A 36×48mm² 48M-pixel CCD imager for professional DSC applications

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Abstract

A 48M-pixel, 6k×8k, 36×48mm² full-frame CCD imager was developed for professional digital SLR cameras and digital camera backs. Compared to the previous generation CCD, the pixel area was reduced by 30% from 7.2×7.2μm² to 6.0×6.0μm² to meet the demands for higher resolution. Still, by improvements in technology and design, the SNR under identical exposure conditions was increased by 30%.

Introduction

High resolution, large optical format, excellent highlight handling, 12bit (72dB) dynamic range, excellent 'raw' image quality, and compatibility with wide-angle lenses with chief ray angles up to 35° are the major requirements for imagers for professional, top-end DSC applications.

A performance summary of our previous 36×48mm² 7.2×7.2μm² 33M-pixel CCD (similar to the 28M-pixel CCD presented in [1]), and a competition benchmark [2] are summarized in Table 1.

This paper will present the advancements in design and technology required to develop a 36×48mm² 48M-pixel CCD with 6.0×6.0μm² pixels with improved imager performance.

Sensor Development

Development Goals

To meet the performance requirements for this next-generation imager, we introduced the following changes in our design, technology, and sensor operation:

(1) Four-phase pixel optimization for high charge capacity with two integrating gates and two blocking gates ('two-two') instead of a conventional 'three-one' approach;

(2) Improvement of QE by integrating an anti-reflective nitride layer on the poly-silicon gate electrodes;

(3) Application of gap-less microlenses on top of the RGB color filter pattern, optimized for wide angular response and low color cross-talk;

(4) Reduction of output amplifier noise.

	[1] **Previous work [1]**	**Benchmark [2]**	**Units**
Image size	36×48	36×48	mm²
Resolution	33	39	M-pixel
Pixel size	7.2×7.2	6.8×6.8	μm²
Max. pixel charge	60,000	66,000	electrons
Microlenses	no	no[2]	-
QE (B-G-R)	15 - 21 - 25	16 - 23 - 18	%
Conversion factor	40	24.5	μV/e⁻
Amplifier noise (after CDS)	17	15	electrons
Dynamic range	70	73	dB
Number of outputs	4	2	-
Max. pixel rate	100	48	MHz
Dark current @ 25°C	4	2	pA/cm²

[1] *Similar to the 28M-pixel CCD*

[2] *Microlenses could be applied only on the smaller 31M 44x33mm² device for less demanding applications with smaller maximum chief ray angles*

Table 1. Overview of previous-generation CCD imager and competition benchmark

Sensor Architecture

Fig. 1 shows the basic concept of the new CCD imager and Fig. 2 shows previous and new pixel structures. Because the size of the imager exceeds by far the maximum size of single exposures for the lithographic equipment, stitching was used to build the imager using 'building blocks'.

