Design Options for 1/4"-FT-CCD pixels

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Abstract

Desktop video applications require unexpensive, compact low-power cameras capable of delivering progressive-scan images captured with square pixels. Thus, a 1/4" FT-CCD compatible with VGA standards was developed. This true progressive scan 640(H) × 480(V) FT-CCD imager with pixels measuring only 5.1 × 5.1 μm^2 was optimized for low-power and low-cost applications.
Because of the small pixel size, a new doping profile was developed for the pixel. In this presentation, some alternatives for the doping profiles and their advantages will be discussed.

Introduction

For multimedia applications, a FT-CCD compatible with VGA standards was developed (Fig.1a). This 1/4" true progressive scan 640(H)*x* 480(V) FT-CCD imager has 3-phase pixels (Fig.1b) measuring 5.1 × 5.1 μm^2. For compactness and power reduction in the application, the device has on-chip vertical level-shifters/drivers and a serial register capable of operating with low-power 3.3V digital inputs. To maintain a good pixel performance for this small pixel, a new doping profile was introduced, which will be further discussed in this presentation.

Development of new doping profile

When shrinking the pixel size from 6.9 × 12.6 μm^2 (interlaced, 1/3" S-VHS- compatible FT-CCD) [1] to 5.1 × 5.1 μm^2 (progressive scan, 1/4" VGA-compatible FT-CCD) [2], 3-D effects adversely affect the performance of the CCD pixels w.r.t. maximum charge capacity, anti-blooming, optical sensitivity etc. To overcome these problems, the newly developed pixel combines the profiled peristaltic CCD (P^2-CCD) structure [3] with vertical anti-blooming (VAB) [4].

The pixel cross-section, doping structure, potential profile and charge distribution of the original buried-channel CCD pixel with vertical anti-blooming is shown in Fig.2. The profiled p-well is obtained by a high-temperature diffusion of p^- implant (boron) through stripes. The n-well is obtained again after diffusion of a blanket n-type (phosporus) implant. A p^+ implant creates the channel stops. This results in the conventional VAB structure. The potential profile plot and the plot of the charge vs. depth clearly shows a buried-channel operation with vertical overflow.

Fig.3 shows the modified pixel. An additional shallow n-type implant on top of a modified vertical n-p-n structure for anti-blooming yields a high charge storage capacity, while maintaining anti-blooming, electronic shutter (flushing all collected electrons from the CCD well to the substrate), and optical and transport properties. Again, the potential and charge plots demonstrate the buried channel operation and vertical overflow capability of this new pixel.
This modified three-phase pixel (Fig.3) holds up to 60 000 electrons under one gate, i.e. 10 000 electrons per μm^2 effective electrode area, whereas the conventional buried-channel CCD pixel (Fig.2)

typically holds only 2500 electrons per μm^2 effective electrode area [1,4].
Because of the short gate lengths, the reduction in fringing field strength sometimes associated with the p^2-CCD structure is completely absent here, and efficient charge transport is achieved, also at high transport frequencies.

Optimisation of new doping profile

To increase the charge capacity even further, or to maintain the same charge capacity at lower vertical clock swings, the CCD potential well should be even further increased by a higher P^2-CCD top doping concentration. Then, to maintain the correct conditions for vertical overflow the barrier over the p-well to the n-substrate should be decreased.

A possible approach to achieve this is by omitting completely the p-well implant in the image pixel (and in the storage cell), as shown in Fig.4a. For this narrow pixel, the nearby presence of the p^+ channel stops is sufficient to create a potential profile with a local minimum, as required for VAB, as shown in Fig.4b.

In a final step, also the deep n-well CCD implant can be omitted, resulting in a pixel profile as shown in Fig.5a. As can be seen from Fig.5b the potential profile is still that of a buried-channel CCD with anti-blooming.

The image pixel presented in Fig.5 has the interesting advantage that the two most critical process steps determining the performance of the sensor (p-well and n-channel implant and drive) are no longer required in the pixel. In the present device, they are still required in the serial register, output amplifier and on-chip drivers, but their exact doping profile is much less critical.

By eliminating the most sensitive steps that determine the potential profiles and thus also the voltage settings for the vertical anti-blooming operation, a sensor may be obtained that does not need any external adjsutments. This in turn reduces the overall cost of the camera module significantly.

