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Optimization of The Ultra-Low Dark Current CMOS Image Sensor Cell Using n+ Ring Reset

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1. Introduction

Comparing to CCD, CMOS image sensor has the advantages of lower power consumption, random access ability of image data, high compatibility to CMOS logic process and lower cost [1]. The main drawback of the CMOS imagers is the large dark signal which degrades its ability to distinguish image at low illumination and also limits its dynamic range (DR). Previous studies [2] show that peripheral and corner leakage currents are the dominant components of the dark current of the photodiode in current CMOS technologies. An ultra-low dark current CMOS image sensor cell is proposed in our previous work [3]. The ring-shaped poly-gate serves as the reset gate at the same time isolates the photo-sensing area from the field oxide edge.

In this work, the novel structure fabricated by 0.25μm CMOS logic technology is investigated and an optimized cell design is proposed.

2. Drawbacks and Optimization of the Novel Structure

The layout views and cross-sectional views of the conventional and the novel photo-sensing structures are illustrated in Fig. 1. When arranged in an array, the poly-gate rings are shared by circumjacent pixels [3]. The shared poly-gate and the nearby two photodiodes (n+ region) can be viewed as a NMOSFET. Once the potential of either n+ region drops to the level, a threshold voltage lower than the gate voltage, the collected charges can flow to the adjacent pixel resulting in a blooming effect. A pixel with an independent poly-gate ring as shown in Fig. 2 can overcome this problem. The reduced photo-sensing area does, however, reduce the fill factor by 0.86X. Another severe drawback is the coupling effect due to the large capacitance from poly-gate ring to the sensing node. When the reset signal changes from high level to ground level, the coupling effect result in output swing degradation as shown in Fig. 3. An optimized novel structure with an independent ring-shaped poly-gate for isolating the photo-sensing diode from the near-by STI is proposed (see Fig. 4). A reset transistor is then added outside the ring. Since no voltage change across the overlap capacitance during operation, the coupling effect is eliminated.

3. Sample Fabrication

The sample pixels of 5μm X 5μm are fabricated by silicided 0.25μm CMOS logic process. In order to avoid sensitivity reduction caused by the optically opaque silicide on source/drain region, an additional mask, RPO (Resist Protective Oxide), is applied to define non-silicided photo-sensing area.

4. Experimental Results & Discussions

The cumulative probability of the dark current of the large-area photodiodes is illustrated in Fig. 5. It is found that the dark current of the novel structure is reduced by approximately 2.5X. The peripheral and corner leakage currents take different ratios of the total leakage current in large and small-area photodiodes respectively. We assume that areal leakage current densities in the conventional and the novel photodiodes are the same. It is demonstrated that peripheral leakage current density takes a more important part in smaller-area photodiodes, hence the dark current reduction is more prominent in smaller pixel as shown in Fig. 6. Fig. 7 shows the cumulative probability of the dark signal. The sensitivity of these two structures is shown in Fig. 8. Apparently, the dark signal of the novel structure is reduced and little difference on sensitivity (~0.1*lux/v*s*) between these two structures is observed. The bias voltage on the poly-gate ring affects the optical sensitivity and dynamic range of this pixel. Pixel sensitivity decreases as the bias voltage increases. The bias voltage determines the location of the turning point and the dynamic range (see Fig. 9). When biased at 2.5V, the dynamic range extends about 4X wider than that biased at 0V.

5. Conclusions

The novel photo-sensing structure presented in [3] with reset ring has been successfully scaled down to 0.25μm technology with good performance. An optimized structure is proposed to suppress the coupling effect and at the same time widens the dynamic range by as much as 4X.

Acknowledgment

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Reference

[1] E. Fossum, IEDM p.17-25, 1995
[2] H.D. Lee, et al, IEEE Tran. on ED vol. 45 p.1848-1850, 1998
[3] H.Y. Cheng, et al, IEEE EDL vol. 23 p.538-540, 2002

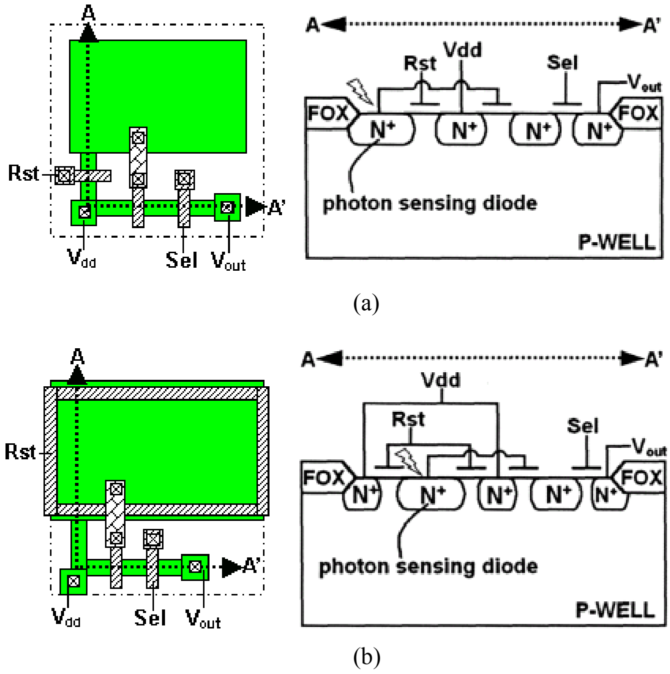

Fig. 1. Layout view and cross-sectional view along-line AA' (a) conventional structure (b) novel structure.

