On Chip Optics Solution on Small Pixel CIS S/N Ratio Improvement

Chih-Ching Chang [(a)], Wu-Cheng Kuo , Ken_Wu , Yu-Kun Hsiao, JC_Hsieh.

VisEra Technologies Company, No12, Dusing Rd.1, Hsinchu Science Park, Taiwan (30078)
[(a)]E-mail: Allen_Chang@viseratech.com
Tel. : +886-3-6668788
Fax : +886-3-6662858

Abstract—

On-chip color filters are the necessary component for CMOS image sensors (CIS). To meet the demand of high array resolution and chip miniaturization, pixel size shrinkage is the development trend. When scaling down the pixel size, the sensitivity degradation and cross-talk from neighboring pixels are the challenges.

In this study, we develop an innovative and flexible process to demonstrate our concepts: The color filter array (CFA) must be separated by a matrix grid that increases the sensitivity and suppresses the cross-talk. Not only dimension and spectral of CFA but also the interaction of refractive index between CFA are the key factors in sensitivity. Metal grid is implanted to suppressing cross-talk but high absorbed rate in light is the shortcoming.

This study will discuss grid dimensions, different refractive index of grid and the relative position between CFA and photo diode. Through the Finite Difference Time Domain (FDTD) simulation model, we design the structures and judge the performance. Quantum efficiency and angular response will be considered and measured by the test vehicle of 1.1um pixel BSI technology.

Keywords—Pixel isolation, Matrix grid, S/N ratio.

I. INTRODUCTION

It is well known that there are four indexes to evaluate the performance of CIS: sensitivity, cross-talk, SNR10 & CRA[1,2]. Sensitivity degradation and cross-talk increasing from neighboring pixels are the major challenges for every CIS manufacturer. Grid structure is the usual practice to suppress cross-talk. Metal grid in BSI and oxide grid in FSI are for the same purpose. But metal grid will affects sensitivity due to its high absorbed rate in light [Fig 1].

An integration solution had been proposed in the former study [3]. The matrix grid has a lower refractive index than that of the plurality of color filters between pixel to pixel arrays. This matrix grid is considered as total internal reflector (TIR) between pixels. That could reflect the oblique incident light back to the targeted unit pixels. Our studies can be divided in three parts as explained in figure 2 that include (1) grid dimensions [Fig2-①], (2) different refractive index of grid [Fig2-②] and (3) the relative position between CFA and photo diode [Fig2-③].

II. GRID PROCESS INTEGRATION DESCRIPTION

In this study, we demonstrate the matrix grid in 1.1um pixel BSI technology. Fig.3.(a) is the simplified process flow that only needs one “photolithography” and “Etch” steps.

Matrix grid is performed on the protection oxide film that processes after metal grid structure. A matrix grid material disposes on the protection oxide film and form a plurality of holes through the Photolithography and Etch steps. For obtaining the best S/N ratio performance, the width/pixel size ratio is 15~18% [1]. A standard color filter process fills into the grids and forms a zero gap micro lens on color filter.

Cross-section inside matrix grid is shown on Fig.3.(b). The matrix grid was integrated in 1.1um pixel BSI technology. It is also realizable to embed the matrix grid in the metal grid structure like Fig.4. Before filling color filter in the embedded matrix grid, an anneal process is necessary to avoid the degradation on dark current and white pixel number that caused by over etch in protection oxide film.

We used a coating type organic material as the matrix grid material. That made the process is flexible to adjust the refractive index of grid to get the best optical performance.

III. OPTICAL SIMULATION & QUANTUM EFFICIENCY

We use Finite Difference Time Domain (FDTD) simulation model to design the structures and judge the performance with the quantum efficiency (QE) and angular response. The designed structure has realized in 1.1um BSI technology and collects QE to verify the performance.

Fig.5. shows the simulation results of QE and angular response after processing matrix grid. Grid structure is helpful in the QE improvement of green and blue but has an adverse effect in Red. Angular response of grid structure is also better than that structure without grid. The results of measurement in fig.6 are quite to close to that of simulation. That means there is a strong relation between our simulation and measurement data.

In the former study, 15~18% in width/pixel ratio will obtain the best S/N ratio performance. The measurement data of different width/pixel ratio is as show in fig.7. It appears that width / pixel ratio=15%

effectively increase the QE peak mainly in Green and Red. Even optimizing the width / pixel ratio, red peak of matrix grid is still lower than that without grid structure. We believe that the effect of total internal reflector in red pixel is less than that of the confinement from different refractive index in blue, green and red.

