SNR Performance Comparison of 1.4um Pixel : FSI, Light-guide, and BSI

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Abstract

SNR (Signal-to-Noise Ratio) at low light condition is a key performance of image sensor. To improve SNR performance with high sensitivity and low crosstalk, advanced light-guide and backside illumination (BSI) pixel technologies are developed. Comparing with the conventional frontside illumination (FSI) technology, SNR10 is improved by 16% for light-guide and by 36% for BSI at the 1.4um pixel node.

Introduction

According to high resolution trend in image sensor, pixel size is shrinking continuously and new technologies have been developed to overcome performance degradation and keep the same image quality as the previous pixel generation [1]. SNR at low illumination is a key performance of image sensor. As a good metric of SNR, SNR10 has been used, which is the scene illumination for Y-SNR=10 after white balance and color correction [2]. Sensitivity, crosstalk, and noise are crucial factors in SNR10 metric. As pixel size gets smaller, technologies for higher sensitivity and lower crosstalk have also been developed such as light-guide [3, 4] and BSI [5, 6], and applied to commercial sensors.

In this paper, SNR10 performances of conventional FSI, light-guide, and BSI of 1.4um pixel are compared and analyzed by simulation and measurement. All devices are fabricated based on 90nm Al-process technology.

Pixel Structures and Simulations

The vertical structures of fabricated FSI, light-guide, and BSI are shown in Figure 1. In conventional 1.4um FSI pixel, although metal wiring is optimized to get larger metal aperture while optical stack is keeping as lowest as possible [8]. Simulation of QE loss is investigated (Figure 2). In F-number 2.8 environment, the optical power loss at metal layers is more than 20% and crosstalk should also be reduced.

Light-guide structure is developed to reduce metal loss and crosstalk of the conventional FSI. The structure is optimized for light to pass through the cavity with minimized optical power loss. The depth and diameter of cavity, the distance between cavity and Si surface, and the refractive index of cavity-filling material are simulated and optimized. The scattering loss in metal stack is reduced by the total internal reflection in cavity and the reflection loss of top metal is also minimized by allowing the focal point of the microlens to be shifted far above the top metal.

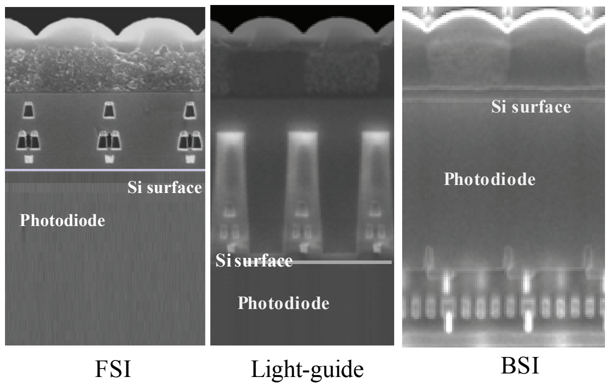

Figure 1. Cross section of fabricated 1.4um conventional FSI, light-guide, and BSI pixels

However, even with light-guide structure, high-angle incident light larger than the critical angle cannot have the benefit of total reflection at the interface of cavity filling material and BEOL dielectric (oxide), resulting in some penetration and thus optical loss. The simulation result shows that it still has optical power loss of about 10% in the BEOL stack.

While the previous BSI technology uses a metal shield to reduce optical crosstalk [6], BSI pixel can basically remove any obstacle completely in optical passage from microlens to Si surface. In addition, the backside optical stack is minimized so that high QE, low optical crosstalk, and better angular response can be achieved. The better anti-reflection coating with an optimized material and thickness is adopted due to the freedom from transistor process of FSI pixel. Furthermore, the thick silicon with deep photodiode and narrow isolation are employed for lower electrical crosstalk as well as higher QE. To minimize the recombination loss while maintaining low dark current and low dark defect, thin p-type passivation layer is employed.

