1.1um Back-Side Illuminated Image Sensor Performance Improvement

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Abstract—

This paper describes the results of S/N ratio improvement on solid-state imaging device. The experiments are implemented on 1.1um 3M BSI sensor.

Usually, metal grid is implemented in BSI CIS product to reduce the optical crosstalk and oxide grid is implemented in FSI product for same purpose. Metal grid absorbs the scattering light without reflecting the light due to high k (extinction coefficient) of metal. From our simulation, device with metal grid gets better crosstalk but suffers lower sensitivity because that partial incident light is absorbed by metal grid which impacts S/N ratio performance. Oppositely, device with low n (refractive index) grid which is a total reflection structure improves the sensitivity and S/N ratio but suffers poor crosstalk.

A new solid-state imaging device comprising low n grid, metal grid, the specific color material and microlens profile is illustrated and works for S/N ratio improvement. In the device, the low n grid performs total reflection structure similar with the light pipe and stands on the top of metal grid. The color filter material with specific refractive index is filled into the space between low n grids.

Finite Difference Time Domain (FDTD) is used to simulate the optimization of such new structure development including the profiles and structures of low n grid and metal grid, the pixel structure under the color filter and n, k of color material, ….and so on.

As a result of the simulation, obvious improvement of S/N ratio (10 db) is achieved on the 1.1um 3M BSI image sensor after the optimization.

Keywords— S/N ratio, low n grid BSI, CIS, image sensor improvement

I. INTRODUCTION

Pixel sensitivity for receiving the incident light is lowered with the trend of size reduction of pixels of the CMOS image sensors and cross-talk is caused between different pixels with incident light, especially in the BSI CMOS image sensors. A method for resolving the cross-talk issue is forming a metal grid disposed under color filters. The metal grid would absorb (or block) the incident light such that the incident light would not diffuse to the neighboring pixels. The cross-talk issue can be substantially reduced by the formation of the metal grid, but the quantum efficiency of the BSI CMOS image sensors is affected since a portion of the incident light absorbed by the metal grid cannot reach the photodiode array [Fig 1(a)].

A low n grid that has a refractive index lower than that of the plurality of the color filters between pixel to pixel array. The low n grid may reflect the incident light diffusion such that a portion of the incident light may diffuse to neighboring pixels can be reflected back to the targeted unit pixels [Fig1 (b)]. In addition, a portion of the incident light that may be absorbed by the metal grid may be reflected by the low n grid before the incident light reaches the metal grid. For example, the metal grid may mainly block the incident light by absorbing it and the low n grid may mainly block the incident light by reflecting it. Thus, by forming the low n grid, the size of the metal grid may be reduced without deteriorating the cross-talk, so that only few portion of the incident light may be absorbed by the metal grid. The BSI CMOS image sensor according to the present embodiment may have enhanced quantum efficiency with low cross-talk. In addition, the metal grid may have an extinction coefficient greater than zero for blocking the incident light diffusion.

II. LOW N GRID DESIGN

The low n grid are designed base on 1.1um 3M BSI sensor. The original structure without low n grid is showed in Fig2 (a). Two types of low n grids materials and structures were designed after FDTD simulation and the structure is showed in Fig2 (b).

The first design of low n grid is CVD oxide grid. The back surface illuminated CMOS image sensor includes a photodiode array; a passivation layer disposed on the photodiode array; a CVD oxide grid disposed on the passivation layer and forming a plurality of holes exposing the passivation layer [Fig2 (c)]. A color filter array including a plurality of color filters filled into the holes, wherein the oxide grid has a refractive index (~1.46) lower than that of the plurality of color filters (>1.6) [Fig2 (b)]. And a metal grid disposed in or under the oxide grid, wherein the metal grid has an extinction coefficient greater than zero.

The second design of low n grid is organic low n grid. The back surface illuminated CMOS image sensor includes a plurality of unit pixels, each unit pixel includes a photodiode and at least one pixel transistor; a plurality of color filters patterning on the unit pixels. Isolated CF unit pixels were designed in the structure and a specific space exist between the CF unit pixels. Fig2 (d) is isolated color filter stand on unit pixel, Fig2 (e) is the color-to-color space designed by simulation for organic low n material filled into [Fig2 (b)]. An organic material with low n characterization is spread and fills into the space by spin coating process, wherein the organic material has a refractive index (~1.25) lower than the color filters, and perform a total refraction.

