Design of Double micro lens structure for 2.8um Global Shutter Pixel

*[1]Toshifumi Yokoyama, [1]Masakatsu Suzuki, [1]Yoshiaki Nishi, [1]Ikuo Mizuno & [2]Assaf Lahav

1Towerjazz Panasonic semiconductor Co,. Ltd. 800 Higashiyama,Uozu City, Toyama, Japan 937-8585.
1*E-mail address: yokoyama.toshifumi@tpsemico.com TEL: +81-50-3739-0551
2 TowerJazz SemiConductors. Migdal Haemeq, Israel.

Abstract

We developed a 2.8um Global shutter pixel. We proposed a new inner lens design concept to realize the both low optical noise and high Quantum Efficiency (QE). New lens based on our concept achieved low optical noise (1 / PLS = 7700) and high QE (62%).

Introduction

CMOS image sensor with Global Shutter (GS) has become popular [1-3]. In the industrial field, GS image sensor with small pixels is demanded for high quality and high resolution pictures. In order to realize GS capability, Memory Node (MN) must be added in each pixel [4]. When the pixel is scaled down, it becomes increasingly challenging to reduce the Parasitic Light Sensitivity (PLS) in the MN.

In this paper we present the advanced approach of optical design in 2.8um GS pixel for drastic improvement of PLS and QE.

Structural issues of small GS pixel

Figure 1 (a) and 1 (b) show the cross-section structure of GS pixel. Figure 1 (a) shows the single lens structure and Fig 1 (b) shows the double lens structure. In the case of the single lens structure, the incident light is collected by the lens, and then passes between the Cu-wirings, and finally enters the Photo Diode (PD). The MN is placed next to the PD in order to read the electrons stored in the PD. In order to improve PLS, it is necessary to reduce the incident light to MN. Tungsten (W) light shield is often placed just above the MN to block incident light as shown in Fig. 1 (a) [5, 6].

Figure 2 shows the pixel size dependence of QE and 1/PLS. The target pixel size in this report is 2.8um. These data were estimated by optical simulation with single lens structure. As the pixel size becomes smaller, QE and 1/ PLS are seriously degraded. The decline of these optical characteristics is due to the fact that the incident light is not concentrated efficiently in the optical aperture. It is not easy to change the wiring width and wiring height in order to keep wiring resistance and capacitance even if the pixel size is scaled down. Therefore the optical aperture size becomes smaller and it becomes difficult to pass the light between Cu-wirings with a single lens structure in small pixel. When the curvature of the lens is large (the solid line in Fig. 1) in order to make the light incident on the narrow optical aperture, the light is blocked by the W light shield and the QE decreases. On the other hand, when the curvature of the lens is small (the broken line in Fig. 1), the incident light is blocked by the Cu-wiring and it also causes the decline of the QE.

The optical aperture reduction by W light shield also has a considerable influence in small pixels. Figure 3 shows the angular response of QE and PLS of 2.8um GS pixel when W-Poly (W-Poly in Fig. 1) extension is changed. Figure 3 (a) clearly shows that QE is increased and the sensitivity degradation to angles is suppressed by decreasing the W light shield extension from the Poly. Conversely it increases PLS by an order of magnitude as shown in Fig. 3 (b). It is difficult to realize both high QE and high 1/PLS by simply adjusting the W light shield extension. It is important to improve the optical characteristics by changing the propagation of light.

A double micro lens structure is often used as a method for efficient light collection into a narrow optical aperture [7, 8]. An inner lens is placed above the Cu-wiring layer as shown in Fig. 1 (b). In the case of the double lens structure, it is possible to adjust the light collection at two positions of the upper lens and the inner lens. It is expected that the light collected by the upper lens can be efficiently collected into the optical aperture.

We compared PLS and QE between with and without inner lens structures by optical simulation using 3-dimentional finite difference time domain (FDTD) method. Table 1 shows the simulation results. By adopting inner lens, incident light was concentrated efficiently in the optical aperture. As a result, QE was improved by 9% and PLS was improved by 30%. For further improvement, we studied the inner lens structure in more detail.

