Paper ID : P10

CMOS Pixels Crosstalk mapping and Modulation Transfer Function

Authors : M.Estribeau, P.Magnan
SUPAERO – CIMI Laboratory
Mailing address : P.O. Box 54032, 31055 TOULOUSE Cedex 4, France
Street address : 10, avenue Edouard Belin, 31400 TOULOUSE, France
Telephone : +33.5.62.17.82.51 *Fax :* +33.5.62.17.83.45 *E-mail :* magali.estribeau@supaero.fr
Telephone : +33.5.62.17.80.79 *Fax :* +33.5.62.17.83.45 *E-mail :* pierre.magnan@supaero.fr

INTRODUCTION

The complex geometry of CMOS pixels and specific crosstalk behavior yield to difficulties in modeling the 2D MTF, required for image deconvolution process, from two 1D MTF. So, additional analysis and measurements at different wavelengths are required in order to get a better knowledge of pixel organization impact on crosstalk and MTF. Three reduced size test chips have been developed using a 0.35µm CMOS optimized technology. One consists in an array of 128x128 photodiodes pixels, 13-µm pitch (Fig.1 & Fig.2) allowing to evaluate these parameters at the same time by using on-chip metal patterns.

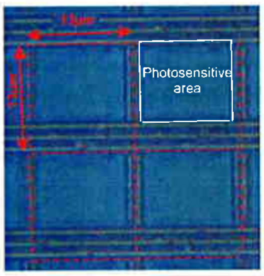

Fig.1 : Photograph of 2x2 pixels, 13 µm pitch, designed to use only two metal layers.

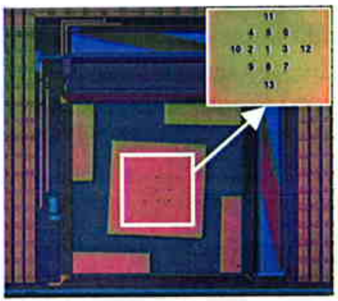

Fig.2 : Photograph of the chip (the upper metal layer is used for light shielding purpose). Pixels n°1 to n°13 are designed for crosstalk evaluation.

A large metal block (Fig.2) emulates the slanted-edge pattern for providing MTF data [1]. Some pixels, located in the center of this block (numbered 1-13), have been kept totally or partially unmasked. By analyzing the responses of these pixels and of their neighbors , an evaluation of the contribution of each part of the pixel to the surrounding pixels signal (crosstalk) is possible.
Additionally, two other arrays have been investigated : an 13µm pitch pixel array having a different pixel organization and a 10µm pitch pixels array.

CROSSTALK EVALUATION

When the amount of charges generated in the central pixel and diffusing to the neighbors ones is evaluated, a significant signal is obtained only on the masked pixels surrounding the unmasked one; so crosstalk is calculated on 3x3 pixels block (Fig.3).

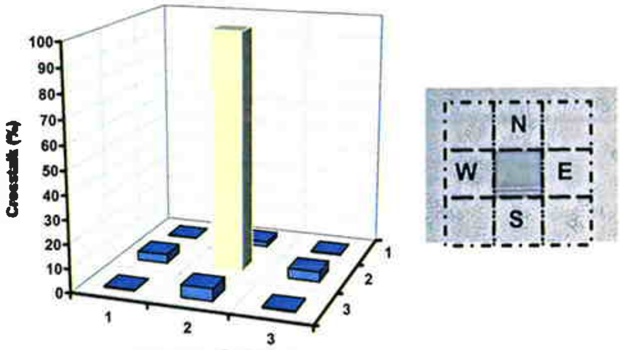

Fig.3 : Crosstalk map @ 800nm

Considering the block containing the pixel n°1 (entirely uncovered), we can notice that crosstalk values are low, even at long wavelength for which diffusion is important (Fig.4).

