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Analysis of blinking pixels in CCD imagers with and without surface pinning

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This paper presents analysis results on blinking pixels observed in CCD imagers for professional DSC applications. The study was done on different devices manufactured in the same technology, but operated both without inverted and with inverted surface. In inverted mode, the number of blinking pixels is significantly reduced.

Full-frame CCD imagers for high-end photography typically have image pixels around 6x6μm^2, imager sizes of 36x48mm^2 or larger, and multiple outputs [1]. To achieve good image quality at long exposure times, low dark current is required. Typically in the camera, black reference images are subtracted from long-exposure images to correct for dark current, as well as e.g. to improve the tap matching between different outputs. Obviously, as the dark current shot noise cannot be corrected, the dark current itself has to be as low as possible. The ‘all gates pinning approach’ (AGP) [2, 3] inverts the surface and thus significantly reduces the dark current, and the corresponding shot noise. However, an additional challenge in dark current correction is “blinking” pixels, i.e. pixels of which the behavior changes with time.

Dark current behavior of CCDs has been extensively reported, but the behavior of blinking pixels (or RTS signals) from CCDs has been studied mainly for radiation effects e.g. [4]. RTS noise in CMOS imagers has focused on the readout structure e.g. [5] and much less on the photodiode dark current behavior. We studied the RTS performance of CCD imager pixels, operating without and with surface pinning (“non-AGP” vs. “AGP”). The relevance of blinking pixels is based on the fact that there are two ways to obtain the black reference images for image correction: (1) immediately after a long-exposure image, a dark image is taken under the same conditions; (2) a ‘synthetic’ dark image is used, based on images taken during camera calibration. Option (1) is most accurate but much more time consuming, option (2) is faster but suffers more from blinking pixels since the time interval between the capture of the actual image and the reference is much larger.

Fig. 1 shows the concept of the CCD pixels used in our analysis, and the potential profile under the center of the integrating and blocking gates. The pixel has an n-channel buried-channel implant in a p-well in an n-substrate.

Fig. 2 shows the ‘blinking’ behavior of two pixels with non-pinned surface operation obtained on a 60M-pixel CCD imager very similar to the 48M-imager presented in [1]. Fig.3 shows a cumulative histogram that was obtained by subtracting pixel-wise a reference dark image taken at t=0 from subsequent dark images taken at t=n minutes, with n = 0, 10, 20 and 30. The analysis was done for various p-well, n-substrate and gate voltages, as these voltages significantly influence the electrical field which in turn influences the dark current behavior. Fig. 4a shows the effect of the applied p-well voltage (Psub, VPS) on the signal level of two blinking pixels, and Fig. 4b shows the effect of the difference in VPS and gate voltage on the signal level. These results show that a relatively low gate voltage and a relatively high p-well voltage reduce the magnitude of blinking pixels. The ability to influence the signal level of blinking pixels by operating voltages suggests that the carrier generation in the blinking pixels is electric-field sensitive.

In the next investigations, we analyzed the blinking pixel behavior on 1M-pixel full-frame CCDs where devices with ‘conventional’ pixels (non-surface pinned, “non-AGP”) and surface-pinned “AGP” pixels were combined on the same wafers. The concept is similar to the imager presented in [1]. The difference between the ‘AGP’ and ‘non-AGP’ devices is the second n-channel implant in the AGP pixels, Fig.1 [2, 3].

Fig. 5 shows a cumulative histogram, obtained in a similar way as Fig.3, for the 1M-pixel “non AGP” CCD, as a function of the p-well voltage. Fig. 6 shows similar results for the AGP version, in which surface pinning occurs for VPS > 6V. As can be seen, the cumulative histogram for VPS=8V in Fig.6 shows that the number of blinking pixels is significantly reduced once pinning occurs.