Conclusions

The combination of the vertical n-p-n profile required for anti-blooming with the shallow p^2-CCD implant yields excellent results for small FT-CCD pixels. A further optimisation can be obtained by eliminating the need for two critical doping profiles in the image pixel, i.e. the profiled p-well and the conventional (deep) buried n-channel implant.

References

[1]. J. Bosiers et al., "A S-VHS compatible 1/3" 720* 588 FT-CCD with low dark current by surface pinning," IEDM Tech. Digest pp. 97-100, 1992.

[2]. J. Bosiers et al., " A 1/4" true progressive scan 640(H)*480(V) FT-CCD for multimedia applications", IEDM Tech. Digest, 1994

[3]. L. Esser, "The peristaltic charge-coupled device", Proc. Charge Coupled Device Applications Conference, San Diego, 1973.

[4]. M. van de Steeg et al., " A frame-transfer CCD color imager with vertical anti-blooming", IEEE Trans. El. Dev., vol. ED-32 no.8, August 1985.

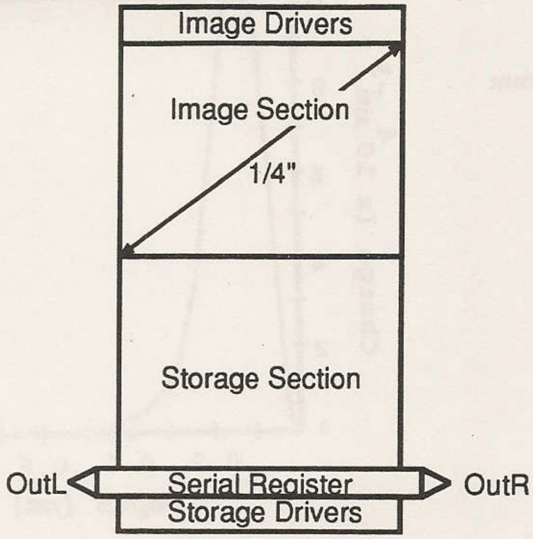

Fig.1a. 1/4" VGA FT-CCD imager

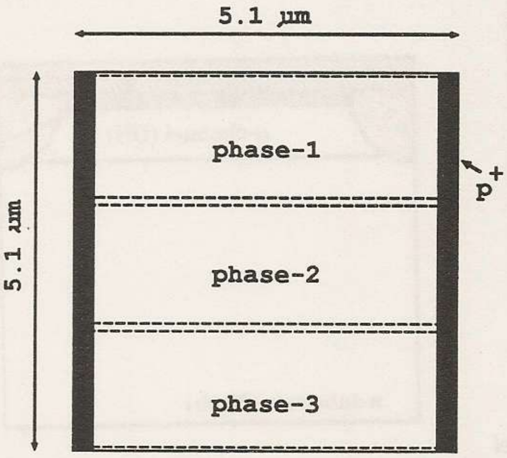

Fig.1b. Schematic top-view of pixel of 1/4" VGA FT-CCD imager

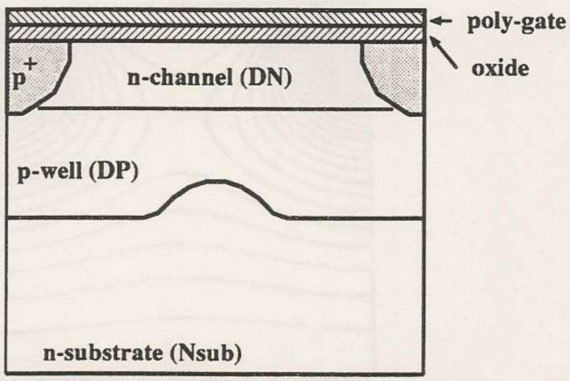

Fig.2a. Cross-section through conventional VAB pixel

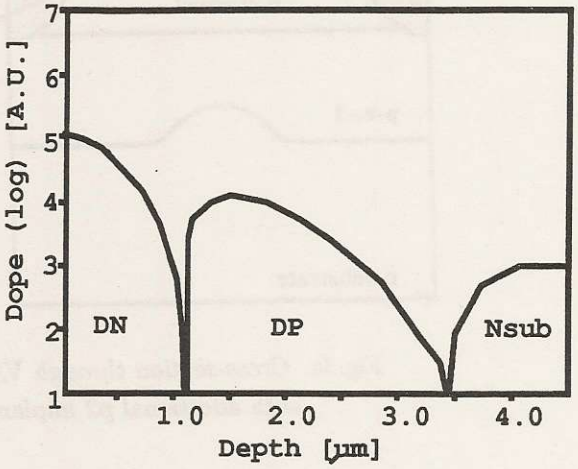

Fig.2b. Doping profile of conventional VAB pixel

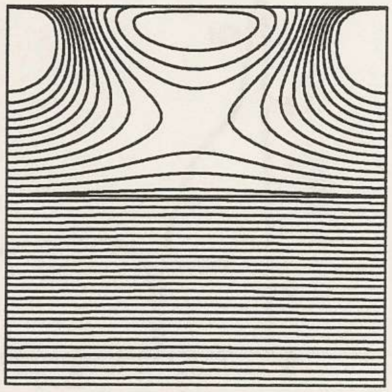

Fig.2c. Potential profile of conventional VAB pixel (Cross-section)