For reducing the optical path, one solution that color filter embedded into metal grid has been proposed. This embedded scheme has good performance in angular response performance but bed QE performance in red, green & blue. High absorbed rate in light of metal grid dominate the QE and angular response in this color embedded scheme. Through adjusting the matrix grid depth, the same angular response performance can be reached as show as fig.8. (b). The QE of grid with depth adjusting is only a little lower than that of matrix grid [Fig.8. (a)]. The real measurement data of grid with depth adjusting appear in Fig.9. QE performance of the grid with depth adjusting can be comparable with that of matrix grid by a critical depth. That mean the grid depth must be optimized to get best performance.

Lower refractive index of grid matrix is one of possible solution for further study. Table1 is the summary of optical index performance when decreasing the refractive index of grid from 1.4 to 1.2. There is no obvious improvement in G sensitivity and SNR10. We think different structure designs and integrations in different refractive index of color filter can find out the possible solution for further study.

IV. CONCLUSION AND DISCUSS.

Grid matrix has obvious improvement in QE and angular response. 15~18% in width/pixel ratio will obtain the best S/N ratio performance in green and blue pixel. It needs more study in the confinement from different refractive index in blue, green and red. Adjusting the ratio of depth/grid height is a total solution in QE and angular response when reducing the optical path in vertical direction. High depth/grid height ratio is not the best solution, so it must be optimized. For the grid structure in 1.1um BSI technology, there is no obvious benefit to use lower refractive index (n <1.4). We will keep finding the possible solution in it.

V. ACKNOWLEDGMENT.

The authors would like to thank the dedicated IC foundry-tsmc for test wafers. Thanks are extended to all members of the R&D group for their effort in design, test and process development.

REFERENCER

[1] Nobukazu Teranishi, Hisashi Watanabe, Takehiko Ueda, and Naohisa Sengoku, "Evolution of Optical Structure in Image Sensors", IEDM 2012.

[2] Tomoko Komatsu, Kyto, Toshihiro Higuchi, Osaka, "Solid Stats Imaging device and Fabrication method thereof, and camera incorporating the solid state imaging device", US8139131 B2, Mar. 20, 2012.

[3] Chi Han_Lin, Chih-Kung Chang, Yu-Kun Hsiao, Yueh-Ching Cheng, Chih-Cherng Jeng, Kuo-Cheng Lee, Chun-Hao Chou, Yi-Yi Cheng, Yen-Hsung Ho, Yin-Chieh Huang, Chin-Chuan Hsieh, "1.1um Back-Side Illuminated Image Sensor Performance Improvement", IISW 2013.

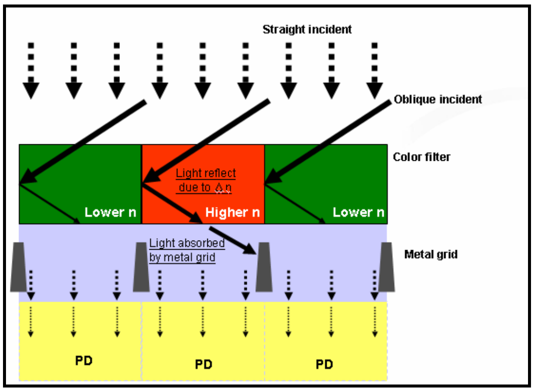

Fig.1. Cross-section scheme of BSI CMOS image sensor

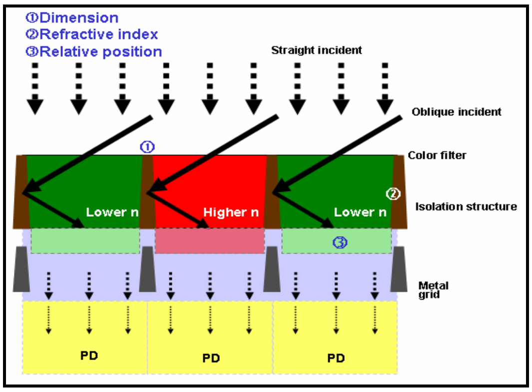

Fig.2. Cross-section scheme of matrix grid in BSI

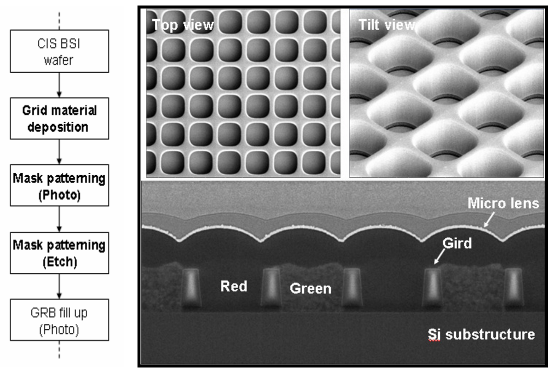

Fig.3 (a) Fig.3 (b)

Fig.3. Matrix grid structure (a) Process flow and (b) Color isolation by matrix grid.

