0.6µm F-DTI based Quad-cell with Advanced Optic Technology for All-pixel PDAF and High Sensitivity/SNR Performance

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Abstract

Smaller pixels with high auto-focus (AF) performance are high in demand and Quad-cell (Q-cell) structure where four photodiodes (PD) are located under a single micro-lens is regarded as a solution. In this paper, we presented a 0.6µm F-DTI Q-cell CMOS image sensor with advanced optic technology such as DTI center cut (DCC) and increased thickness of DTI reflecting oxide layer (ROL). As a result, sensitivity and SNR were increased by 112% and +0.5dB, respectively compared to the conventional Q-cell and a brighter image was also obtained at low light environment.

Introduction

Recently, strong demands for smaller pixel size and better AF performance of image sensors are emerging throughout the years. Several pixel structures have been developed to ensure high AF performance. [1, 2] Among them, the Q-cell structure where one micro-lens covers four PDs enables both high resolution and high AF performance owing to their small-sized pixel and 100% AF density. In addition, full-depth deep-trench isolation (F-DTI) technology is essential to achieve low crosstalk between neighboring pixels and large full-well capacity (FWC) of small pixels. [3, 4] In this paper, we developed 0.6µm-pitch F-DTI based Q-cell and proposed advanced optic technologies to achieve high sensitivity and SNR performance.

Pixel micro-lens technology

Figure 1(a) and (b) show the schematics of Tetra-cell and Q-cell and their AF disparity performances according to illuminance. Q-cell demonstrated improved AF performance especially at low light compared to the Tetra-cell with sparse AF since all the pixels of Q-cell operate as AF pixels. However, due to the physical structure where 4 PDs are located under the single micro-lens, the light is focused on the boundary of the 4 PDs. So the signal difference between 4 pixels occurs more sensitively, and this difference is denoted as “intra tetra pixel difference”. Intra tetra pixel difference causes image quality degradation because the light entering each PD is not uniform. Generally, intra tetra pixel difference is highly affected by the mismatch of chief ray angle (CRA) between the micro-lens and the pixel arrays, and micro-lens mis-alignment. As shown in Figure 1(c), in the Tetra-cell structure, the light passing through each micro-lens reaches each PD uniformly regardless of CRA difference and micro-lens misalignment. On the other hand, Q-cell is more sensitive to these two factors than Tetra-cell, and an optimized Q-cell design suitable for these characteristics was required. In addition, in Q-cell structure, the light is focused on the DTI center of intra four pixels. Since the DTI center is composed of poly-silicon which absorbs visible light, sensitivity and SNR loss occur. Figure 2 shows the schematic and beam profile simulation of light loss from gap-filled poly-silicon.

Experimental results

In order to reduce the sensitivity loss, we applied advanced optic technologies such as DCC and increased thickness of total reflection material by thickening the DTI ROL. As shown in images in Figure 3 (a), the DCC technology, which partially removed the DTI located in the center of the 2 by 2 pixels, allowed the light entering the Q-cell micro-lens to reach the center of DTI and prevented the light lost by the gap-filled poly-silicon. Sensitivity improvement as the increment of DCC width was verified by the simulation and measured data as shown in the graph in Figure 3 (b). Furthermore, sensitivity was also improved by increasing the thickness of the DTI ROL. Images in Figure 4 (a) shows the DTI ROL between the Si and poly-silicon. Since poly-silicon has the same absorption coefficient and refractive index with Si, the light penetrating the ROL was absorbed into poly-silicon, which reduced sensitivity loss. As the thickness of ROL increased, the poly-silicon area was reduced and the reflected light also increased. As shown in Figure 4 (b), QE improvement as the increment of the thickness of ROL was confirmed from the optical simulation and measurement data. Figure 5 (a) shows the normalized QE of the conventional and advanced Q-cell according to the wavelength. The QE peak and overall sensitivity of the advanced Q-cell were improved by 12% compared to the conventional Q-cell with non-DCC and thin DTI ROL. Photographic images in Figure 5(b) also showed that a brighter image was taken in advanced Q-cell owing to the improved sensitivity and SNR. Major pixel characteristics of the conventional and advanced Q-cell are summarized in Table 1. These results demonstrated that high sensitivity and SNR were implemented in 0.6μm Q-cell structure with high AF performance.