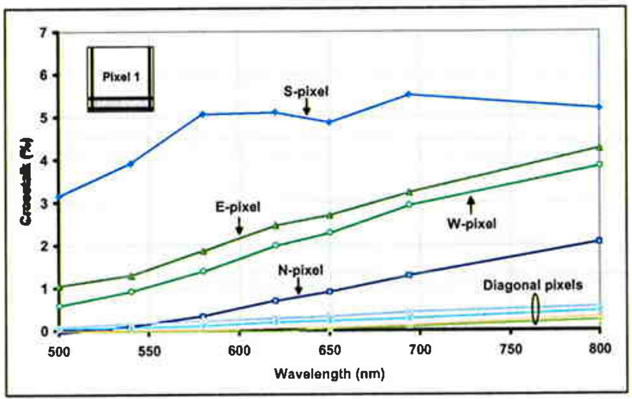

Fig.4 : Crosstalk evaluation on the pixel n°1 block

We can notice that: first, crosstalk shows a quasi-linear trend with regard to the wavelength, which has already been found by simulation and measurements on CCD test structures [2] as on CMOS pixels [3][4] by photocurrent calculations. This last work showed also evident differences between crosstalk values depending on the diffusion direction, as we can see on the vertical direction. Measurements made on four CMOS image sensors revealed an equivalent asymmetry [5], which is in contradiction with the isotopic behavior of the diffusion. The contribution of the entire transistor area to crosstalk can be quantified on pixel n°2 for which transistor area is totally covered (Fig.5).

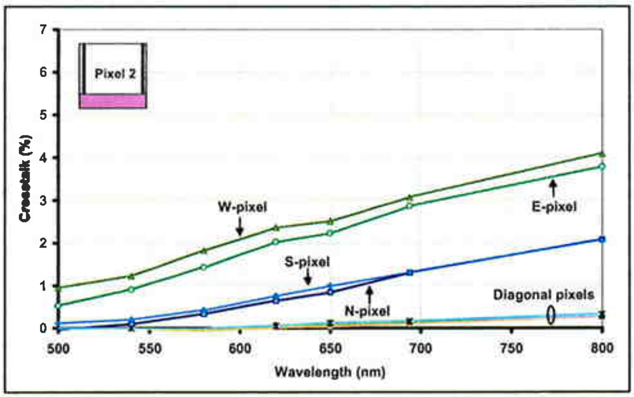

Fig.5 : Crosstalk evaluation around the pixel n°2 (transistor area totally covered)

While the crosstalk is unchanged in the horizontal direction, transistor area masking reduces crosstalk values and allows to recover a symmetry in the vertical direction, with just a limited loss of QE as shown in Fig.6.

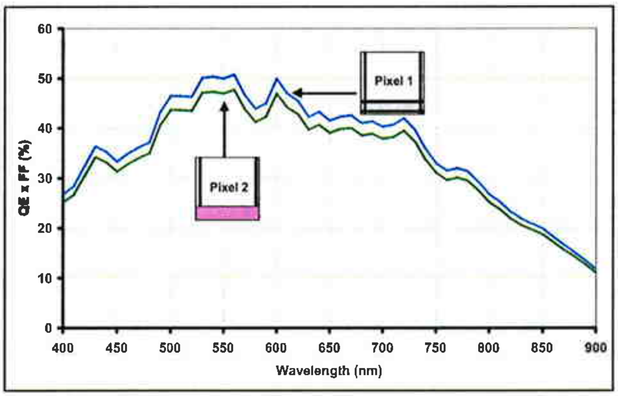

Fig.6: Transistor area masking influence on QE. High values obtained prove really good performance in photon transmission and collection efficiency.

Further similar analyses have been made on partially masked pixels (Fig.7).

