDP) electrostatic potential 2-D simulation result performed using TCAD software for the reset/readout condition (*x-x'* plane in Fig. 3).

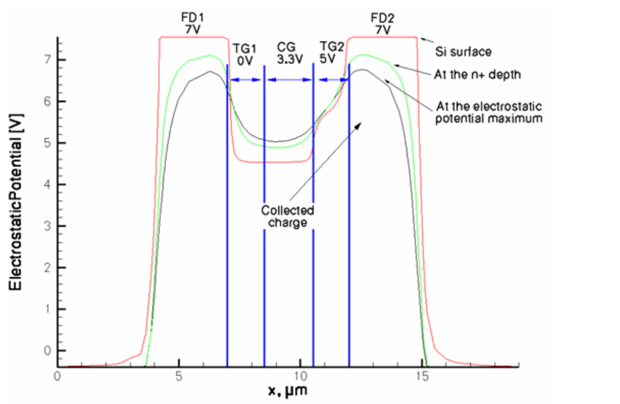


Fig. 6 - Lateral Drift-Field Photodetector (LDP) electrostatic potential 2-D simulation result performed for the readout condition where the photocharge is transferred to FD2.