Analysis and Design concept of inner lens (our proposal)

We analyzed the inner lens curvature dependence of QE and PLS by optical simulation. Figure 4 shows the simulation results. These data were calculated by changing a diameter of inner lens (lens height was constant). PLS depends on curvature and small curvature was better for PLS. On the other hand, QE was stable in the curvature range. It indicates that once the incident light collected by the upper lens enters the inner lens, the light reaches the PD regardless of the inner lens curvature. In other word, inner lens can be designed to dedicate to reducing PLS. We compared the electric field between large curvature and small curvature to analyze the key factor of PLS. Figure 5 (a) and 5 (b) shows the cross-section of electrical field distribution. When the inner lens has a large curvature, the beam spread is wide near the W light shield as shown in Fig. 5 (a). When the inner lens has a small curvature, the beam sprad is narrower than that of large curvature lens and the beam is incident almost perpendicularly to Si as shown in Fig. 5 (b).

We analyzed the electric field distribution near the MN in more detail. Figure 7 (a) and 7 (b) are the enlarged view of the broken line portion of Fig. 5 (a) and 5 (b). When the inner lens has a large curvature, a large amount of oblique light bended by inner lens enter to the MN as shown in Fig. 6 (a). On the other hand, when the inner lens has a small curvature, light entering to the MN decreases as shown in Fig. 6 (b).

From these analysis, it is important to make the light incident perpendicular to Si in order to reduce oblique incidence to the MN. To summarize the results, the double lens design concept we propose is as follows. The incident light collected by the upper lens should be concentrated on the inner lens in order to improve the QE and the inner lens should be designed so that light enters straight into the silicon.

We developed a new inner lens based on this concept. Figure 6 (c) shows the electrical field distribution around the MN of the newly developed lens. Light enters straight into the silicon and incidence light to MN is drastically reduced.

Results of newly developed inner lens based on our design concept

We made the real 2.8um GS devices with two type (conventional inner lens and newly developed inner lens for GS) structures. The pixel was designed in 110nm process with 3Cu layers and 1AL. Table 2 shows the measurement result. We confirmed superiority of the new inner lens based on our concept. The simulation results agreed with the experimental results. The QE of green pixel was the same 62% in both types. The inner lens developed with the new concept obtained two times better 1/PLS than conventional lens and the value was 7700. Figure 7 shows the QE curves with the newly developed inner lens. The QE of blue pixel was 59% and the QE of red pixel was 48%.

Conclusion

We proposed a new lens design concept for small GS pixel. The double lens design concept we propose is as follows. The incident light collected by the upper lens should be concentrated on the inner lens in order to improve the QE and the inner lens should be designed so that light enters straight into the silicon. We developed a new inner lens based on a new concept. We achieved both high QE 62% and high 1/PLS 7700 in 2.8um GS pixel.

References

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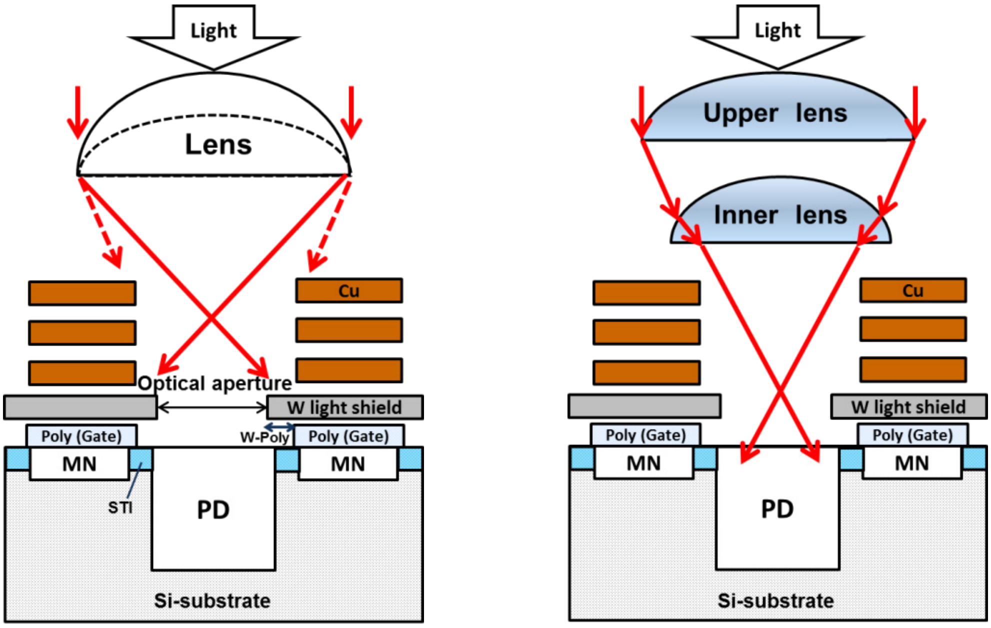


