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World first mass productive 0.8㎛ pixel size image sensor with new optical isolation technology to minimize optical loss for high sensitivity

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Abstract

More and more pixels are needed to implement CMOS image sensors with high resolution while reducing the size of the chips. As the beam size of the incoming light nears the pixel size, the light loss from the conventional metallic grid increases. Development of an architecture that minimizes optical losses is key technology to secure pixel performance of sub-micro sized pixel. In this paper, we analyzed the light loss according to the pixel size and the optical structure. Based on this, we are going to introduce a new isolation structure that minimizes optical losses applied to the world's first 0.8um pixel size product.

Introduction

One of the most important features of the smartphone market in recent years is the hiring of high-resolution multiple cameras. Competition to decrease size of pixels to implement high resolution is accelerating even while area of image sensors is being controlled as much as possible. Pixel size has declined significantly over the years, image sensor products with sub-micrometer sized pixel coming to the market.[1] As pixel size is decreasing continuously, it is expected that pixel size will decrease as well as visible light wave level.[2] It is very difficult to maintain sensitivity of small sized pixel due to reduction of photons that goes through micro-lens and limitations of light diffraction. For these reasons, the technology to maximize the quantum efficiency of pixels in order to maintain picture quality in image sensors is important. We made a conclusion from the light loss analysis in image sensors that the metallic grid structure commonly used is not suitable for small sized pixels. In this paper, a new structure with reduced light loss was proposed.

Analysis and result

Light loss in common image sensors is affected by the light collection efficiency of the micro-lens, the color filter transmittance, the structure of the metallic grid structure, and the performance of the anti-reflective layer of silicon. We analyzed the major light loss components through 3D finite-difference time-domain (FDTD) simulations, color filter properties, and device spectrometry. Table1 is a summary of the analysis results, and at 0.8um pixels it was shown that the major light loss component was caused by the metallic grid structure.

	Micro lens	Color filter	Metallic grid	Anti reflective layer
normalized light loss ratio	3.8%	21.4%	71.4%	3.3%

Table 1 Summary of major light loss components at 0.8um pixels

We prepared three structures, such as Table2, which experimentally demonstrates the light loss rate from metallic grids. Structure 1 is a typical image sensor, and metallic grids were removed in Structure 2. By comparing these two structures, the light loss due to the metallic grid can be quantitatively identified. The performance of the micro-lens can also be compared by comparing Structure 2 with Structure 3.

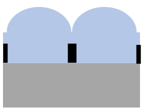
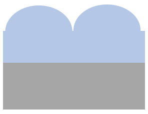
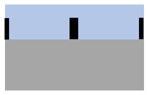
	Structure 1	Structure 2	Structure 3
micro lens	O	O	X
metallic grid	O	X	O
schematics			

Table 2 Structure for the Analysis of losses by optical structure

Figure 1 is a QE graph of the three structures showing the level of light loss by the metallic grid and light loss recovery by the micro-lens. Even if the micro-lens collects light well, optical losses still occurs by metallic grids.

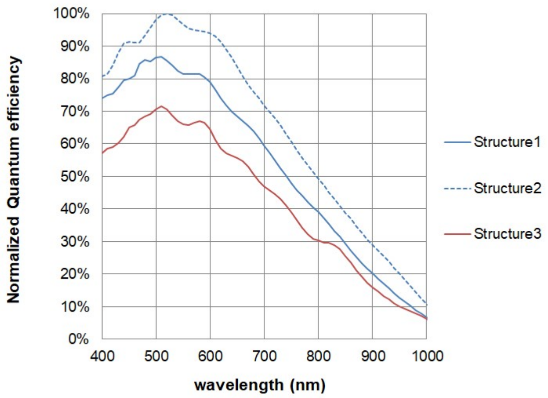


Figure 1 Quantum Efficiency graph according to the optical structure.

The 3D FDTD simulation results in Figure 2 show that some portion of the light through the micro-lens would enter the metallic grid. Light entering the metallic grid includes not only primary peak of light but also secondary one, indicating that increased light collection efficiency of the micro-lens does not completely prevent light loss due to the metallic grid. It was also shown that the focused light spot size goes bigger with increasing wavelength. The above facts were used to predict higher light loss due to metallic grid in small pixel under long wavelength light conditions.

