3D Modeling of CMOS Image: Comparison between Front- and Back-illumination

Y. G. Xiao, K. Uehara, S. Gao, Y. Fu, M. Lestrade, Z.Q. Li, Y.J. Zhou, and Z.M. Simon Li

Crosslight Software Inc, 230-3410 Lougheed Hwy, Vancouver, BC V5M 2A4, Canada

Abstract — **Three-dimensional (3D) modeling is reported for CMOS active pixel image sensors particularly by comparing front- and back-illumination. The opto-electronic responses are presented versus various power intensity and illumination wavelength. For appropriately designed sensor structure, it is shown that back-illumination could achieve improved sensitivity within certain wavelength range. The presented results demonstrate a methodological and technical capability for 3D modeling optimization of complex CMOS image sensor.**

I. Introduction

The complementary metal oxide semiconductor (CMOS) active pixel sensor (APS) has attracted increasing interest due to demand for miniaturized system-on-chip capability, low-power, and cost-effective imaging systems during the past two decades [1,2]. Back-illuminated image sensor has attracted attention due to enhanced sensitivity [3] and its commercialization in recent years. Due to the complexity of the 3D integration of photodiode and the optimization of metal layer distribution to maximize the sensitive area, 3D modeling together with effective optical modeling method is indispensable [4,5]. In this work, based on Crosslight CSuprem and APSYS [6], we present 3D modeling of an APS unit designed for comparing the opto-electronic effect between front- and back-illumination.

II. 3D APS Development by CSuprem

The schematic APS unit structure is similar to Ref. [1,2,4,5] including a pinned photodiode, a transfer (TX) gate, and a reset (RST) gate, but particularly designed to favor back-illumination. The whole 3D APS unit is partially process-built and simulated by Crosslight CSuprem with structure mesh, material together with doping exported and interfaced to Crosslight APSYS. Due to the thinning request and also to reduce mesh size, we assume 5-μm-thick p-type starting substrate. The APS unit is partially process-built with Crosslight MaskEditor with 9 mask layers. These simplified pixel units do not include metal blocking aperture frame and the micro lens to reduce computation complexity. The color filter array (CFA) layer is on the top for front-illumination and at the bottom for back-illumination APS. The 3D device structures for both front- and back-illumination are presented in Fig 1(a) and (b) respectively. The typical 2D plane around photodiode and transfer gate is shown in Fig 2.

III. 3D Opto-electronic modeling by APSYS

Taking the exported file from CSuprem, 3D modeling of opto-electronic responses is performed by APSYS software based on drift-diffusion theory. The optical modeling is done by plane wave transfer matrix method. The relative optic power intensity is also shown in Fig 2 (a) and (b) for front- and back-illumination respectively.

The APS unit operating bias clock is the same as previously reported for similar APS unit [4,5]. The evolution of the potential on the floating drain (FD) versus time is shown in Fig. 3(a) and (b) respectively for front- and back-illumination. The potential difference (relative to dark case) on the FD after transfer stage (the end of the time evolution cycle) versus optical power intensity is shown in Fig. 4 for front- and back-illumination cases at 0.55 μm wavelength. The back-illumination case show larger potential difference indicating improved sensitivity than the front-illumination case. The improved sensitivity with back-illumination is also observed with the potential difference versus wavelength plots for both front- and back-illumination cases within certain wavelength range. The large enhancement is observed around 0.6 μm although we tried to design the CFA for 0.55 μm response. This indicates that more optimization work is needed on CFA design together with the combined opto-electronic simulation.

IV. Conclusion

The 3D modeling of CMOS APS is presented. It is shown that back-illumination could achieve improved sensitivity within certain wavelength range for appropriately designed APS structure. The results demonstrate a methodological and technical capability for 3D modeling of complex CMOS image sensor.

References

[1] E. R. Fossum, *IEEE Trans. Electron. Dev.,* vol. 44, no. 10, pp. 1689-1698, Oct. 1997.

[2] M. Bigas et al, *Microelectron. Journal,* vol. 37, pp. 433-451, 2006.

[3] T Arai et al, *Proc SPIE* Vol. 8982, pp. 898227-1-9, 2014.

[4] Y. G. Xiao, et al, poster presentation with the 17th Microoptics Conference (MOC'11), Oct. 30-Nov. 2, 2011, Sendai, Japan (2 journal pages).

978-1-4799-8379-7/151$31.00 ©2015 IEEE

[5] Z. M. Simon Li, Y.G. Xiao, et al, EDSSC 2011, Nov 17-18, 2011, Tianjin, P R China (2 journal pages).

[6] CSuprem 2013 and APSYS 2013 and technical manuals, Copyright © Crosslight Software Inc.