(a) Single lens structure. (b) Double lens structure.

Fig.1 Cross-section structure GS pixel.

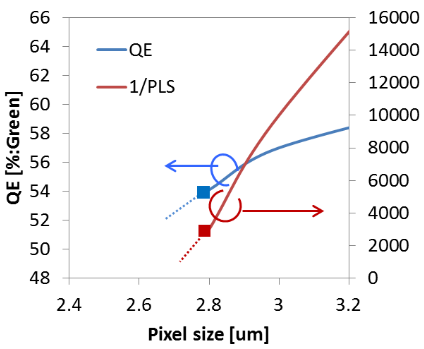
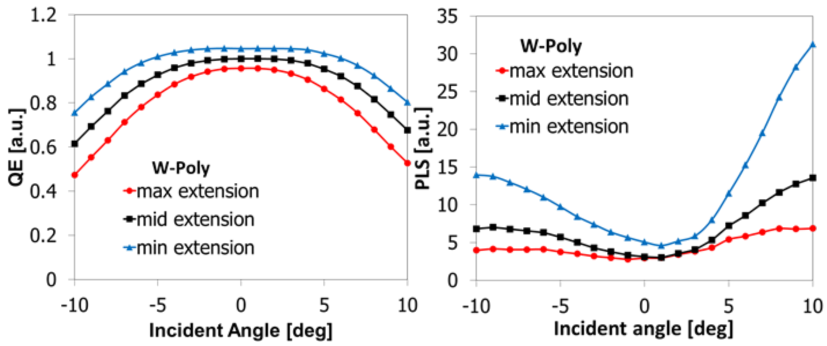


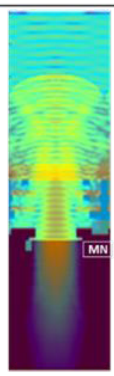
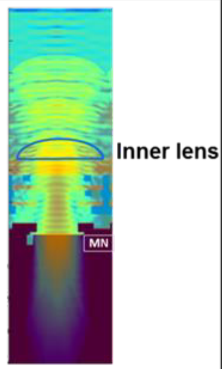
Fig.2 Pixel size dependence of QE and 1/PLS.



(a) Angular response of QE. (b) Angular response of PLS.

Fig.3 Angular response of QE and PLS when W-Poly extension is changed.

Table1 Results of optical simulations

	Without Inner lens	With Inner lens
Electrical Field (cross section)		
QE(%)	54.1	58.9
1/PLS	2700	3500

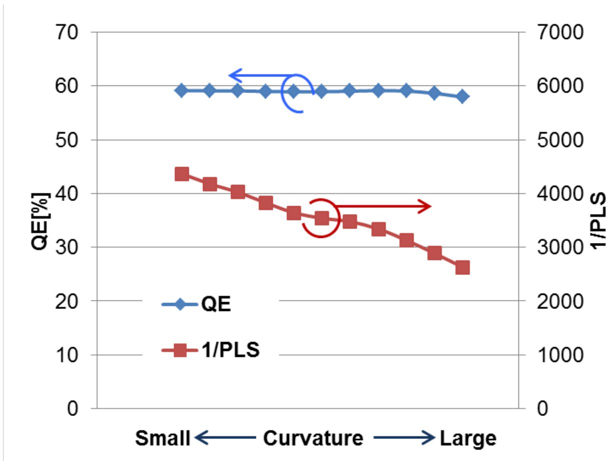


Fig.4 curvature dependence of QE and 1/PLS.