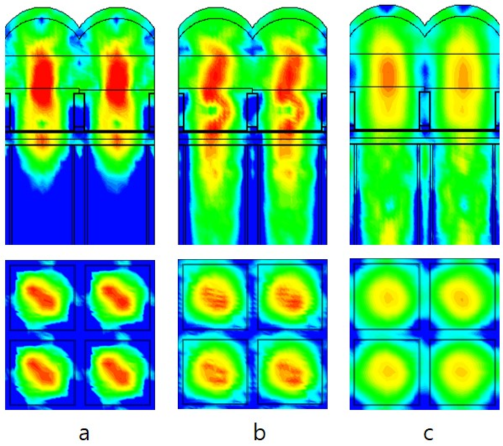


Figure 2 3-D FDTD simulation result with various wavelength a) 450nm b) 550nm c) 650nm

In order to identify the cause of light loss in the metallic grid, the properties of the metallic grid were checked and the absorption coefficient was found to be high as shown in Figure 3. This shows that the high k value of metallic grids is the major cause of light loss.

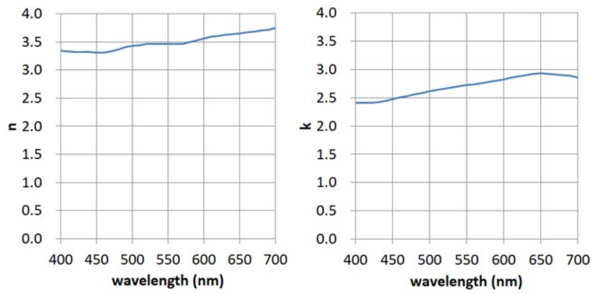


Figure 3 Optical constant according to wavelength of metallic grid

To verify this analysis, we produced and evaluated various pixel sizes devices. Experiments have shown that the light loss due to the metallic grid due to wavelength can be verified as shown in Figure 4.

Differences in light loss rates due to wavelengths can cause problems such as large differences in blue, green, and red sensitivity, which increase the gain in the white balance process. This result shows that it is very important to reduce the light loss caused by the metallic grid as the pixel size decreases, even if there are micro-lenses.

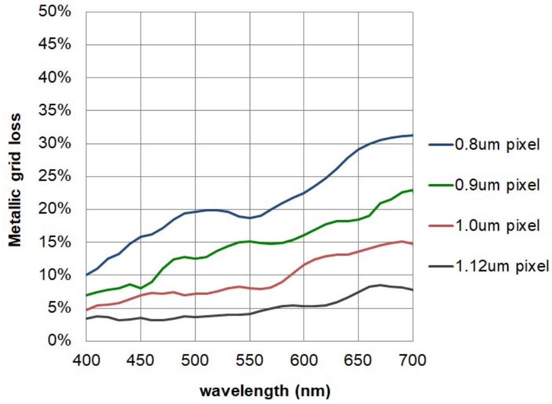


Figure 4 Experimental result of optical loss due to metallic grid according to pixel size and incident light wavelength

We successfully made a novel structure to reduce the light loss caused by metallic light absorption while maintaining the good function of the existing metallic grid's control of crosstalk and ESD attack prevention.

In order to reduce the light loss but avoid crosstalk to adjacent pixels, the total reflection structure was designed by the difference in refractive index between color filter and new grid. Figure 5 shows the simulation results showing the reflection by the difference in the refractive index. Based on these results, it was possible to verify that the crosstalk could be reduced without loss of light absorption if a grid with a lower refractive index than the color filter.

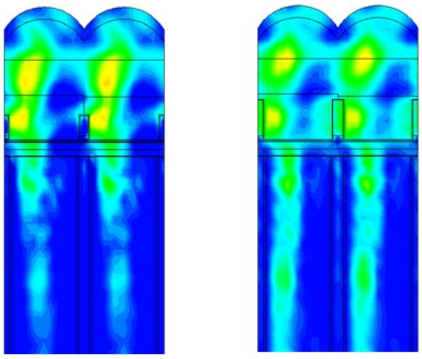


Figure 5 Simulation result of crosstalk suppression using light reflection with low refractive index grid materials

Based on the analysis above, a composite blockage structure to prevent ESD attack, low refractive index materials, patterning process to fabricate grid and defects control technology were developed. Figure 6 shows a comparison of the existing and new structures. We named this technology "ISOCELL PLUS".