III. OPTICAL SIMULATION MODEL

Finite Difference Time Domain (FDTD) is used to simulate the optimization of such new structure development including the profiles and structures of low n grid and metal grid, the pixel structure under the color filter and n, k of color material, ….and so on.

Fig.3 is the comparison between FDTD simulation and measured QE curve. The result of measurement is quite to close to simulation.

The red QE curve at 470nm~530nm wavelengths has 5% gap between simulation and measured QE spectrum curve. This difference might derive from test vehicle characteristics. It does not affect the validity of FDTD simulation model in the paper. Therefore, we use this FDTD simulation model to design low n grid structure and judge the performance with the sensitivity and S/N ratio (10db).

IV. RESULT

The low n grid was designed to obtain the best S/N ratio performance.

In our simulation model, color filter thickness was defined first based on the QE spectrum of the device. Different CVD oxide grid height was designed in the structure and performed different S/N ratio performance. The best S/N ratio performance will be obtained when the oxide grid height equal to the color filter thickness. In the conditions of different oxide grid width, it still got the same result. In the other word, the oxide grid height will be determined by chosen color filter thickness. The result is showed in the Fig. 4.

The same concept was used for the design of oxide grid width. The S/N ratio will be changed alone with different grid width. The best S/N ratio performance will be obtained in the condition of 15~18% width/pixel size ratio by different grid height. The result is showed in the Fig.5. Based on the simulation, it is independent between oxide grid height and width under the best S/N ratio performance consideration.

Another similar structure was designed to replace the low n grid is an organic material. Compared to CVD oxide, adjustable refractive index and more flexible process is the ascendant to achieve lower S/N ratio (10db). An organic material with lower refractive index (~1.25) was chosen to be a low n grid material. It performs better S/N performance compared to oxide grid because of lower n characterization. Fig.6 is the S/N ratio comparison between these 2 structures. In different grid width design, organic low n grid always perform better S/N ratio than oxide grid.

Low n grid was designed to achieve best S/N performance based on the above simulation result. Compare to the device with metal grid only, an extra oxide grid stand on metal grid can improve S/N ratio (db10) around 14%. If it replace to low n organic material, S/N ratio (db10) will improve around 16.7%. The result is showed in Fig7.

V. CONCLUSION AND DISCUSS.

CVD oxide (refractive index 1.46) is a common material in semiconductor, with a relative low refractive index compare to color filter material (refractive index >1.6). The 1st structure we process CVD oxide as low n grid material and then fill color filter by spin coating process. Simulation showed both sensitivity and S/N ratio got significant improvement. The oxide grid dimensions (height/width/slope) will constrain color filter dimensions and also the refractive index difference between CF and low n grid will be a constant. Both of the limitation will reduce the CF process flexibility. Once the Si structure was fixed, it means the sensitivity and S/N ratio are also constrained unless we change the color filter material.

We try to use a coating type organic material to be a low n grid material. The advantage is that we can adjust the dimensions of CF and low n grid rapidly and even we can change low n grid material to have different refractive index and get the best optical performance. We defined color pixel first then fill low n material to the space between color pixel arrays. Etch back process will be performed to remove the material above color pixel. From the simulation data, a low n organic material with refractive index 1.25 will get a better sensitivity and S/N ratio result compared to the CVD oxide grid.

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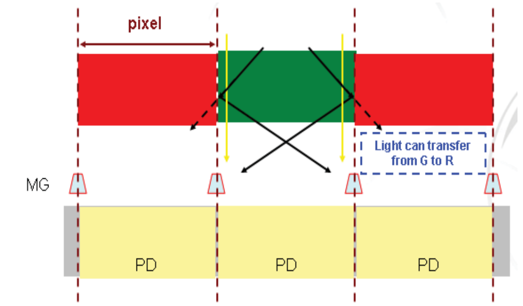


Fig1 (a)