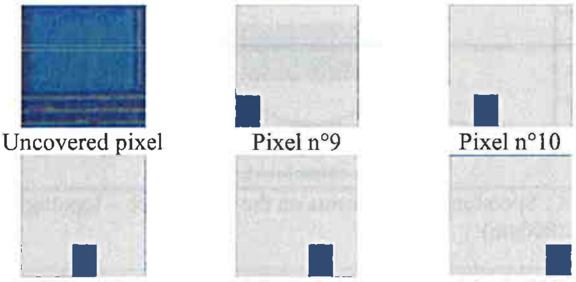
Uncovered pixel
Pixel n°9
Pixel n°10
Pixel n°11
Pixel n°12
Pixel n°13

Fig.7 : Photograph of pixels n°9 to n°13 on which only a part of the transistor area is uncovered

Results show that the asymmetry of crosstalk in the vertical direction is due to a non-symmetric contribution of the remaining naked part (areas containing only isolation oxide) of the transistor area (Fig.8).

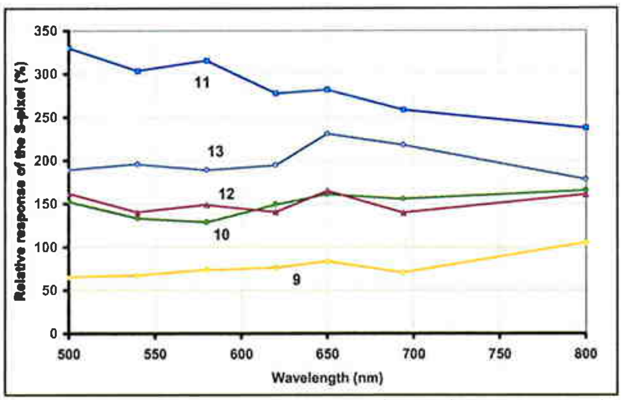

Fig.8 : Relative response of the S-pixel with regard to the central one. Topologies of the remaining naked areas explain the differences between the curves.

So one way to obtain a reduced and symmetrical crosstalk is to mask any part of the pixel which is not designed to be photosensitive[4][6]. Another one is to choose a very symmetrical layout organization by a proper elements placement in the transistor area.

MTF MEASUREMENTS

MTF measurements have been made using the on-chip slanted-edge metal pattern. Results have been validated by sine and slanted-edge targets measurements [7]. The integration MTFs, calculated applying a 2D Fast Fourier Transform to the photosensitive area shape [8], is shown with the measured MTFs. We can notice that measured MTFs are very close to the integration MTF, particularly in the row (X) direction (Fig.9).

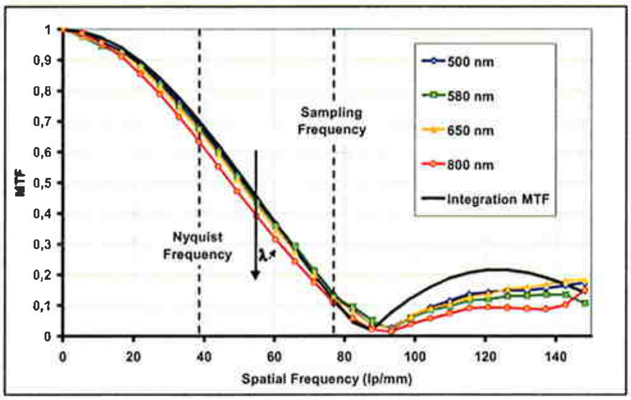

Fig.9 : MTF in the horizontal direction (X)

The photosensitive area has a rectangular shape, larger in the horizontal direction than in the vertical direction. As expecting, the vertical MTF is higher than the horizontal one (Fig.10).