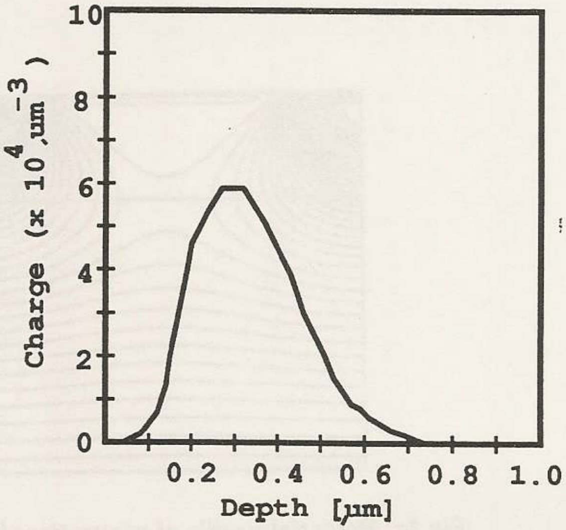

Fig.2d. Charge distribution in conventional VAB pixel

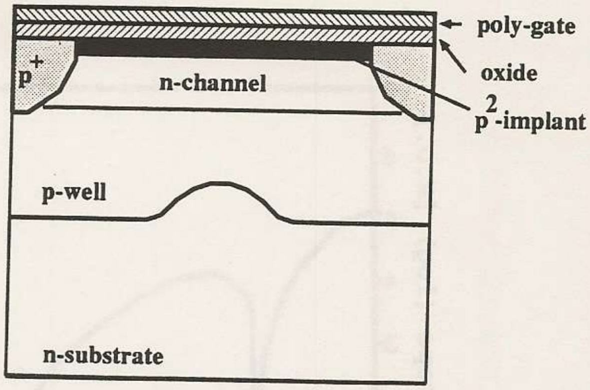

Fig.3a. Cross-section through VAB pixel with additional p2 implant

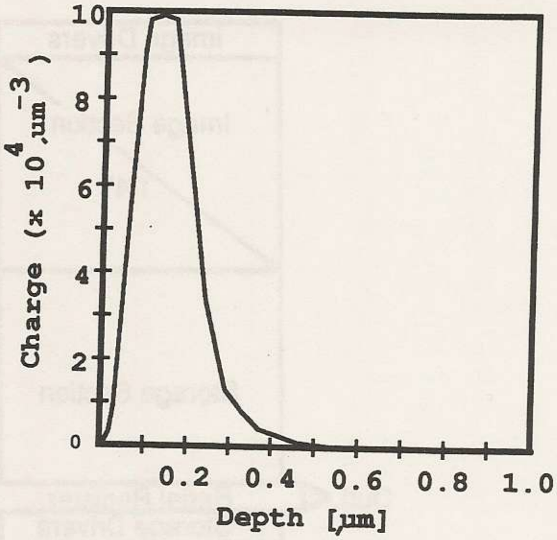

Fig.3d. Charge distribution in conventional VAB pixel with additional p2 implant

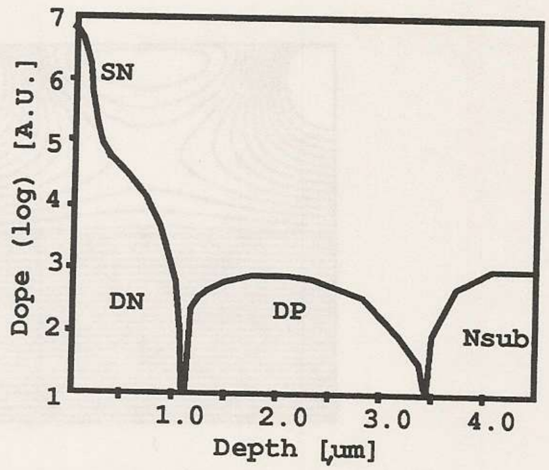

Fig.3b. Doping profile of conventional VAB pixel with additional p2 implant (cross-section)

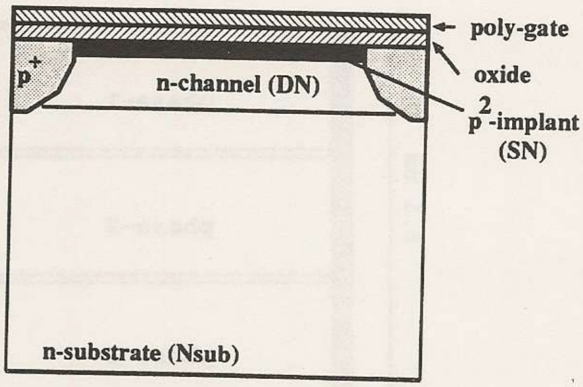