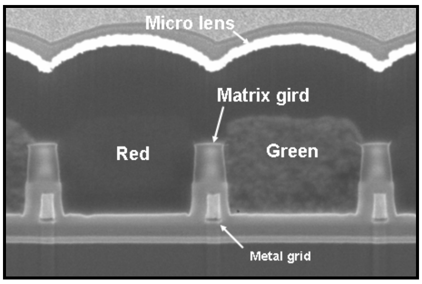

Fig.4. Cross-section view of grid with metal grid

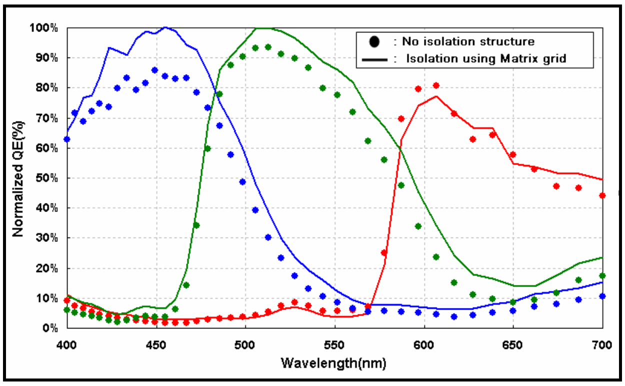

Fig.5. (a) Quantum efficiency

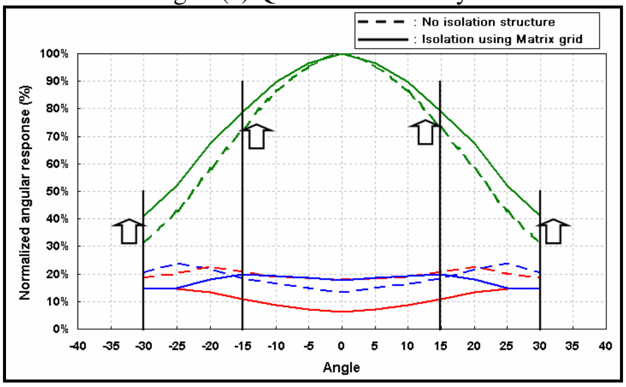

Fig.5. (b) Angular response

Fig.5. The optical simulation comparison of no isolation structure and isolation using matrix grid under different wavelengths. (a) QE (b) angular response

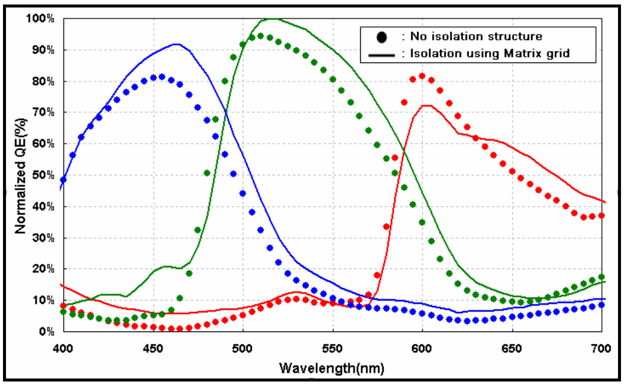

Fig.6. (a) Quantum efficiency

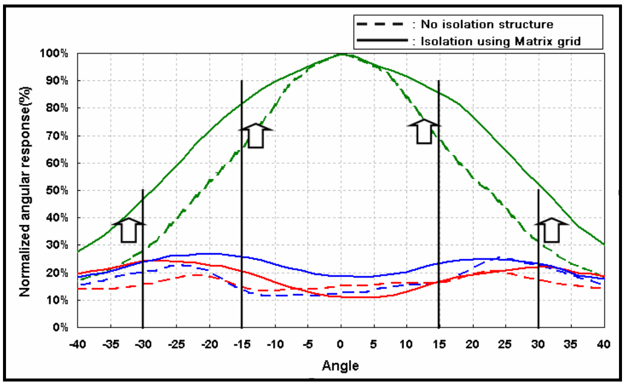

Fig.6. (b) Angular response

Fig.6. The real measurement of no isolation structure and isolation using matrix grid under different wavelengths. (a) QE (b) angular response