To investigate the blinking pixels in more detail, four different blinking pixels of both non-pinned and pinned 1M-pixel CCDs were monitored over a period of approximately 25 minutes. By plotting the pixel signal as a function of frame number, i.e. the time after the reference frame, the temporal behaviour of these four pixels is visualized. Fig. 7 depicts the signal of four “non-AGP” sensor pixels as a function of frame number for different VPS voltages. Although the height of the signal does depend on the VPS voltage, comparison of the pixel levels shows that the signal level as well as the time-behaviour can not be predicted. For VPS = 8V, the fluctuation is relatively small in comparison with the fluctuation at lower VPS settings. But the time-behaviour is not suppressed. Fig. 8 shows similar results for the “AGP” sensor. A similar trend is observed regarding the signal level. As pinning sets in (VPS > 6V), however, the time-behaviour is fully suppressed except for Pixel 1. This observation is in agreement with the histograms. So AGP can significantly reduce the number of blinking pixels, but not entirely.

In conclusion, the number of blinking pixels can be reduced by lowering the electrical field in the pixel, by modifying either the gate, n-substrate or p-well voltages. When the surface of the CCD is pinned, the occurrence of blinking pixels can be significantly reduced, but not completely eliminated. The results obtained in this work complement results reported in CMOS imagers by Yamashita et al. [6] and by Zhang et al. [7].

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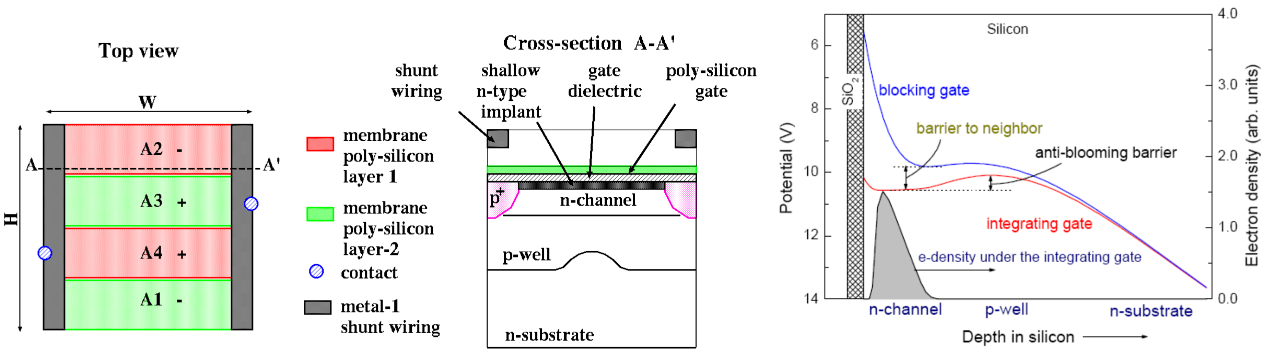


Fig.1. Pixel structure for 60M- and 1M-CCDs used in blinking pixel analysis (left) and potential distribution and charge collection in the pixel (right). The AGP sensor has an additional n-channel implant under gates A3 and A4, and is integrating with all four gates at low voltage.

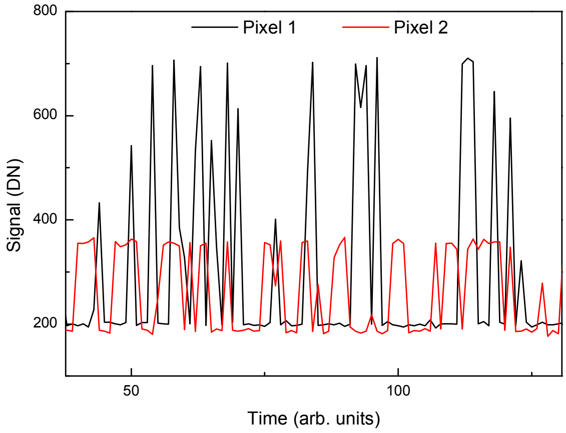


Figure 2: Pixel signal as a function of time for two different pixels. (45C, Tint=1s)