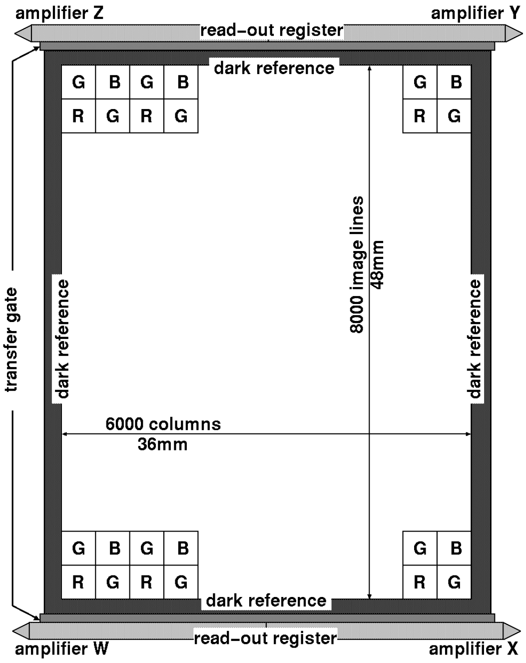

Fig. 1. Architectural concept of new CCD imager

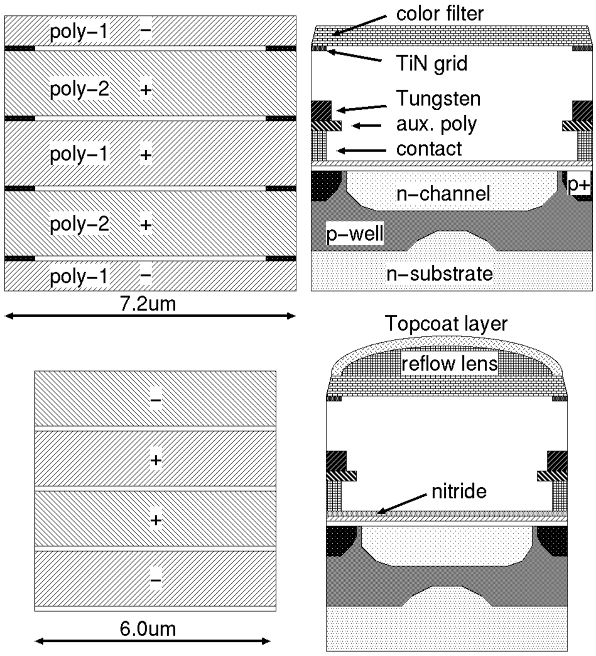

Fig. 2. Previous (top) and new (bottom) pixel; top view (left) and cross section perpendicular to columns (right)

Pixel optimization

The previous $7.2\times7.2\mu m^2$ pixel was operated with three integrating gates and one blocking gate to achieve a high maximum charge capacity and sensitivity, Fig 3a. When shrinking the pixel size, the drawback of this concept is that the length of the blocking gate becomes too short to combine high charge capacity with vertical anti-blooming: the barrier to the neighboring pixel tends to become smaller than the barrier to the substrate, resulting in blooming, Fig. 3b. Increasing the n-substrate voltage could solve this problem, but at the expense of maximum charge capacity. A better solution is to optimize the pixel doping profiles and operating voltages for two blocking gates and two integrating gates, Fig. 3c. This results in a maximum charge capacity of 55,000 electrons without compromising transfer efficiency, anti-blooming or electronic shutter performance.

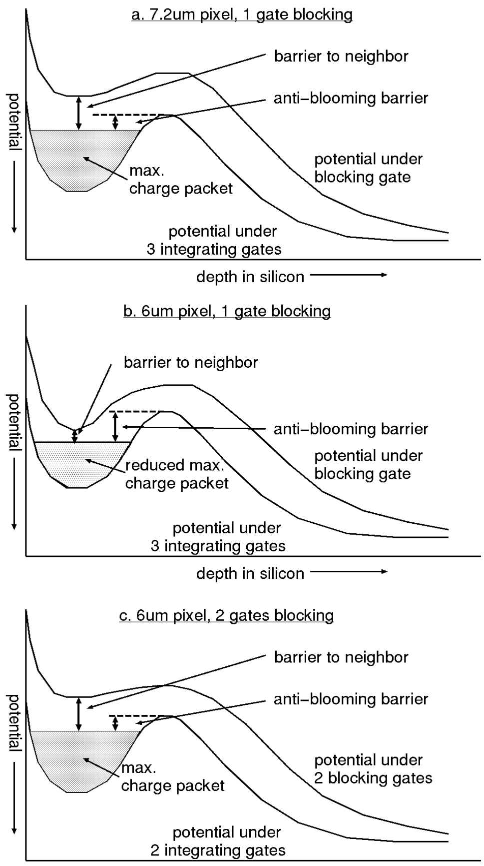

Fig. 3. Effect of short blocking gate on vertical anti-blooming performance

Improvement of Quantum Efficiency

The transparent membrane gate technology used to manufacture these imagers [3] was improved by integrating a nitride layer on top of the poly-silicon electrodes. The better matching of refractive indices results in an improvement of the QE up to 40%, depending on wavelength, as shown in Fig.4. To integrate the extra nitride layer some technological challenges had to be overcome for the poly-silicon electrode contact technology due to increased complexity. By proper implementation of this technology, this nitride layer has no impact on the dark current performance.