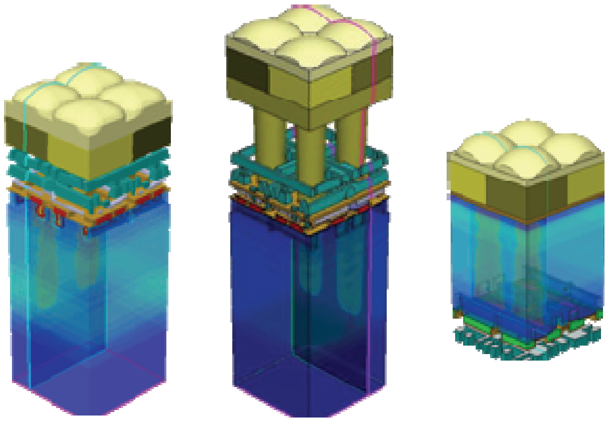

Figure 2. Simulated pixel structures

Results and Discussions

Quantum efficiency curves of 1.4um conventional FSI, light-guide, and BSI are measured and compared in Figure 3. Peak QE's of 55%, 62%, and 70% are achieved for the conventional FSI, light-guide, and BSI pixels. Comparing the conventional FSI pixel, light-guide and BSI pixels have low crosstalk levels. Even though BEOL structure is optimized in the conventional FSI pixel, SNR10 of 135lux is measured, which is almost double of 1.75u pixel. Light-guide structure reduces metal loss and crosstalk. As a result, sensitivity is improved by 15% and SNR10 of 113lux is achieved. Finally, SNR10 of 87lux is achieved in BSI pixel, which is comparable level with the performance of 1.75u FSI pixel.

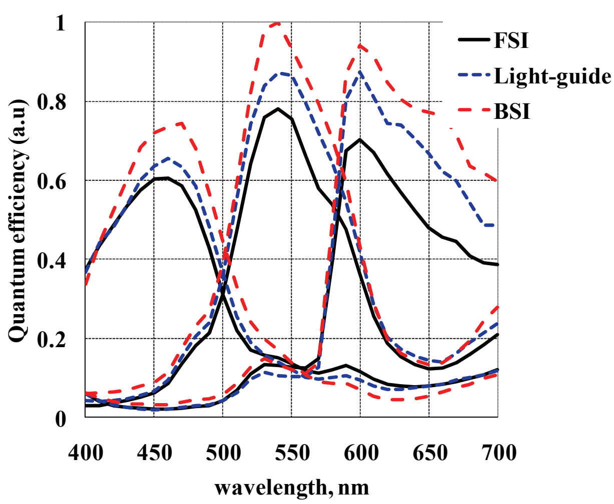

Figure 3. Measured quantum efficiency curves for 1.4um conventional FSI, light-guide, and BSI pixels

Figure 4 shows that relative sensitivity of BSI pixel at oblique incidence is far superior to FSI, due to low stack height. Maximum incidence angle of BSI is more than 35deg while that of FSI is 25deg. Captured images and SNR's are compared as shown in figure 5. Pixel performances are summarized in Table 1.

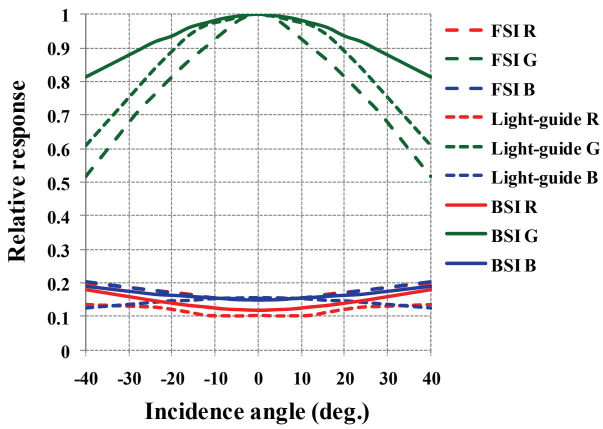

Figure 4. Angular responses at 540nm of 1.4um conventional FSI, light-guide, and BSI pixels