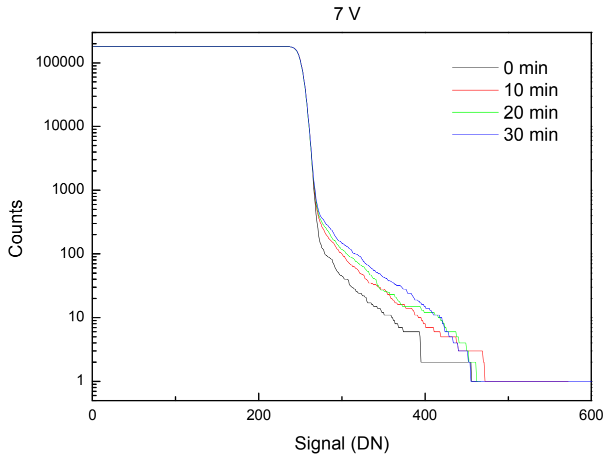
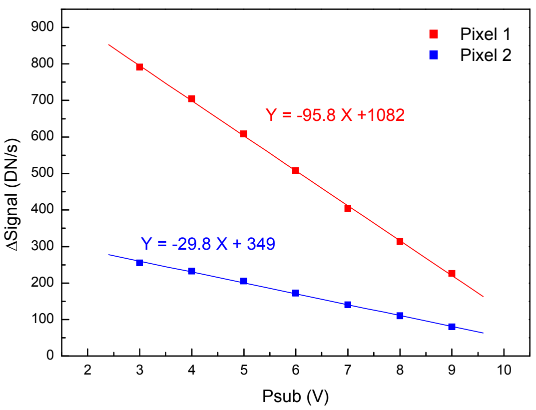


Figure 3: Cumulative histograms of reference-corrected dark images for different moments in time over a period of up to 30 minutes, 60M-pixel CCD.



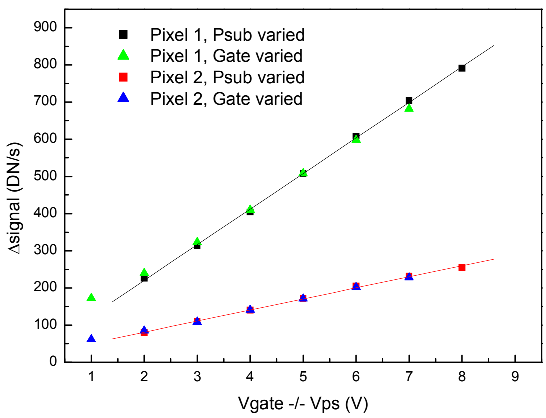


Figure 4a (left): Change in blinking pixel signal (Δsignal) as a function of p-well voltage (Psub), Pixel 1 (34, 210), Pixel 2 (291, 203); 4b (right): Change in blinking pixel signal (Δsignal) as a function of applied voltage difference between gate and Psub. The lines are experimental linear fits.

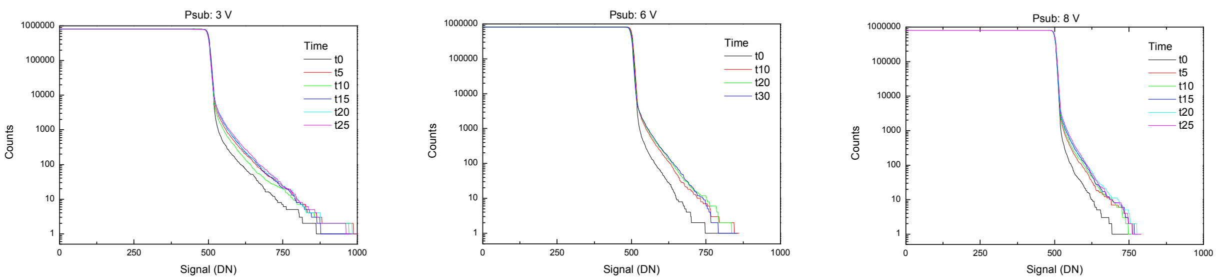


Figure 5: Cumulative histograms of reference-corrected dark images for different VPS voltages and different moments in time over a period of 25 minutes, 1M-pixel non-AGP sensor.