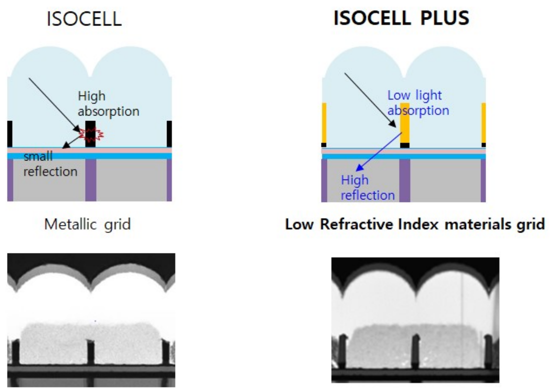


Figure 6 New isolation (ISOCELL PLUS) schematic & TEM image.

Evaluation result of 0.8um pixel device using ISOCELL PLUS technology, 15% sensitivity and 0.4dB SNR improvement were confirmed. Figure 7 shows the quantum efficiency curves of ISOCELL and ISOCELL PLUS and sensitivity of ISOCELL PLUS is increased with the crosstalk suppressed.

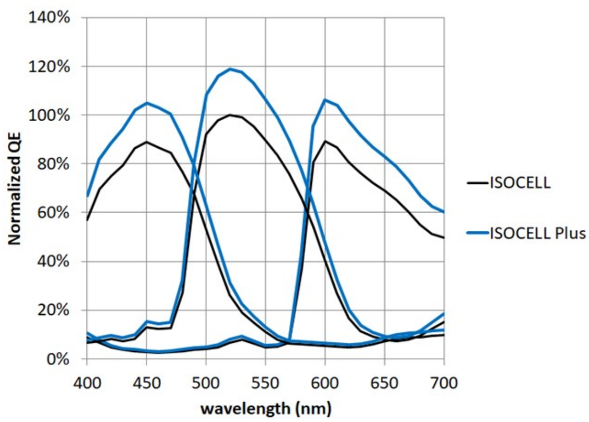


Figure 7 Quantum efficiency comparison of ISOCELL and ISOCELL PLUS

In addition, as shown in Figure 8, we were able to identify increased sensitivity and improved image quality.

Figure 8 Image comparisons of ISOCELL and ISOCELL PLUS

Comparison of properties with previous generation 0.9um confirmed that crosstalk can be kept equal while preventing sensitivity reduction. The technology has been proven to improve the optical properties of almost one generation. Table 3 below summarizes the main characteristics.

	0.9um ISOCELL	0.8um ISOCELL PLUS
Optical grid	metallic	Low Refractive Index materials
Sensitivity, e-/lux-sec	2,600	2,300
Crosstalk, %	14.2%	14.5%
Dark current, e-/sec Tj 60℃	2.0	2.0

Table3 Comparison of 0.9um pixel ISOCELL and 0.8um ISOCELL PLUS

When applying ISOCELL PLUS technology, it was possible to improve AF performance by reducing the difference in focal distance between AF pixels and normal pixels. Focal distance difference can occur in metal shielded PDAF performance as shown below figure 9.

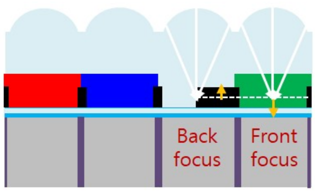


Figure 9 conventional structures of PDAF and normal pixel and focal distance difference

It can be seen that ISOCELL PLUS technology is essential to improving characteristics

Despite these advantages, we have had many difficulties in securing mass-produce level process. Through continuous process improvement, we are currently reliably supplying a number of products equipped with ISOCELL PLUS technology.

Conclusions

Demand for camera using small pixels is expected to continue as "more pixel, more camera", which has recently been settling down as a trend in the smartphone market. Sensitivity maximization technology is very important for image quality in high resolution camera using small pixels. We succeeded in mass production of 0.8um pixel products by utilizing novel structural design and process technology based on low refractive materials, which we call ISOCELL PLUS. We expect the ISOCELL PLUS technology to be used in smaller pixels to provide superior image quality.

References

[1] Y. Kim et al. “A 1/2.8-inch 24M pixel CMOS image sensor with 0.9 ㎛ pixels separated by full-depth trench isolation” *Proc. ISSCC*, Jan., 2018

[2] S. Choi et al., "An all pixel PDAF CMOS image sensor with 0.64 ㎛ x 1.28 ㎛ photodiode separated by self-aligned in-pixel deep trench isolation for high AF performance", *IEEE Symp., VLSI Tech.*, Jun., 2017