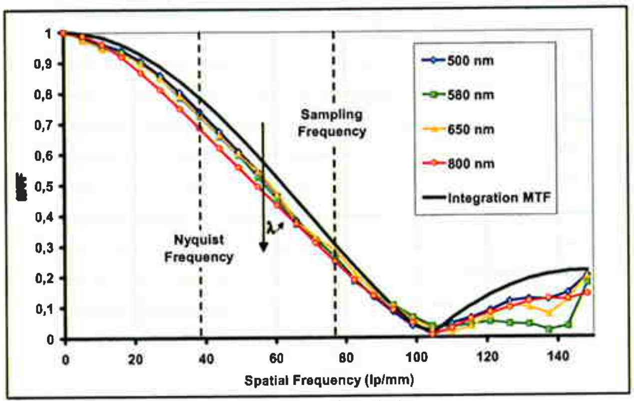

Fig.10 : MTF in the vertical direction (Y)

Larger crosstalk values obtained in the column (Y) direction can explain the larger difference between integration and measured MTF. Regarding the MTF measured at the Nyquist frequency it appears that this one varies quasi-linearly with wavelength (Fig.11) and the same tendency is observed with regard to the measured crosstalk (Fig.12).

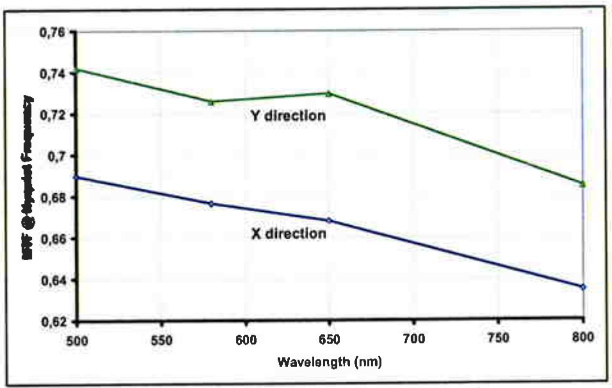

Fig.11 : MTF @Nyquist frequency vs. Wavelength

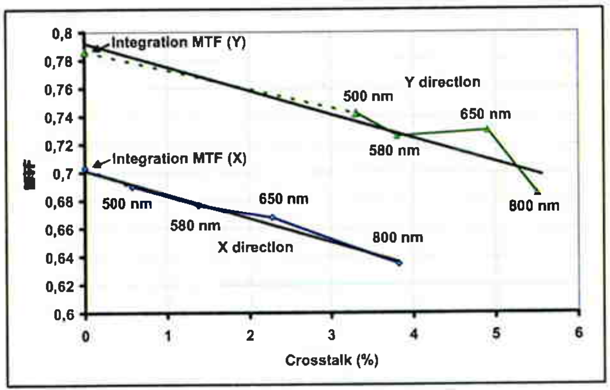

Fig.12 : MTF @Nyquist frequency vs. Crosstalk

This behavior appears in agreement with the theoretical calculation based upon Blouke and Robinson model describing the overall MTF as the product of integration and diffusion MTFs [9]. A good agreement has also be found between this model and MTF measurements performed by T.Dutton & al. [10].

SPOTSCAN MEASUREMENTS

Spotscan measurements allow us to confirm that the spatial photoresponse contribution do match the photosensitive area shape. First, they have been made with an optical spot (about 1.5µm diameter at 500nm), obtained using a source point associated with a microscope objective. The following figure (Fig.13) shows the results obtained on the 13µm pitch – topology 1 pixel.

