

# Development of Lensed Color Filter technology for higher SNR and lower crosstalk CMOS image sensor

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## Abstract

To enhance SNR performance by reducing crosstalk in backside illumination (BSI) pixel structure of CMOS image sensor, a new process technology, named as 'lensed color filter', was developed. Effective color filter thickness is increased while optical height is lower than conventional structure. The real chip with 1.12 $\mu$ m pixels and 12Mega resolution was manufactured. It has 25% higher color filter thickness and 15% lower optical stack. Evaluation shows that SNR10 performance is improved by 10% and crosstalk is reduced by 11%.

## Introduction

Backside illumination (BSI) technology is widely used for improvement of pixel sensitivity and signal-to-noise ratio (SNR) in CMOS image sensors. It removes metal layers between microlens and photodiode and reduces optical loss. Microlens and color filters also play an important role in determining SNR performance of pixels [1]. SNR and crosstalk performances can be improved by optimizing optical structure above backside silicon surface. SNR is a key performance of image sensor. As a good metric of SNR which takes into consideration crosstalk as well as sensitivity, SNR10 has been used, which is the scene illumination for Y-SNR=10 after white balance and color correction [2, 3]. In this paper the novel process technology, which unites microlens and color filter in a single body, is introduced which enables lower crosstalk and higher SNR without changing color filter materials. The experimental result from a manufactured chip is also described.

## Development of lensed color filter technology

Optical stack above silicon in general consists of color filter, top planarization layer, and microlens. Pixel spectral response depends on optical property of color filter materials, final pattern thickness of color filter, and optical stack height. Increase of the color filter thickness lowers spectral crosstalk of color filters, but larger pixel height increases optical crosstalk. Reversely smaller thickness of color filters makes larger color filter crosstalk and results in little SNR improvement.

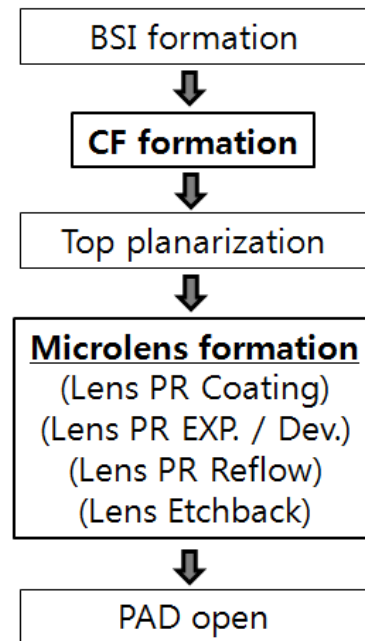


Fig. 1 Flow sequence of lensed CF process

Therefore a novel method needs to be developed to satisfy both larger effective color filter thickness and lower optical stack. The newly developed method is to form lower part of microlenses with color filter materials, named as 'lensed color filter'. Figure 1 shows the simple process flow to manufacture the newly designed color filter and microlens structure. The features of new process technology are thicker patterning of color filters and optimization of etchback process after forming micro lenses. The vertical structures are compared in Fig. 2 between conventional and lensed color filter processes.

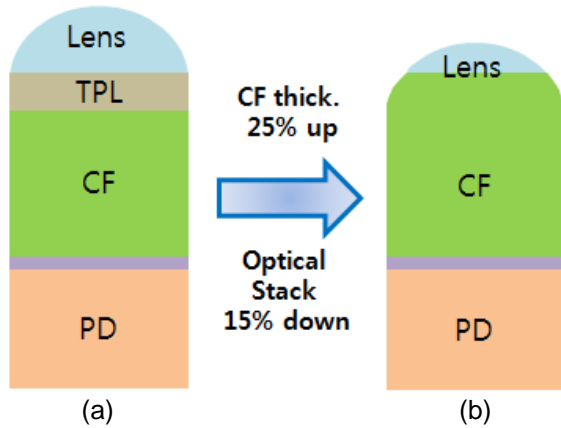


Fig. 2 (a) Vertical structure of normal process  
(b) Vertical structure of lensed CF process

## Experiment and discussion

A CMOS image sensor was manufactured with lensed color filter technology. It has 1.12μm pixels and 12Mega resolution, based on BSI technology. Figure 3 shows microscope image of micro lenses and vertical structure of lensed color filter process.

