Near Infra-Red Enhanced 2.8um Global Shutter Pixel with Light Pipe Structure and High Resistivity P-type Substrate

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Abstract **In this paper, near IR (NIR) enhanced 2.8um global shutter pixel on p-type substrate is presented. With high resistivity p-type epitaxial layer and deep n-type implant to enhance electric field toward photodiode, and with light pipe structure to reduce optical crosstalk, quantum efficiency of 35% and modulated transfer function of 63 lp/mm at 850nm are achieved.**

Introduction

CMOS Image Sensor (CIS) with Global Shutter (GS) takes a strong attention in markets for industrial and automotive. Small GS pixel with high Near Infra-Red (NIR) sensitivity is attractive for especially motion recognition of human because of small footprint, no-motion artifact. For these purposes, both modulated transfer function (MTF) and quantum efficiency (QE) are required. In GS pixel, metal-shield is used for suppressing parasitic light sensitivity (PLS) to memory node [1, 2]. Its small metal window makes it difficult for the pixels to have good MTF due to diffraction at W-shield. P-type epitaxial layer is usually used for QE enhancement at NIR [3]. Electric field toward photodiode in such layer is needed for good MTF. In this paper, we will report on two approaches to enhance NIR performances of 2.8um GS pixel in 65nm CIS with W-shield process [1].

Approaches

Pixel under evaluation is schematically drawn in Fig.1. There are two concerns of MTF degradation. One is optical crosstalk to the adjacent pixels caused by diffracted light at W-shield. The other one is electrical crosstalk in p-type epitaxial layer/p-type substrate.

The approach to reduce optical crosstalk is introducing light pipe structure to confine light energy in small area [1]. In this case, it is expected that incident light is kept distant from W-shield and diffraction is suppressed. Fig.2 (a) and (b) shows the simulation results of incident NIR light in pixel with and without light pipe. Smaller power of light close to W-shield is clearly shown in Fig.2 (a). The pixel with light pipe can prevent incident light from spreading to the adjacent pixels by 35% as shown in Fig.3.

The approach to reduce electrical crosstalk is using high resistivity p-type substrate with deep photodiode implant as shown in Fig.4. This enhances electric field in photosensitive region and reduces electrical cross-talk to adjacent pixels [3, 4]. Two wafers of p-type epitaxial layer/p-type substrate in 12-inch wafer with high resistivity are prepared. Specifications of each wafer are listed in table. 1. Both wafers have 10um epitaxial thickness to enhance QE. The wafer with the higher resistivity (HR) epitaxial layer has the limited high resistivity of p-type substrate to prevent auto-doping in the epitaxial step. Results of potential simulation in photosensitive region are shown in Fig.5. As shown in Fig.5 (a), deep photodiode implant in lower resistivity (LR) p-type epitaxial layer makes photodiode deeper by 1.5um and reduce neutral region where electric filed is zero. Potential gradient at 8~9um depth is due to Boron up-diffusion from low resistivity p-type substrate. This also help to reduce neutral region. As shown in Fig.5 (b), HR p-type epitaxial layer makes slightly deeper photodiode compared

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to the LR p-type wafer. However, the neutral region of the HR wafer is expected to be much deeper than that of the LR wafer, because high resistivity of p-type substrate of HR wafer increases lifetime of electrons in the substrate. Diffusion length of electron in HR wafer is calculated to be around 180um, which is two order longer than that in LR wafer case. Higher QE@NIR with degraded MTF is expected in HR wafer.

Experimental Results

The pixels with light pipe and with/without deep photodiode implant in LR p-type substrate in 65nm CIS process, and the pixel without light pipe and with deep photodiode implant in 110nm CIS process [4-6] were prepared for comparison. The pixels in HR wafer are also prepared for comparison. Pixels evaluated are summarized in table 2. The all pixels have 2.8um-pixel pitch.

Spectral response of each pixel is shown in Fig.6. There is no difference between pixels with low resistivity p-substrate. Pixel with high resistivity p-epitaxial layer/p-substrate shows 2~3 times larger QE@NIR as expected. Figure.7 shows MTF measurement result of pixels with/without light pipe and deep photodiode implant. Setup for MTF measurement with Imatest is described in [4]. MTF50 in our measurement system is limited to around 100 lp/mm by system lens. We are updating the system and will update values of MTF. In the current system, MTF of the pixel with deep photodiode implant is 65% higher than that of the pixel without deep photodiode implant. This indicates electrical cross-talk is suppressed by deep photodiode implant. MTF of the pixel with light pipe is also 65% higher than that of the pixel without light pipe.

Conclusion

To enhance NIR performances of small GS pixel, we analyzed to minimize optical and electrical cross-talk in pixels. We verified light pipe and deep photodiode implant are effective for good MTF in low resistivity p-type epitaxial layer with keeping QE. Table 3 contains a list of pixel performance of NIR enhanced 2.8um GS pixels. Our developed pixel shows the best-in-class NIR performance with suppressed parasitic light sensitivity.