Fig.4a. Cross-section through pixel without p-well implant

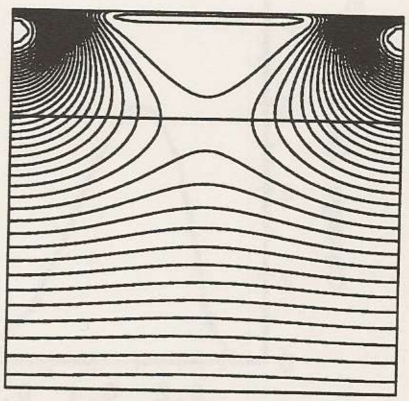

Fig.3c. Potential profile of conventional VAB pixel with additional p2 implant (Cross-section)

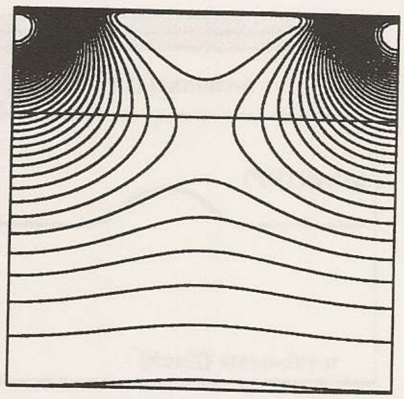

Fig.4b. Potential profile of p-well-less pixel (cross-section)

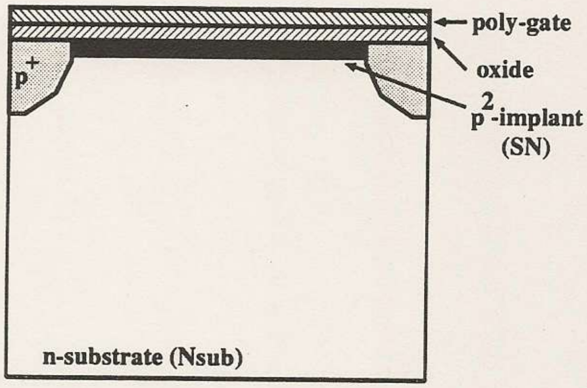

Fig.5a. Cross-section through pixel with only p+ and p2 implant

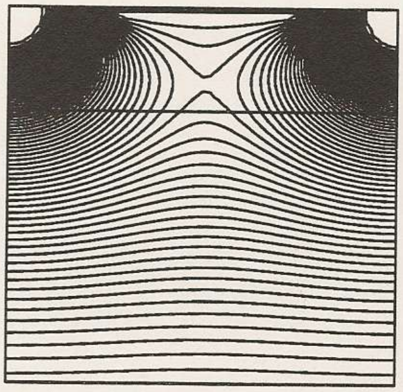

Fig.5b. Potential profile of pixel with only p+ and p2 implant (cross-section)