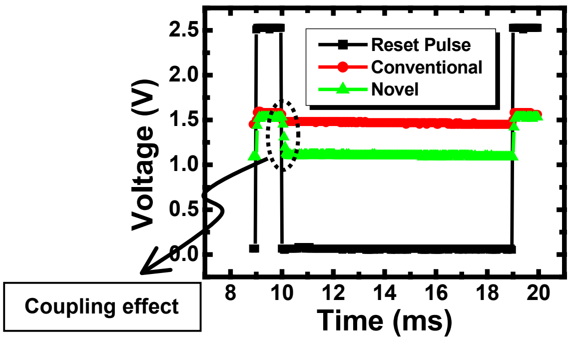

Fig. 3. Illustration of the coupling effect due to the ring-shaped poly-gate.

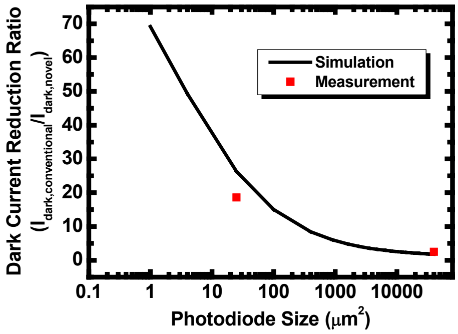

Fig. 6. Dark current cancellation Ratio for photodiode size from 1μm^2 to 40000μm^2.

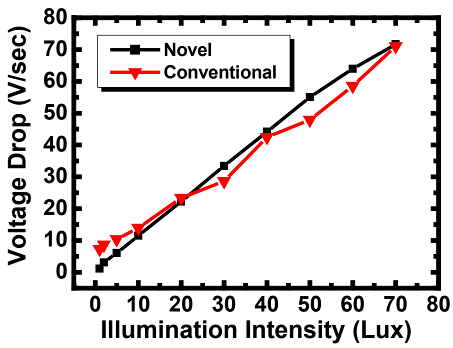

Fig. 8. The optical sensitivity of the novel pixel and the conventional pixel.

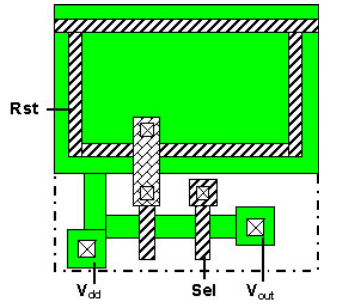

Fig. 2. Novel structure with independent poly-gate ring.

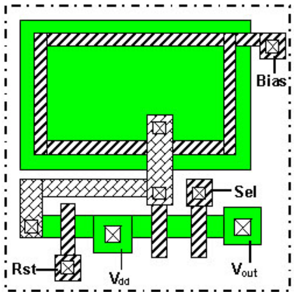

Fig. 4. Optimized novel structure for suppressing coupling effect.

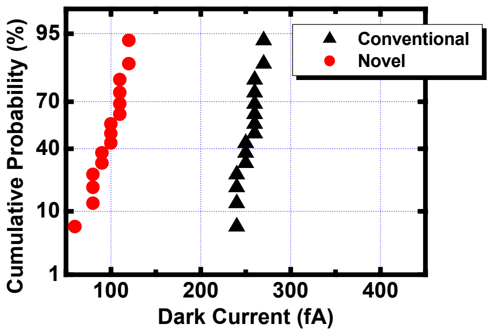

Fig. 5. Cumulative probability of dark current for different photodiode structure.

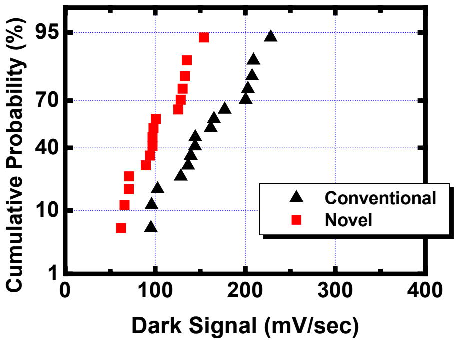

Fig. 7. Cumulative probability of dark signal of the novel pixel and the conventional pixel.

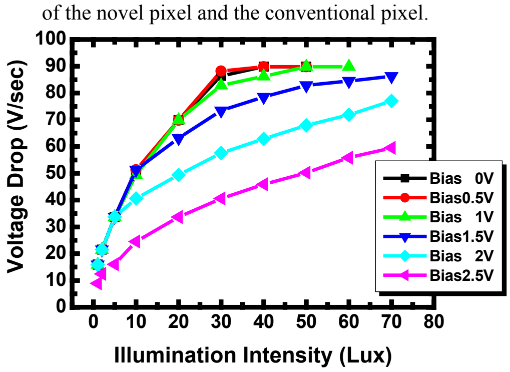

Fig. 9. Dependence of optical sensitivity and dynamic range on bias voltage.