References

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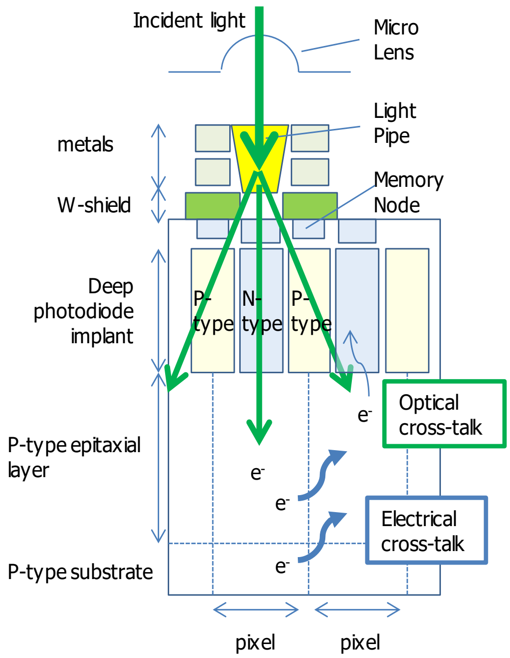

Figure 1 Schematic of Pixel Structure

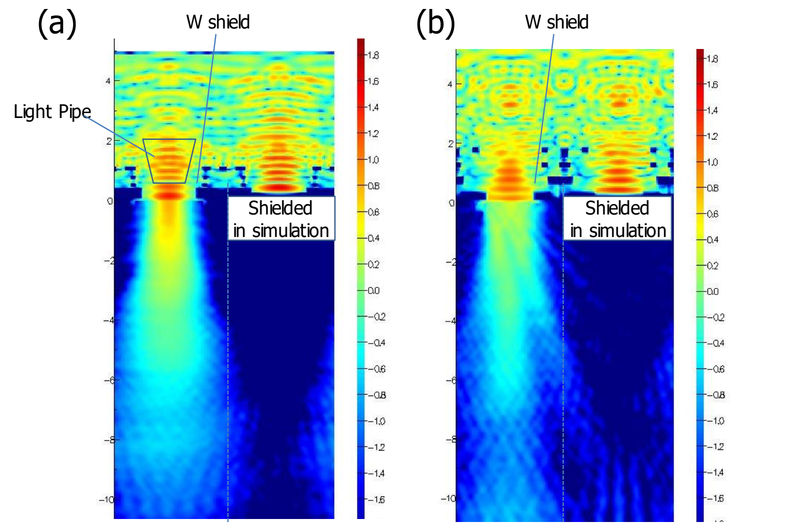

Figure 2 Electric field of incident light@λ=850nm in pixel (a) with light pipe and (b) without light pipe. Right side pixel is shielded by metal intently to clearly show light intensity from left side pixel in substrate.

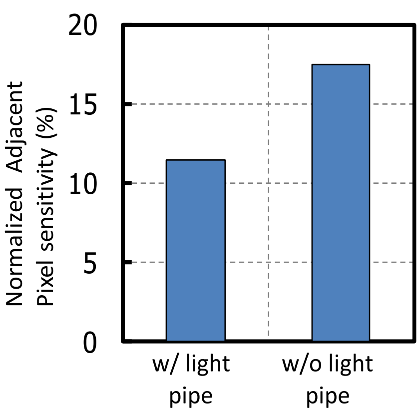

Figure 3 Comparison of parasitic sensitivity of the adjacent pixel with and without light pipe. Parasitic sensitivity is normalized by that of the pixel irradiated.

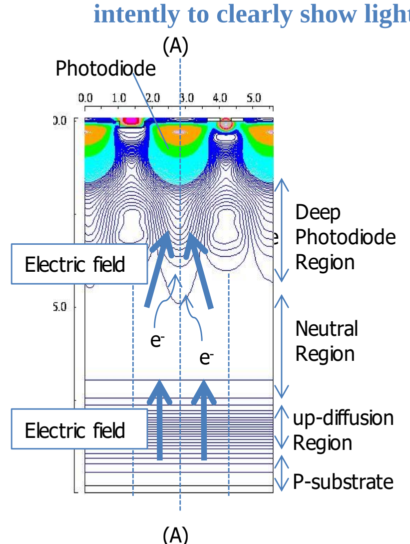

Figure4 Electric static potential of pixel with deep photodiode implant

Table 1 Specification of wafers evaluated.