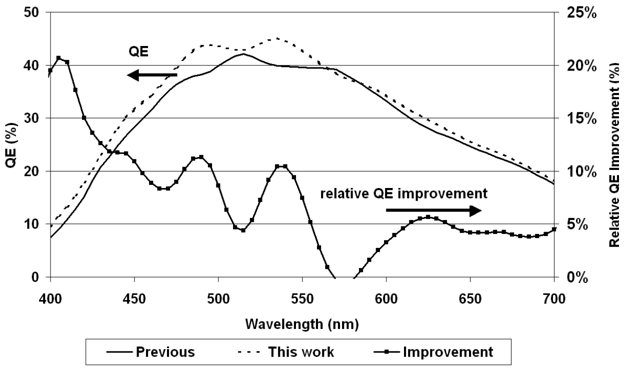

Fig. 4. Improvement in QE by integration of nitride layer

Optimization of Microlenses

In a next step to increase the QE, gap-less microlenses consisting of reflowed resist covered with a topcoat layer [4] were applied for the first time on imagers for this kind of professional application. Angular response is essential for professional DSC applications using interchangeable lenses with chief ray angles up to 35°. A high angular response with limited cross-color was maintained by the low stack height of the CCD technology (2.5µm from gate dielectric to bottom of color filters) and by carefully adjusting the microlens curvature for correct focus. Fig.5 compares the angular response of a 7.2×7.2µm^2 pixel without microlens with the new 6.0×6.0µm^2 pixel with microlens. As can be seen, the response normalized to normal incidence is still 73% at 35°. Fig. 6 shows the QE of previous and new pixels. From these results one can also conclude that the effect of a smaller pixel size with two integrating gates is more than compensated by the use of nitride and microlenses.

Amplifier Noise Reduction

By improving the first stage of the triple-source follower amplifier, the readout noise at 25MHz pixel frequency was decreased from 17e- noise to 11e- noise after CDS. The bandwidth was maintained at 125MHz, required for good color separation. The noise-bandwidth plot is shown in Fig. 7. With a maximum charge capacity of 55,000 electrons, a dynamic range of 74dB is achieved, exceeding the requirement (72dB).

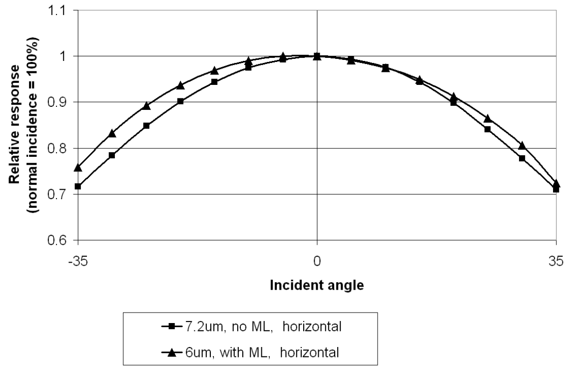

Fig. 5 Angular response (green pixels, white light) of previous 7.2µm pixel without microlens and new 6.0µm pixel with microlens and nitride

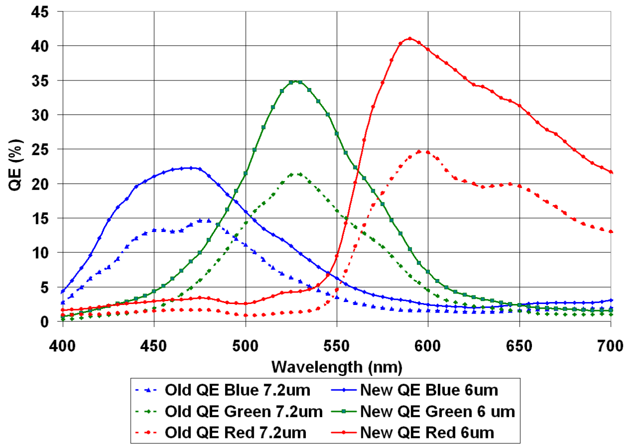

Fig. 6. QE of previous 7.2×7.2µm^2 pixel without microlens and of new 6.0× 6.0µm^2 pixel with microlens and nitride layer