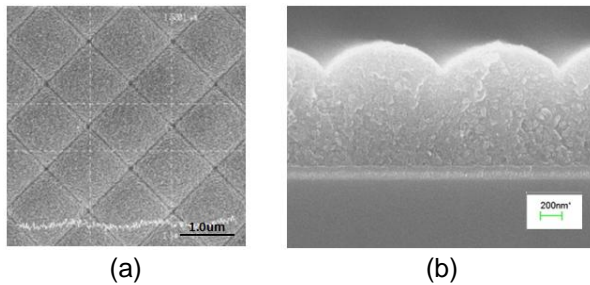


Fig. 3 (a) Micro scope image of lensed CF process  
(b) Vertical structure image of lensed CF process

Pixel performances of the sensor are compared with those of conventional sensor (Table 1). SNR10 and crosstalk were improved by 10% and 11%, respectively, while PRNU and dark current were kept same. Sensitivity is decreased by 4% due to reduced crosstalk, but QE peaks are kept at the same levels. Relative quantum efficiency curves are compared in Figure 4.

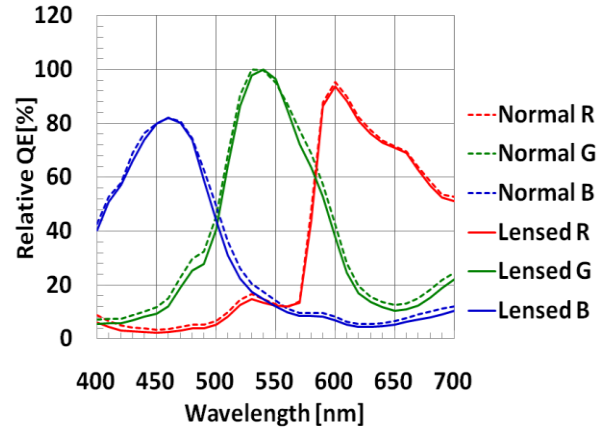


Fig. 4 Comparison of quantum efficiency curves of BSI sensors based on normal and lensed CF processes.

The improvement was analyzed by optical simulation based on FDTD method. Beam profiles at 550nm are shown in Fig. 5. Figure 5(a) shows the beam profile of normal structure, while figure 5(b) shows the case when only color filter thickness gets larger. In this case optical crosstalk inside silicon bulk increases while crosstalk component through color filter material is suppressed. Figure 5(c) shows the beam profile of the lensed color filter structure, where both the crosstalk inside silicon and the crosstalk through color filter material are suppressed well. This is because optical height is reduced even with larger effective color filter thickness. Improvements of SNR and crosstalk were analyzed in Figure 6 to distinguish the contribution of thicker color filters and that of reduced optical stack. It was revealed that 40% of SNR improvement from normal to lensed color filter is due to the increase of color filter thickness and the remaining 60% is explained by lowered optical stack. Contributions of thicker color filters and lowered optical stack to crosstalk reduction are 36% and 64%, respectively. Figure 7 is an example image which was

captured from the manufactured sensor. Improvement of image quality at both high and low illumination was confirmed thanks to the decreased crosstalk.

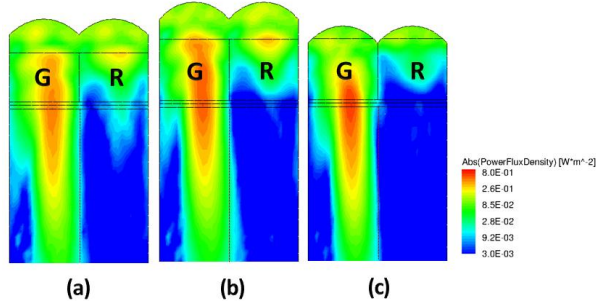


Fig. 5 Simulated beam profiles of (a) normal structure, (b) structure of thicker color filters, and (c) lensed CF.

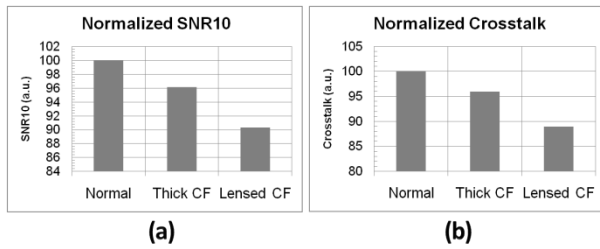


Fig. 6 Analysis of SNR and crosstalk for the structures in Figure 5

## Conclusion

In summary, the novel process technology was successfully developed, which increases effective color filter thickness and reduces optical stack without changing color filter materials. As a result, improvements of both SNR10 and crosstalk were confirmed. No degradation of PRNU and dark current was observed. The technology is promising because it provides further performance enhancement in combination with backside illumination (BSI) technology. [4, 5]



Fig. 7 Captured image of 12Mega, 1.12um pixel at 700Lux (F/2.8, D65, 33msec) with BSI sensor of lensed CF process.

	Normal	Lensed CF
SNR10 [Lux]*	155	140
Average crosstalk [%]	19	16.9
Sensitivity @Gr [e-/Lux.s]	3298	3156
PRNU [%]	1.25	1.23

\*Lens F/2.8, Lens transmittance 0.8, CCM of color error 2.5

Table 1 Comparison of pixel performances for normal and lensed CF processes.

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