Conclusion

In conclusion, we have proposed advanced optic technologies such as DCC and thick DTI ROL and achieved high sensitivity and SNR of 0.6μm F-DTI Q-cell. The sensitivity and SNR have dramatically improved, reaching up to 112% and +0.5dB compared with the conventional Q-cell. This advanced Q-cell with high AF performance can be essential technology for high sensitivity and SNR of CMOS image sensors in the future.

References

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Figures

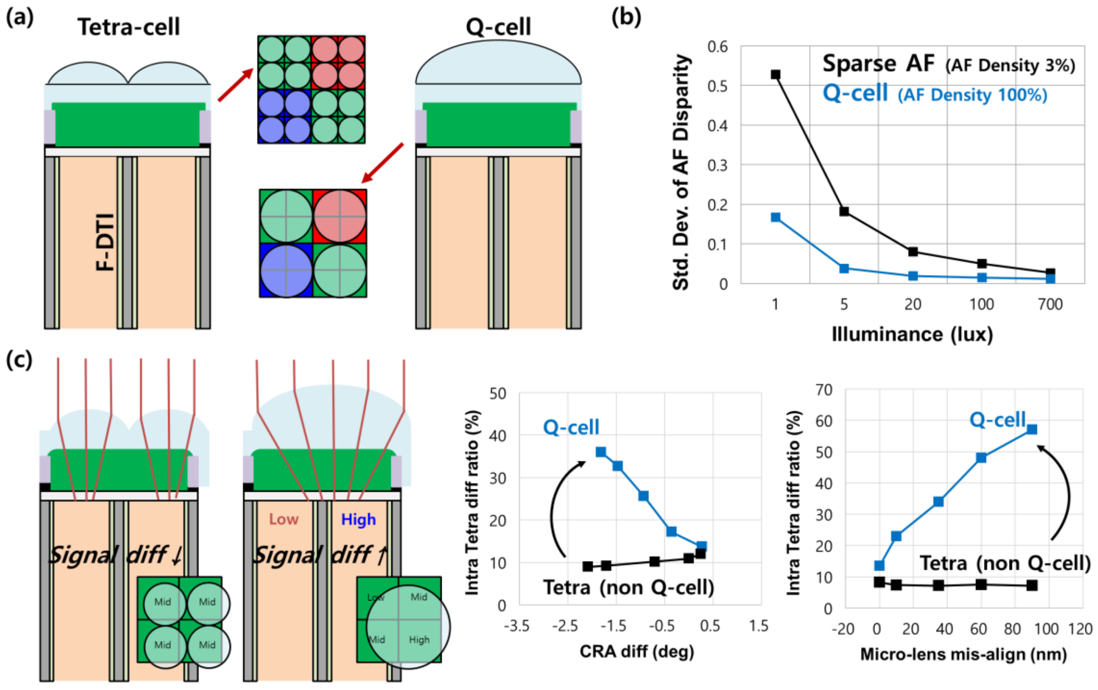

Figure 1. (a) Schematics of Tetra-cell and Quad-cell (Q-cell). (b) Standard deviation of AF disparity of Q-cell and Tetra-cell according to illuminance. (c) Tetra difference according to CRA mismatch and mis-alignment of micro lens.

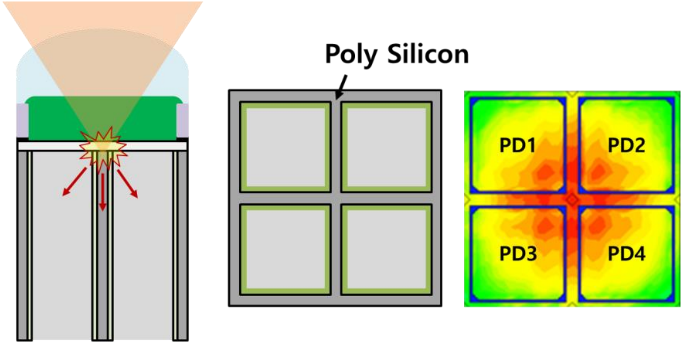

Figure 2. Schematic and beam profile simulation of light loss from poly-silicon.