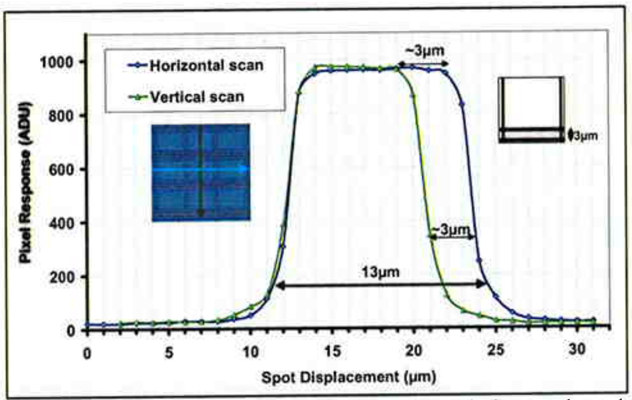

Fig.13 : Spotscan measurements on the 13µm pitch– topology 1 pixel at 500nm

The 3-µm annotated on the figure corresponds to the dimension of the transistor area in the Y direction. The edges sharpness allows us to confirm that the integration MTF is a good approximation of the sensor MTF at short wavelengths. In order to confirm the good MTF and crosstalk behavior of the technology used, we have made additional spotscan measurements (with a 800nm wavelength) on two other types of pixel having a different geometry (13µm and 10µm pitch). In both cases, we can notice the low response of the neighbors when the spot is centered on the pixel (Fig.14 - Fig.15).

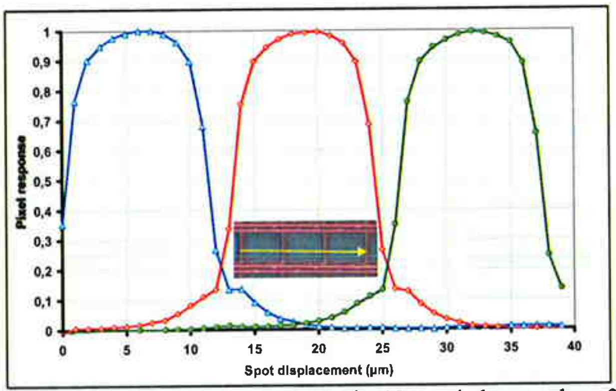

Fig.14 : Spotscan measurements on the 13µm pitch – topology 2 pixel (800nm)

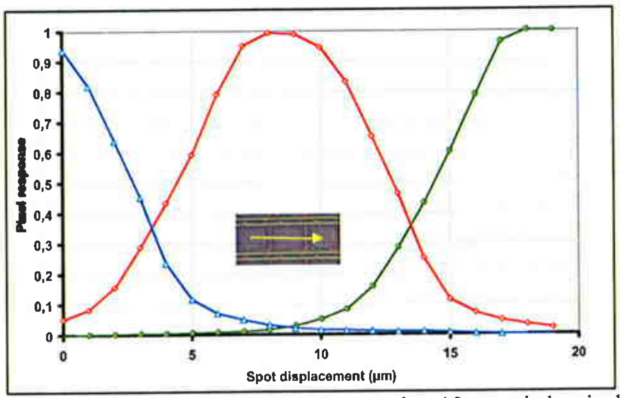

Fig.15 : Spotscan measurements on the 10µm pitch pixel (800nm)

This technique is relatively simple to implement but presents some limitations. The spot diameter is fixed by the Airy diffraction figure. So it is impossible to get the same spot at 500nm and 800nm. More, it is really difficult to keep a good focusing all along the measurements, especially for two-dimensional spotscan.

In order to get the complete Pixel Response Function (PRF) of the pixel, we use now a SNOM (Scanning Near-Field Objective Microscope) system. A Laser Light is injected into an optic fiber with a cut-end metallized tip. The distance between the fiber tip and the surface of the detector is kept constant by a feedback loop. Our measurements have been made using 535nm (Fig.16) and 780nm (Fig.17) laser lights on the 10µm pitch pixel.

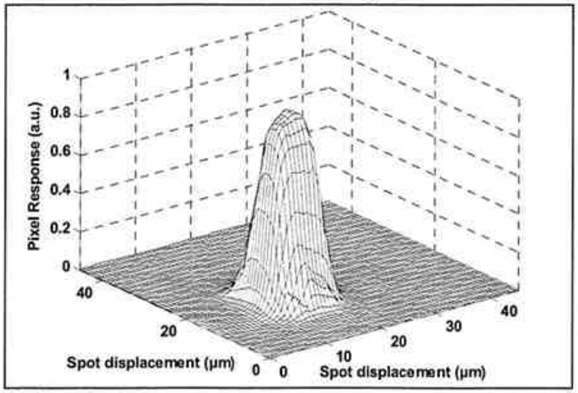

Fig.16 : Pixel Response Function of the 10µm pitch pixel (535nm)