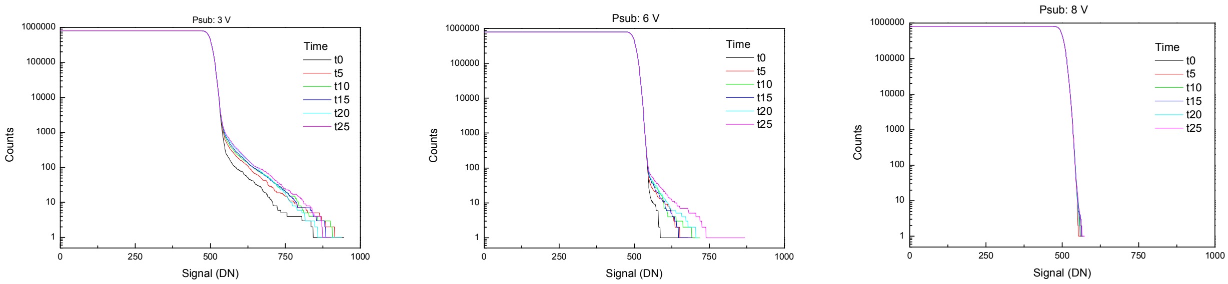


Figure 6: Cumulative histograms of reference-corrected dark images for different Psub voltages and different moments in time over a period of 25 minutes, 1M-pixel AGP sensor.

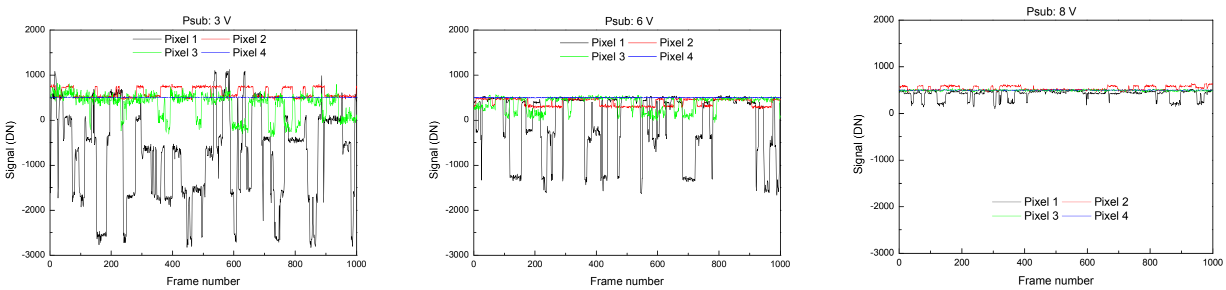


Figure 7: Non-AGP pixel signal for different frames in time, for four different pixels.

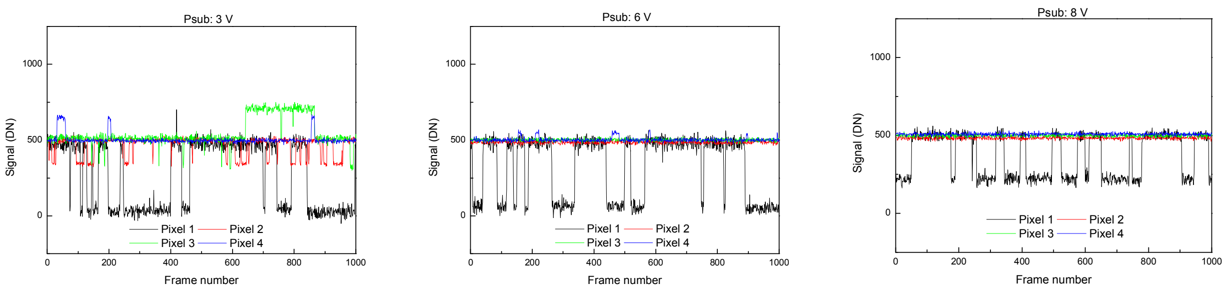


Figure 8: AGP-pixel signal for different frames in time, for four different pixels.

References

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