	Conv. FSI	Light-guide	BSI
G-sensitivity (e-/lux.sec)	4120	4760	5320
Average crosstalk (%)	19.9	17.3	17.0
SNR10 (lux)	135	113	87

Table 1. Comparison of pixel performances for 1.4um conventional FSI, light-guide, BSI pixels

Conclusion

In conclusion, various technologies to improve SNR performance of 1.4um pixel are experimented and compared. SNR10 performance is improved from 135lux down to 113lux and 87lux by light-guide and BSI technologies, respectively, which remove metal loss in conventional FSI structure and thus improve QE and crosstalk. Especially the BSI technology allows us to jump over one pixel generation and showed similar SNR performance compared with 1.75um pixel.

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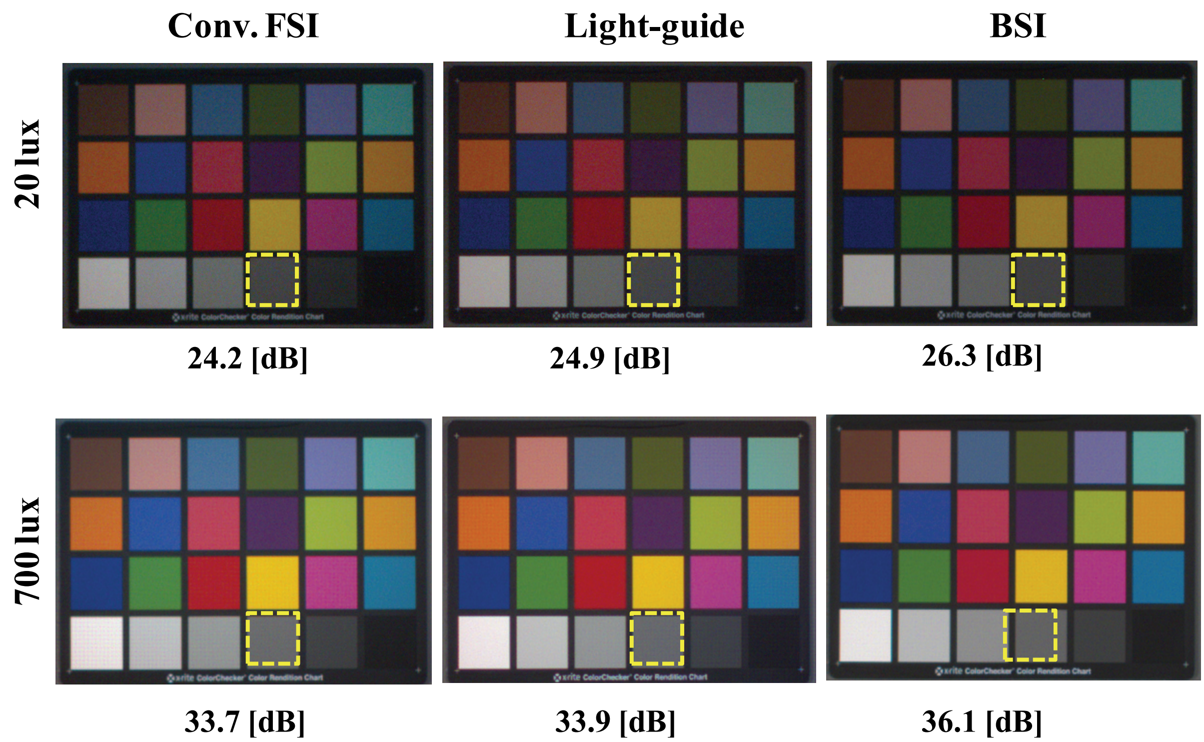

Figure 5. Image comparison of 5M, 1.4um-pixel at 20lux and 700lux (F/2.8, D65, 145msec)