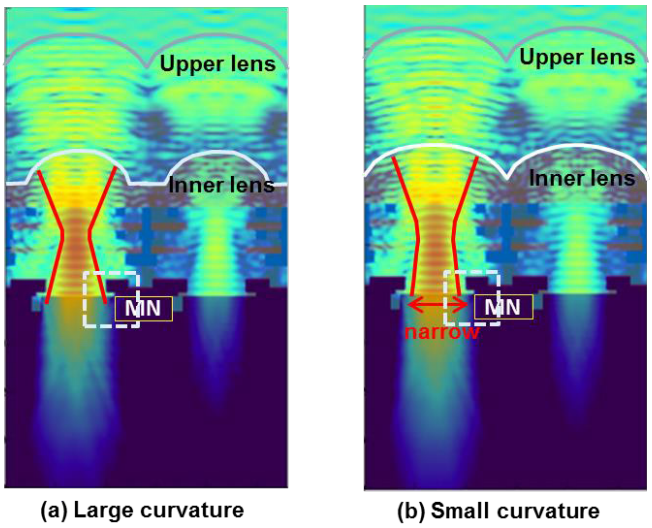


Fig.5 Cross-section of Electrical field.

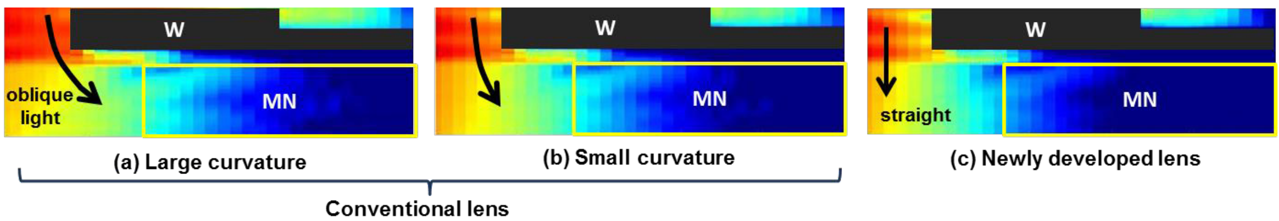


Fig.6 Electrical field around MN.

Table2 Measurement results of optical characteristics

		Without Inner lens	Conventional Inner lens	**Newly developed Lens for GS**
QE(%)	simulation	54.1	58.9	58.6
	measurement	-	62.0	62.0
1/PLS	simulation	2700	3500	7100
	measurement	-	4000	7700

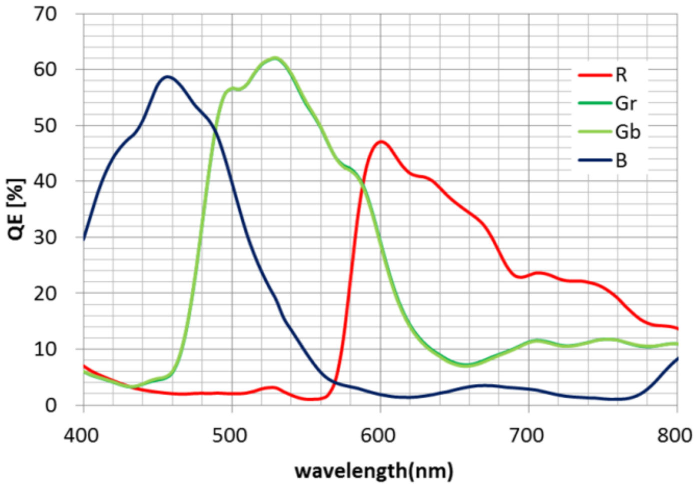


Fig.7 QE curves of 2.8um GS image sensor with newly developed lens.