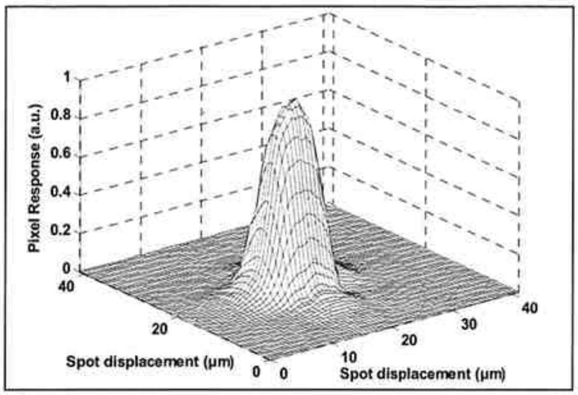

Fig.17 : Pixel Response Function of the 10µm pitch pixel (780nm)

Comparing the results obtained at 535nm and 780nm, we can see that the crosstalk is slightly increasing with the wavelength. Photosensitive area shape is still preponderant.

CONCLUSION

This work allows us to bring up the transistor area participation to crosstalk and the direct impact of the choice of element and naked remaining area placement on both crosstalk value and dissymetry. This last characteristic appears as a consequence of the designer decision. Crosstalk symmetry can be recovered by proper masking the transistor area without an important loss in quantum efficiency.
It also demonstrate that when using optimized process, photosensitive area shape is preponderant in PRF and also determine the sensor MTF that can be evaluated by integration MTF at short wavelengths. The observed quasi-linear dependence of crosstalk and MTF demonstrates that Blouke & Robinson diffusion MTF may be used to predict MTF at longer wavelengths.
By an attempt of maximum symmetry of the layout, it is then possible to recover a separable MTF, that allows for easiest deconvolution process.

REFERENCES

1. International Standard ISO 12233:2000(E)
2. J.P.Lavine & al., "Monte Carlo Simulation of the Photoelectron Crosstalk in Silicon Imaging Devices", IEEE Trans. on Electron Devices, Vol.32, Oct. 1985, pp 2087-2091.
3. Qun Sun & al., ,"Color Reproduction Driven CMOS Image Sensor Design", Electronic Imaging 2005, Vol.5678, Jan.2005, pp 85-95.
4. H.Mutoh, ,"3-D Optical and Electrical Simulation for CMOS Image Sensor", IEEE Trans. on Electron Devices, Vol.50, Jan.2003, pp 19-25.
5. J.S.Lee & al, "Empirical Characterization of Lateral Crosstalk for CMOS Image Sensors and Deblurring Operations", IEEE Workshop on CCD & AIS, Elmau, Germany, May 2003.
6. M.Furumiya & al., "High-Sensitivity and No-Crosstalk Pixel Technology for Embedded CMOS Image Sensor", IEEE Trans. on Electron Devices, Vol.48, Oct. 2001, pp 2221-2227.
7. M.Estribeau, P.Magnan, "Fast MTF measurement of CMOS imagers using ISO 12233 slanted-edge methodology", SPIE Optical Systems Design 2003, Proceeding of SPIE, Vol.5251, October 2003.
8. O.Yadid-Pecht, "Geometrical modulation transfer function for different pixel active area shapes", Opt. Eng.,, Vol.39, n°4, April 2000, pp 859-865.
9. M.Blouke, A,Robinson, "A method for Improving the Spatial Resolution of Frontside-Illuminated CCD's", IEEE Trans. On Electron Devices, Vol.28, March 1981, pp.251-256.
10. T.Dutton &al., "Measurement and Analysis of Pixel Geometric and Diffusion modulation Transfer Function Components in Photodiode Active Pixel Sensors", IEEE workshop on CCD & AIS, Elmau, Germany, May 2003..