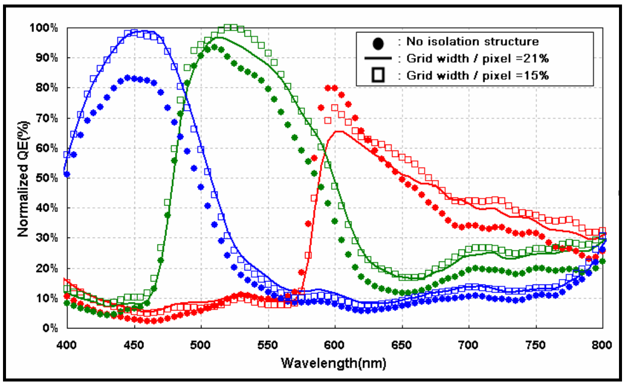

Fig.7. The real measurement of normalized QE vs. grid width/ pixel ratio

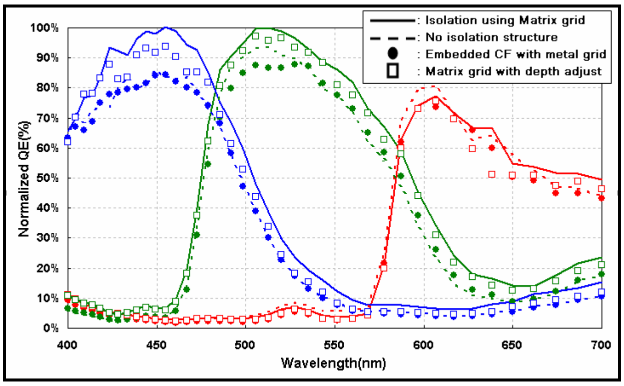

Fig.8. (a) Quantum efficiency

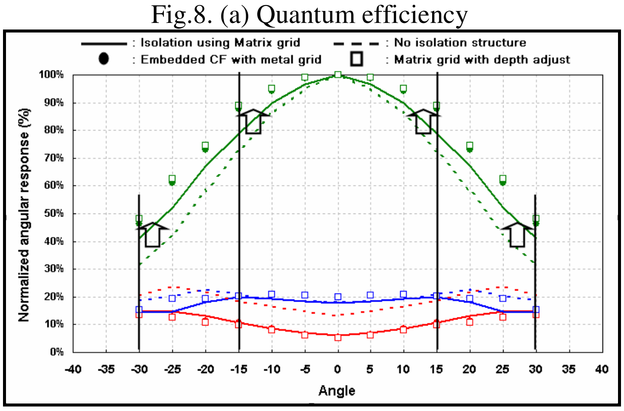

Fig.8. (b) Angular response

Fig.8. The optical simulation comparison of different scheme designs for optical path reduction

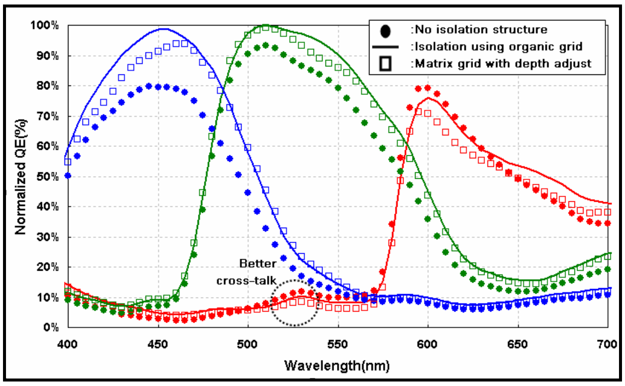

Fig.9. The real measurement of QE between different scheme designs for optical path reduction

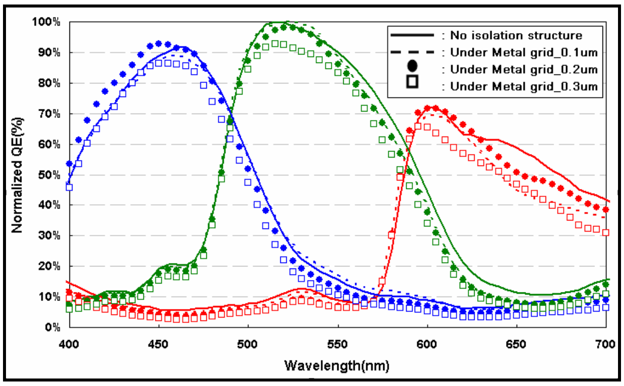

Fig.10. The real measurement of QE between different scheme grid depth adjusting

Refractive index of grid	Optical index	Depth / Grid height (Ratio)				
		0.00	0.19	0.29	0.38	0.50
n=1.4	G sensitivity (Normalized ratio)	1.00	0.97	0.96	0.93	0.93
n=1.2		0.98	0.97	0.96	0.93	0.93
n=1.4	SNR10 (Normalized ratio)	1.00	1.02	1.03	1.07	1.04
n=1.2		0.99	1.02	1.03	1.07	1.04

Table1 The summary of optical index performance between different refractive index of grid