Hybrid Optical Structure with 1x1 and 2x2 Micro-lens Mixed Array for Image Resolution Improvement

Gyeong Jin Lee[1], Hyungeun Yoo[1], Wooseok Choi[1], Jina Kim[1], Sangwoo Lee[1], Sungho Gil[1], Seunghyeok June[1], Hyungchae Kim[1], Yujeong Baek[1], MinYoung Jung[1], Junga Koh[1], Wonjun Kang[1], EuiYeol Kim[1], Jungbin Yun[1], Bumsuk Kim[1], and Kyungho Lee[1]

[1]System LSI Division, Samsung Electronics Co., Ltd.

Hwaseong-si, Gyeonggi-do, Korea. TEL: +82-31-8037-3063, e-mail: g.j.lee@samsung.com

Abstract

This study demonstrates a CMOS image sensor (CIS) with a hybrid optical structure which combines the benefits of Quad-cell and sparse AF optical structure. The hybrid structure has 1x1 micro-lenses to the green channel for low intra-channel signal differences (Ch diff) and better resolution and 2x2 micro-lenses to the red and blue channels for phase-detection auto-focus (PDAF). Serifs of micro-lens patterns are modified to reduce deformation caused by loading effects during micro-lens etching process. The hybrid structure shows improved sensitivity, signal-to-noise ratio (SNR), and intra-channel differences compared to Q-cell, with the green channel showing less than one-fifth of Ch diff than Q-cell. Measurements of the modulation transfer function (MTF) and real-image comparisons demonstrate that the hybrid structure provides better resolution and more detailed expression than Q-cell.

Introduction

Recently, CISs have been equipped with all pixel PDAF due to its superior PDAF performance. When it compared with sparse AF optical structure, they maintained stable PDAF performance even in the low light environment [1].

Q-cell is an optical structure which has 2x2-shared micro-lens; four pixel shares one micro-lens. This structure is able to perform PDAF in all pixel even vertical direction not to mention about horizontal direction [2]. Due to its features, Q-cell have become a representative structure for all pixel PDAF.

However, Q-cell has inherent Ch diff and loss of full mode resolution compared with 1x1 micro-lens optical structure with sparse AF as described in Figure 1(a). Unlike sparse AF structure, Q-cell is more sensitive to spot shift which leads to Ch diff increase; furthermore, sampling point overlap in Q-cell structure resulting in resolution loss at full mode.

In this paper, we developed 1x1/2x2 micro-lens hybrid optical structure (Hybrid) to combine the advantages of two optical structure; Q-cell and sparse AF optical structure. By applying 1x1 micro-lens on green channel and 2x2 micro-lens on red and blue channel, we tried to harness the strong point of both optical structure; sparse AF and Q-cell. 1x1 micro-lens on green channel confers low Ch diff resulting in lesser resolution loss during image signal processing (ISP) and better full mode resolution. 2x2 micro-lens on red/blue channel performs PDAF (Figure 1(b)).

Formation of Hybrid Optical Structure

Hybrid has heterogenous pattern on micro-lens layer composed of 1x1 and 2x2 micro-lens array. As shown in Figure 2, we've observed deformed micro-lens array compared with Q-cell which has homogenous 2x2 micro-lens pattern.

It was thought that the deformation of micro-lens derived from loading effect during micro-lens etch process [3]. The balance between inflow of etchant and outflow of byproduct during the etch is affected by the dimension of etch pattern; the dimension is determined along with the layout. Changes in the balance along with the layout

leads to different etch rate.

To circumvent this phenomenon, all dimensions should be equal to make uniform pattern. As a solution for it, serifs have been applied to every 1x1 and 2x2 micro-lens pattern. By applying serifs, the deformation was suppressed comparing with Hybrid w/o serif. It was also noticed that deformed micro-lens affected spectral response (SR) as shown in Figure 3(a). Based on this phenomenon, we have designed layout of the serifs to improve sensitivity.

Characteristics of Hybrid

We analyzed that area of each lens affected SR. The analysis about comparing the area of micro-lens between Q-cell and Hybrid revealed that 1x1 lens cluster has bigger area than 2x2 lens of Q-cell, while the area of 2x2 lens of Hybrid has slightly bigger area than that of Q-cell (Figure 3(b)). By adjusting the serifs, sensitivity of green channel is improved by 10% when it compared with the sensitivity of Q-cell as shown in Table 1.

In Table 1, characteristics of Hybrid are summarized. It demonstrated superior performance in terms of sensitivity, SNR, Ch diff. Hybrid has earned 10% better sensitivity, 0.2dB higher SNR comparing with Q-cell. When it comes to Ch diff, green channel has less than one fifth level than Q-cell due to its 1x1 lens structure. It requires lesser correction algorithm power resulting in smaller ISP block and better full mode resolution. In addition, the Ch diffs of red/blue channel showed similar level with those of Q-cell.