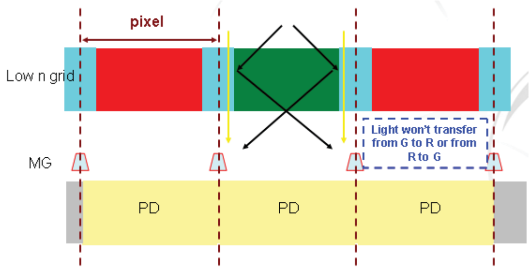
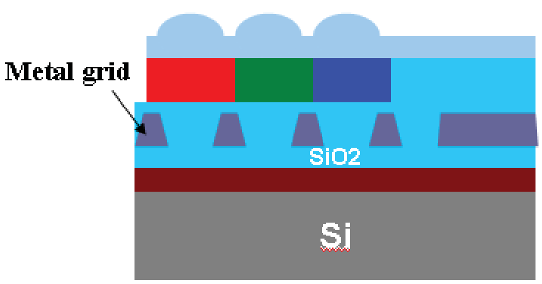
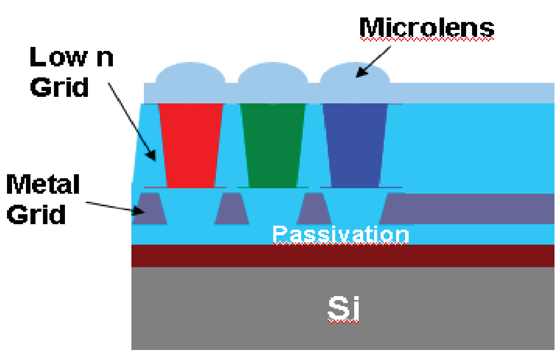


Fig1 (b)

Figure1: (a) Structure with low n grid (b) Structure with low n



(a)



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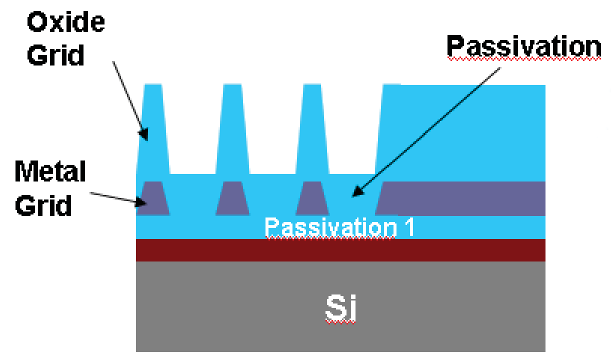
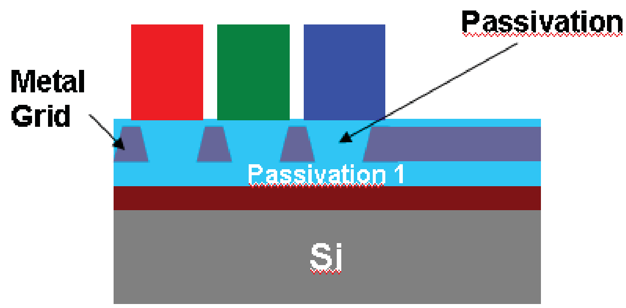
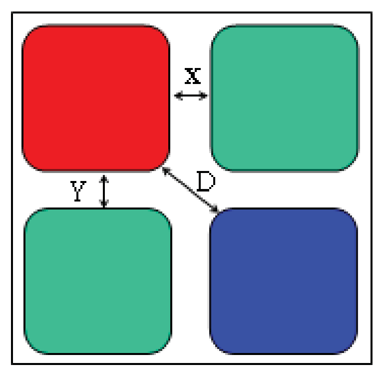


(c)



(d)



(e)

Figure2: (a) Structure without low n grid (b) Structure with low n grid. (c) A plurality of holes exposing the passivation layer (d) A isolate and plurality of color filters unit pixel. (e) Isolated CF design in organic low n grid structure, X,Y and D is space between color filter unit pixel.