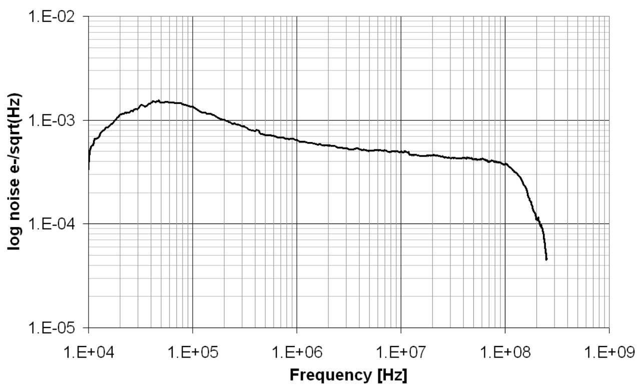

Fig. 7 Noise-bandwidth plot of CCD amplifier

Summary

Table 2 compares the performance of the new 48M imager with a competitive 50M imager announced in summer 2008 [5]. The increase in QE (QE×1.7 in Green) and reduction in amplifier noise (Noise×0.65) more than compensate for the

30% shrink in pixel size; resulting in a 30% increased maximum ISO sensitivity. Fig. 8 is a SEM topview photo of a partially de-processed device, Fig. 9 shows an image captured with this CCD.

In conclusion, we demonstrated that by improvements in design, technology and operation a 48M-pixel CCD imager for very demanding professional applications was made that shows a significantly improved imaging performance in spite of the 30% reduced pixel size.

	Previous work [1]	**New Bench-mark [5]**	**This work**	**Units**
Image size	36×48	37×49	36×48	mm^2
Resolution	33	50	48	M-pixel
Pixel size	7.2×7.2	6.0×6.0	6.0×6.0	μm^2
Micro-lenses	No	No	Yes	-
Max.charge	60,000	41,000	55,000	electrons
QE (B-G-R)	15-21-25	20-20-15	22-35-41	%
Angular response (35^o)	72	n.a.	73	% of norm. incidence
Conversion factor	40	31	37	$\mu V/e^-$
Amp. noise (after CDS)	17	12.5	11	electrons
Dynamic range	71	70	74	dB
# outputs	4	4	4	-
Max. pixel rate	100	72	100	MHz
Dark current	4	2	4	pA/cm^2 @ 25^oC

Table 2. Performance comparison between previous generation CCD imagers and this work

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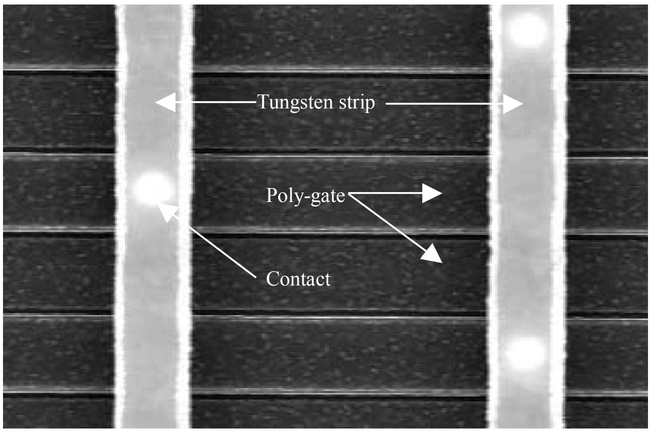

Fig. 8. SEM topview photograph of pixel of partially de-processed device

Fig. 9. Image obtained with new 48M imager

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