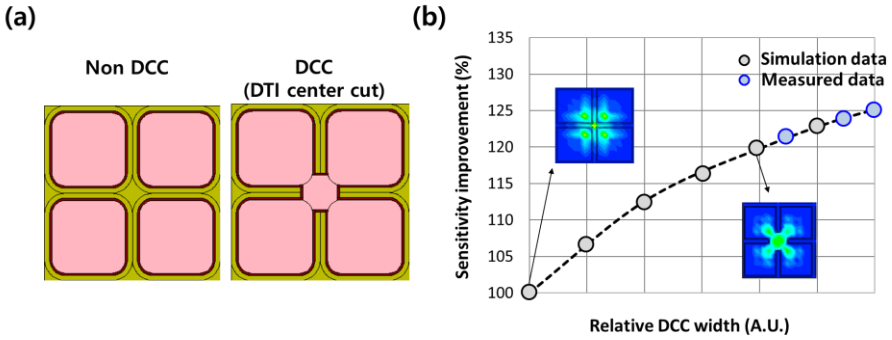

Figure 3. (a) Non DCC and DCC images. (b) Sensitivity improvement according to the DCC size.

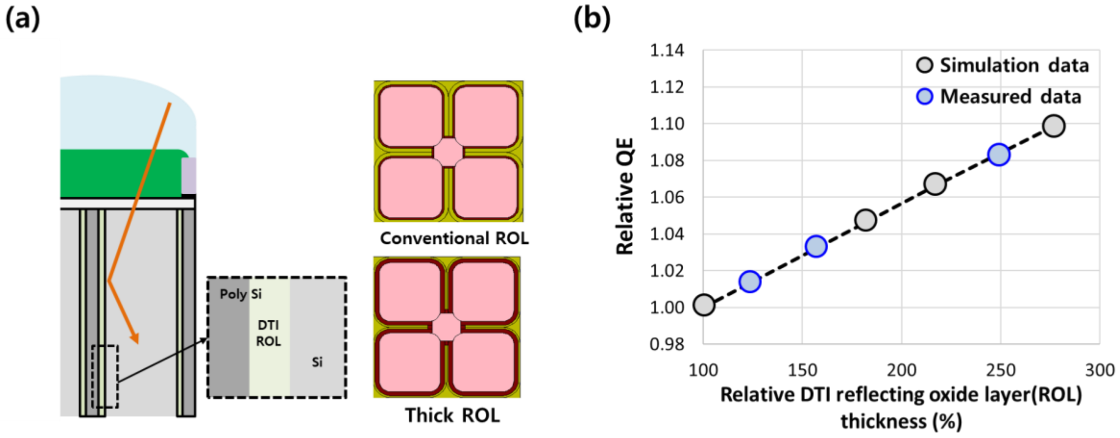

Figure 4. (a) Schematics of DTI reflecting oxide layer (ROL). (b) Relative quantum efficiency (QE) according to the DTI ROL thickness.

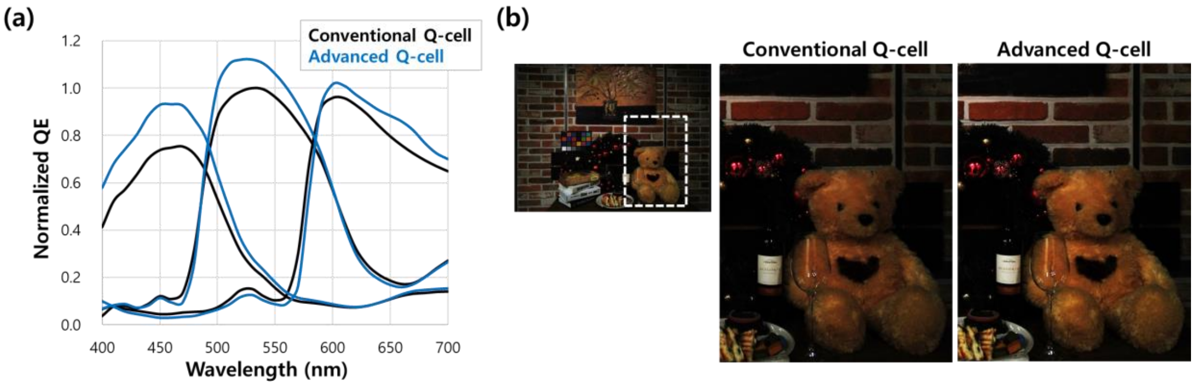

Figure 5. (a) Normalized quantum efficiency and (b) Photographic images of conventional and advanced Q-cell. The photographic images were taken at low light illuminance of 10lux.

	unit	Conventional Q-cell	Advanced Q-cell
Pixel Size	*μm*	0.6	0.6
Sensitivity	*%*	100	112
SNR	*dB*	-	+0.5
AF density	*%*	100	100
AF contrast ratio	-	2.75	2.6
Intra Tetra diff ratio	*%*	29	26
Gr/Gb ratio	*%*	2.2	2.0

Table 1. Characteristics of the conventional Q-cell and new Q-cell.