To confirm the effect of resolution improvement, MTF measurement and qualitative assessment based on real image were conducted. As shown in Figure 4(a), the measurement of TE42 Siemens star chart demonstrated that Hybrid has ~13% better MTF25 than Q-cell. Real image comparison also demonstrated that Hybrid has better resolution and showed more detailed expression. When it comes to cropped images, unlike Q-cell displaying blurry character, Hybrid showed clear image and character.

Conclusion

In conclusion, we have proposed CIS with hybrid optical structure harnessing the benefits of Q-cell and sparse AF optical structure. Hybrid demonstrated improved sensitivity, signal-to-noise ratio (SNR), and lower green Ch diff compared to Q-cell. MTF and real-image comparisons demonstrated that Hybrid provides better resolution and more detailed expression than Q-cell confirming superiority of hybrid optical structure.

References

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[2] J. Pyo et al., A Smart Dual Pixel Technology for Accurate and All-Directional Auto Focus in CMOS Image Sensors, International Image Sensor Workshop (IISW) (2021)

[3] M. Wu et al., Leakage in CMOS devices induced by pattern-dependent microloading effect, 2012 10th IEEE International Conference on Semiconductor Electronics (ICSE) (2012)
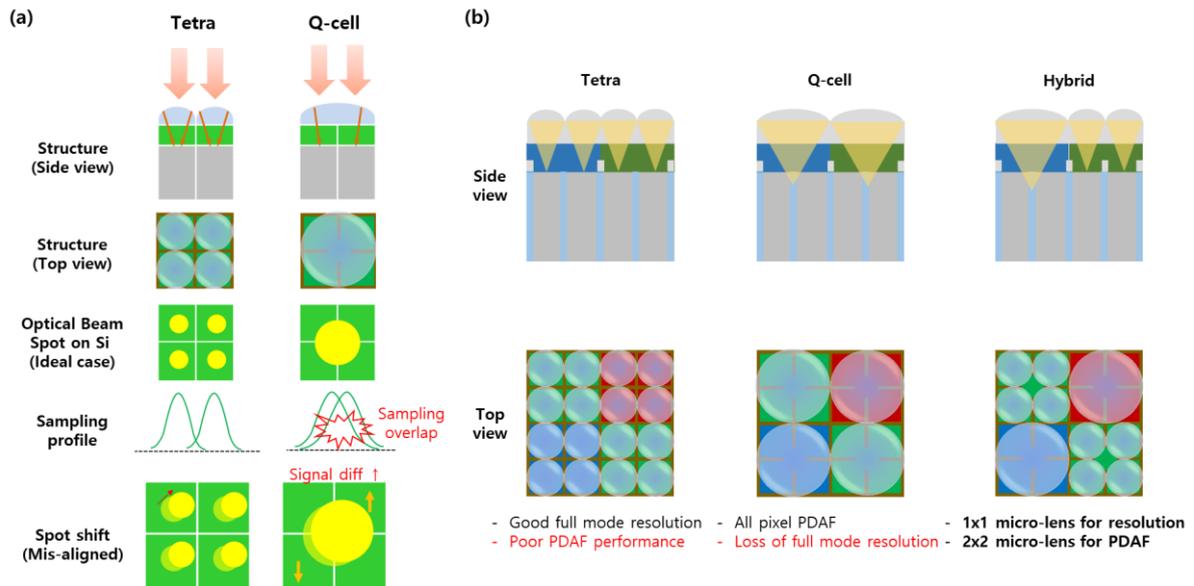
Figures

Figure 1. (a) Schematic diagrams of Tetra and Q-cell structure, sampling profile, and spot shift for intra channel signal difference. (b) Schematic diagrams of Tetra, Q-cell and Hybrid optical structures with the pros and cons.
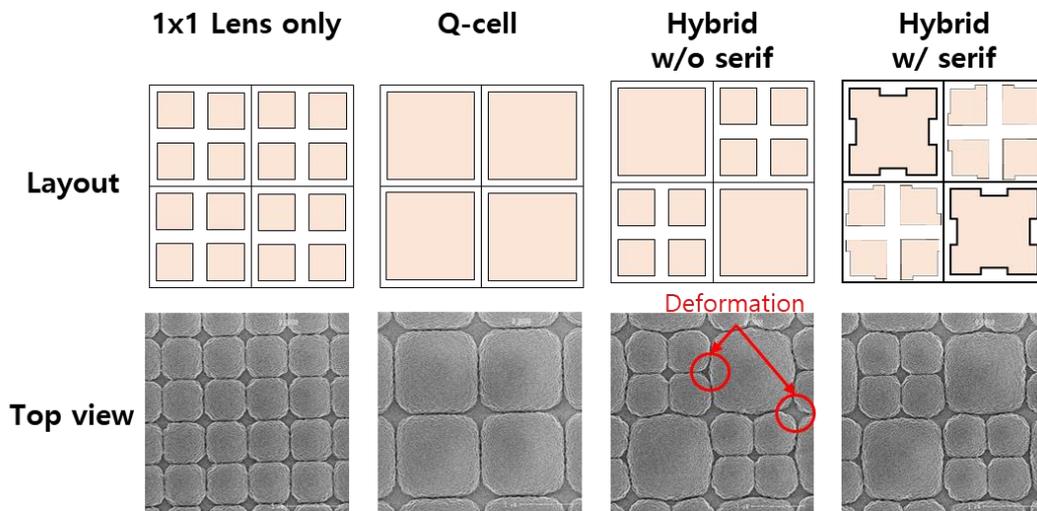