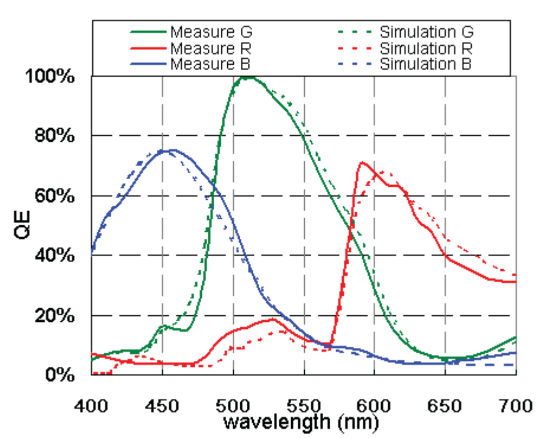


Figure3: The comparison between simulation and measurement under different wavelengths.

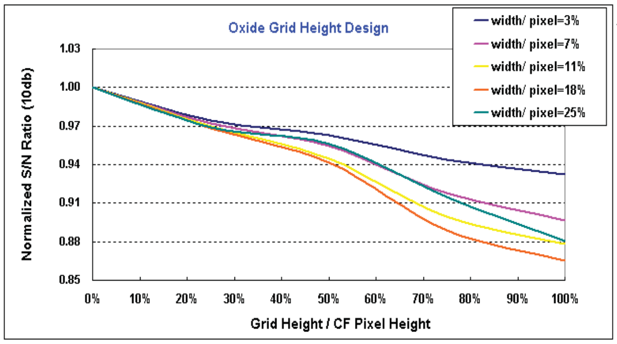


Figure4: Normalized S/N performance vs grid height under different grid width/pixel size (1.1um). under (1) grid width/CF pixel is 3%, (2) grid width/CF pixel is 7%, (3) grid width/CF pixel is 11% and (4) grid width/CF pixel is 18%, (5) grid width/CF pixel is 25%.

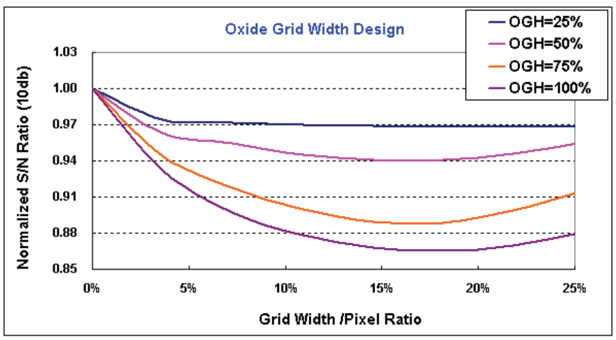


Figure5: Normalized S/N performance vs grid width/ pixel ratio under (1) grid height/CF thickness is 25%, (2) grid height/CF thickness is 50%, (3) grid height/CF thickness is 75% and (4) grid height/CF thickness is 100%.

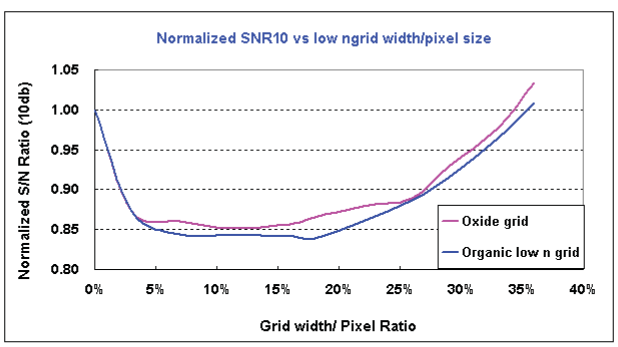


Figure6: Normalized S/N ratio (10db) vs different width/pixel size (1.1um) under (1) organic low n grid structure and (2) oxide grid structure

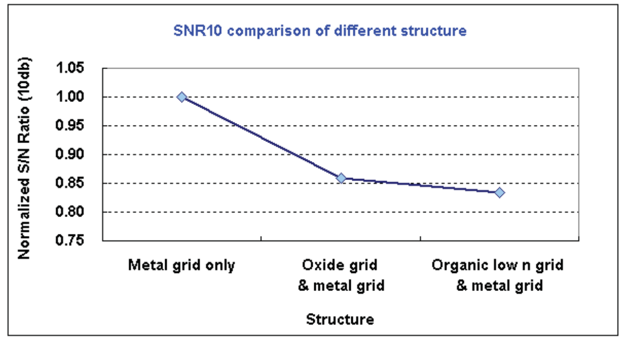


Figure7: Normalized S/N ratio (10db) comparison of different structure.