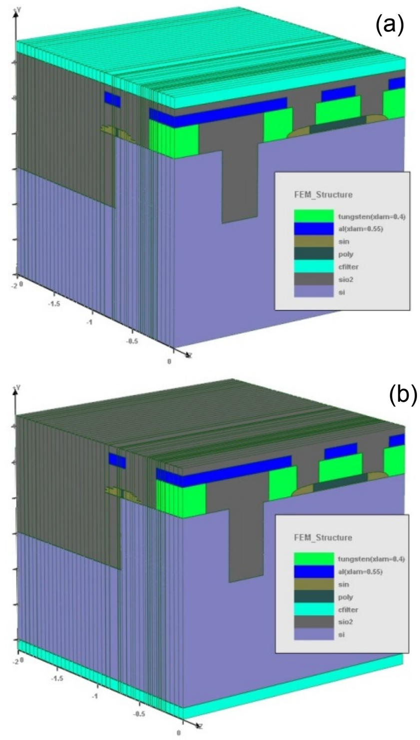

Fig. 1. APS unit: for (a) front- and (b) back-illumination simulation.

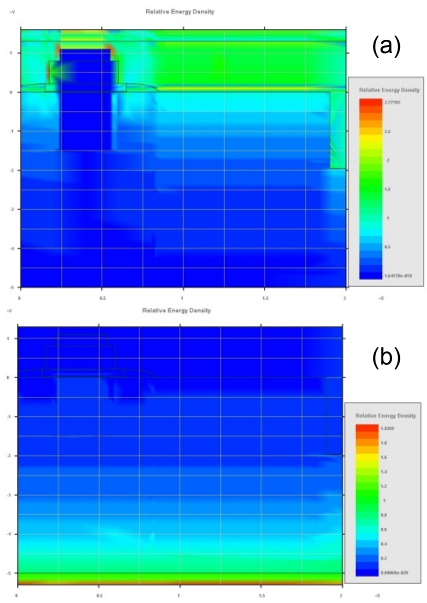

Fig. 2. 2D cut plane showing the photodiode and transfer gate region together with the optic power intensity profile of (a) front- and (b) back-illumination.

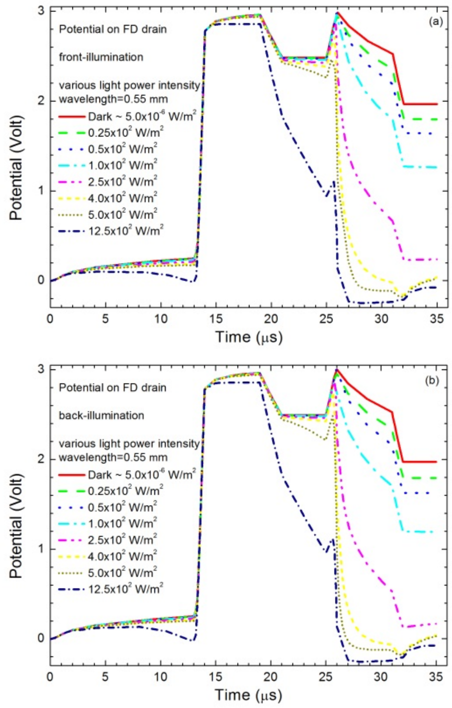

Fig. 3. Potential on FD versus time with various optical power intensity under (a) front- and (b) back-illumination.

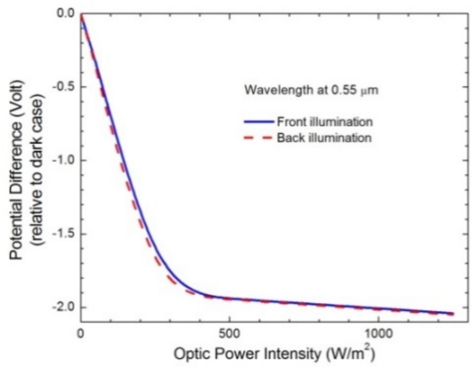

Fig. 4. Potential difference (after TX stage) versus optical power intensity.

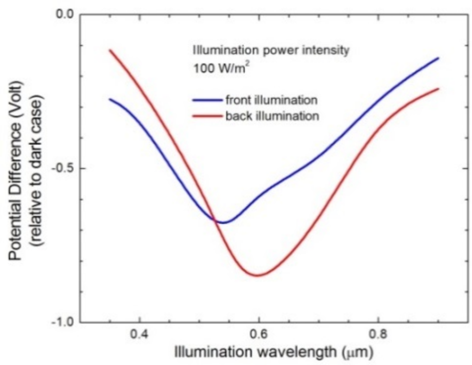

Fig. 5. Potential difference (after TX stage) vs. wavelength.