Figure 2. Micro-lens layouts and resultant top view images of 1x1 lens only, Q-cell, Hybrid w/o serif, and Hybrid w/ serif.
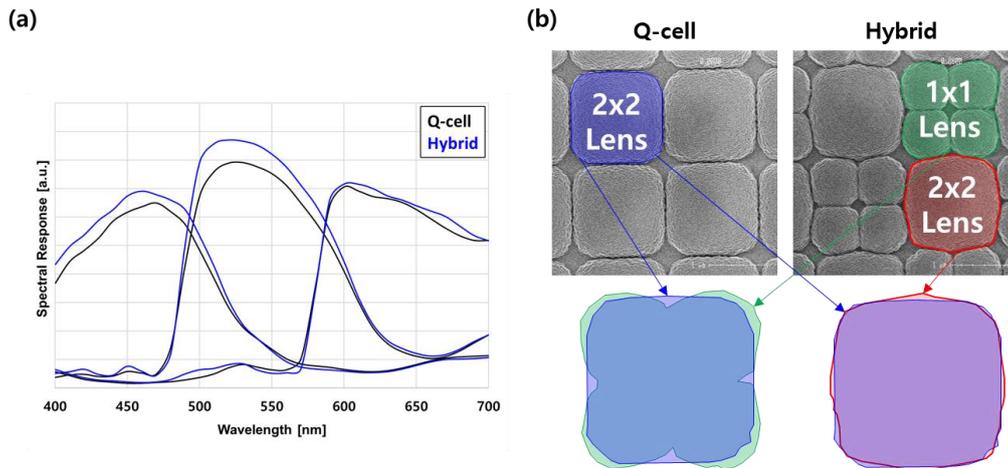
Figure 3. (a) Spectral response of Q-cell and Hybrid. (b) The analysis on the micro-lens area between Q-cell and Hybrid.
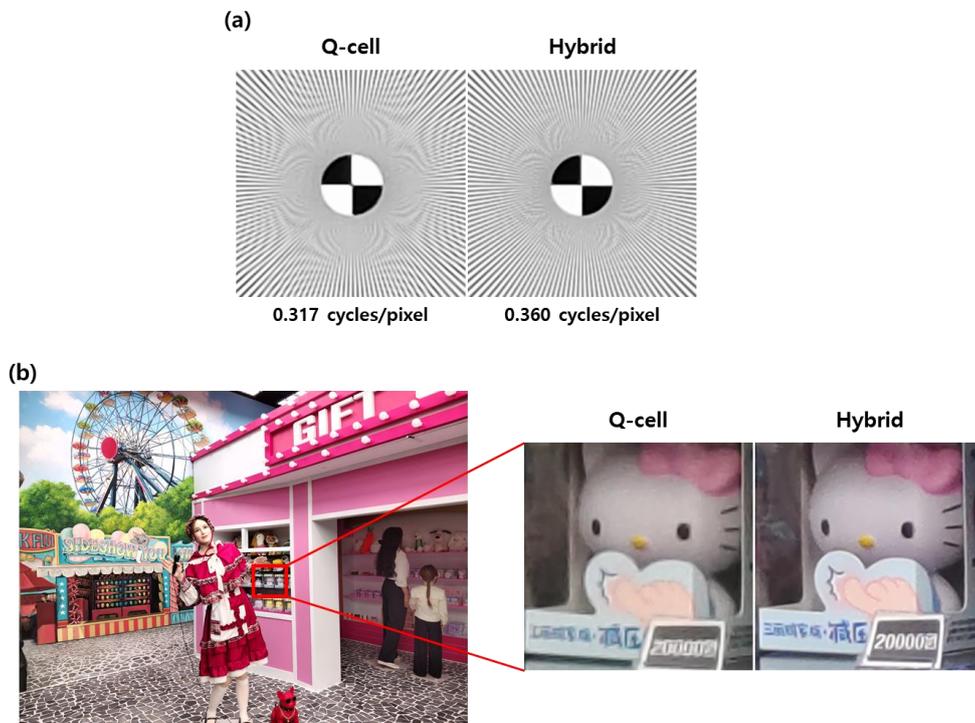

Figure 4. (a) TE42 Siemens star chart measurement result of Q-cell and Hybrid. Numbers mean MTF25 value. (b) Cropped images of qualitative assessment for full mode resolution and detail expression evaluation.

	unit	Q-cell	Hybrid
Pixel size	μm	0.8	0.8
Sensitivity	%	100	110
SNR	dB	-	+0.2
AF density	%	100	50
AF contrast ratio	-	2.5	2.4
Intra Channel diff	%	100	19 (Green) 96 (Blue/Red)
GrGb diff	%	100	100

Table 1. Characteristics of Q-cell and Hybrid. Sensitivity, Intra Channel diff, and GrGb diff are displayed as relative value.