Wafers	Unit	Lower Resistivity P-epi	Higher Resistivity P-epi
P-epi Resistivity	Ω cm	~100	~800
P-epi Thickness	um	10	10
P-substrate Resistivity	Ω cm	~0.01	~10

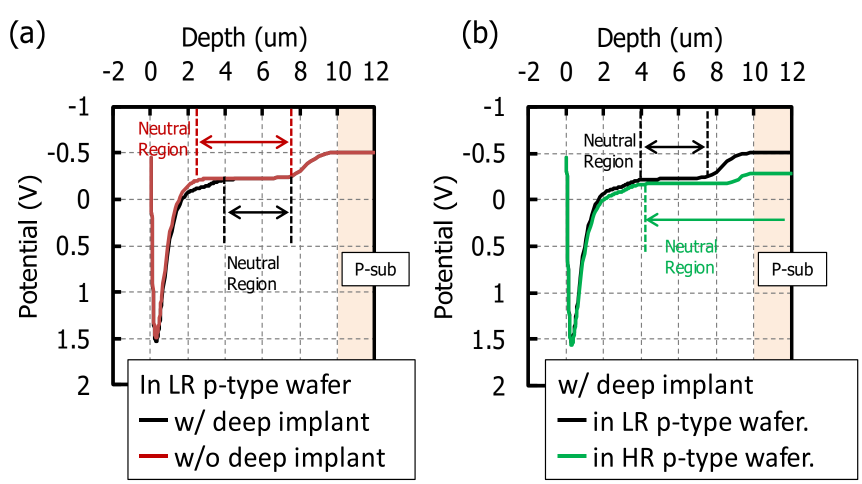

Figure 5 Electric static potential at the center of photodiode, which is shown as line (A)-(A) in Figure 4. (a) Comparison between pixels with and without deep photodiode implant low resistivity p-type epitaxial layer. (b) Comparison between pixels in LR and HR wafers.

Table 2 Pixels prepared for experiment

Type	P-Substrate Resistivity	P-epi Resistivity /thickness	Deep photodiode implant	Light Pipe	Process	Length of Neutral Region	QE@830nm	MTF@830nm
1	Low	High/10um	W/	W/O	110nm CIS	2.5um	34%	38lp/mm
2	Low	Low/10um	W/O	W/	65nm CIS	5um	35%	39lp/mm
3	Low	Low/10um	W/	W/	65nm CIS	3.5um	35%	63lp/mm
4	High	High/10um	W/O	W/	65nm CIS	14um	59%	--
5	High	High/10um	W/	W/	65nm CIS	14um	59%	--

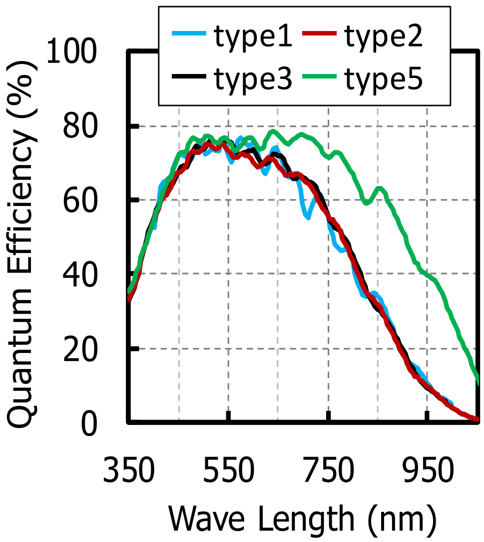

Figure 6 Comparison of spectral response.

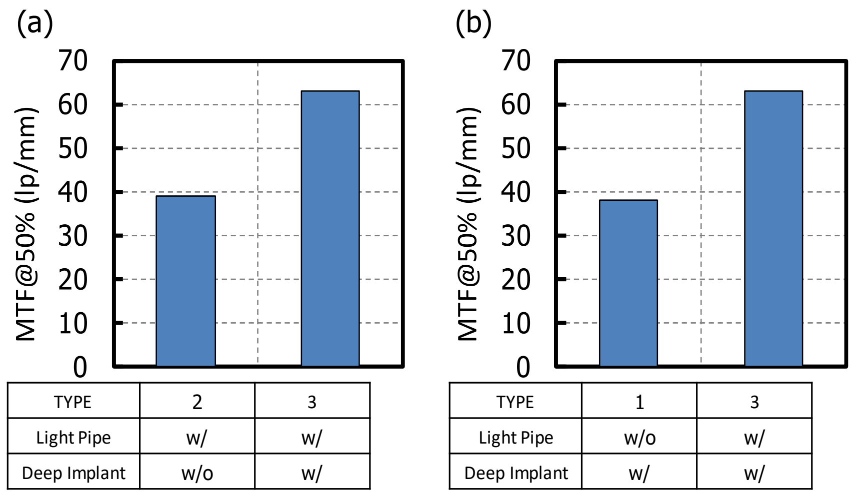

Figure 7 Comparison of MTF50. (a) Pixels with and without deep photodiode implant. (b) Pixels with and without light pipe.

Table 3 Pixel performance of NIR enhanced 2.8um GS pixel.

Characteristics	Value	Note
Pixel Pitch	2.8um	
Color Filter	Monochrome	
Full Well Capacity	8.6kele	@60C
Linear Full Well	7.0kele	@60C
Image Lag	None	@half signal
Dark Current	80ele/s 10ele/s	@60C, photodiode @60C, memory node
Quantum Efficiency	35% 11%	@830nm @940nm
Angular Response	+/-12degree	@80% signal to peak
Parasitic Light Sensitivity	15k 12k	@Halogen,f/9,with IR cut @940nm,f/2
MTF@50%	63lp/mm 45lp/mm	@830nm @940nm