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Dynamic Range Improvement of CMOS Active Pixel Sensor by Controlling the Energy Barrier between Photo-Diode and Expansion-Diode

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1. Introduction

Typical scenes to be acquired by means of electronic cameras exhibit a huge variation of illumination that depends on the ambient light conditions, which can range from 10^{-3} up to 10^{5} lux when changing from night to bright sunlight. One of the challenging issues in complementary metal oxide semiconductor (CMOS) image sensors is dynamic range, which is dependent on the effective maximum detectable signal level, referred to as the saturation signal, and it is one of the major parameters to classify the quality of an imager. Therefore, many methods to enhance the dynamic range of CMOS image sensors have been reported [1-6].

The logarithmic response of a diode-connected MOS transistor [1], [2] or a lateral overflow gate [3] has been used. However, this approach suffers from the poor fixed pattern noise (FPN) performance, requiring extra calibration circuitry [4] or external image processing [5]. The other techniques let the pixel achieve its saturation level and extrapolate the incident light by measuring the time needed to achieve the saturation state. Different implementations have been reported, but they exploit only the time-to-saturation information [6], so that the overall dynamic range is limited and low-intensity images exhibit poor quality.

In this paper, the proposed active pixel sensor (APS) with a wider dynamic range has a novel pixel structure that exhibits a linear response as well as the minimized loss of the photo-charge at the low light intensity. We have measured the characteristics of the chip which was fabricated through a 0.35㎛, 2P4M, 3.3-V standard CMOS technology.

2. Pixel description

Pixel structure

Figure 1 shows the schematic diagram of the proposed APS. The conventional 3-transistor APS has very simple structure and operational principle [7], although it has a problem, such as narrow dynamic range. To overcome this problem, we proposed a novel structure APS with control barrier (CB) between the photo-diode (PD) and the expansion-diode (ED). The proposed APS consists of one additional diode (ED) and one additional NMOSFET (CB gate) in comparison with a conventional 3-transistor APS. The ED region is connected to the PD region via a CB gate and P^{+} diffusion layer is formed within the N-well in both the PD region and the ED region, respectively. The operational principle of the proposed APS will be explained in the next subsection. Figure 2 shows the chip micrograph of the prototype wide dynamic range APS with 0.35 ㎛ technology. The pixel pitch is 10 ㎛.

Operational principle

The in-pixel operation is based on two principles: the output voltage is in proportion to the light intensity and the well-capacity is in proportion to the feedback output voltage. The simplified cross-section of the proposed APS and the flow diagram of the photo-charges are shown in figure 3. This figure shows the direction of photo-charges flow when the CB is controlled by the magnitude of the feedback output voltage. Through these operations, we can achieve a relatively satisfactory sensitivity in comparison with a non-linear APS such as a logarithmic APS [1], [4] and a wide dynamic range as compared with a conventional 3-transistor APS.

3. Experimental results and discussion

The measured output voltage waveforms as incident light intensity varies in the conventional 3-transistor APS and the proposed APS are shown in figure 4. It is confirmed that the output voltage of the conventional 3-transistor APS is already saturated when the light intensity is about 4000 lux, while that of the proposed APS is not saturated until 8000 lux.

The photo-electric conversion characteristics are shown in figure 5. Variation of the output voltages of the conventional 3-transistor APS and the proposed APS with light intensity were measured. In this figure, we can confirm that the dynamic range of the proposed APS is expanded in comparison with a conventional 3-transistor APS.

4. Conclusion

A dynamic range expansion technique of CMOS APS by controlling the energy barrier between the PD and the ED has been described in this paper. The dynamic range increases at the cost of an additional diode and an additional MOSFET. The proposed structure enables the control of the output voltage level by itself, as the incident light intensity varies. Consequently, this CMOS APS might be applied to a wide dynamic range CMOS image sensor.

Acknowledgements

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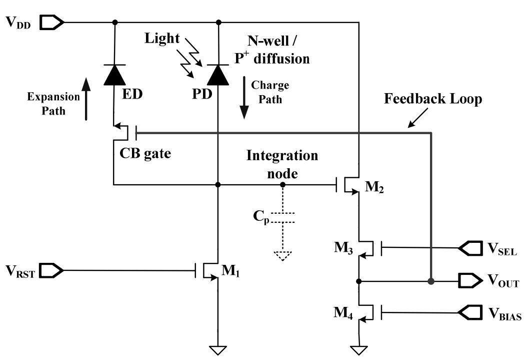

Fig. 1 Schematic diagram of the proposed APS.

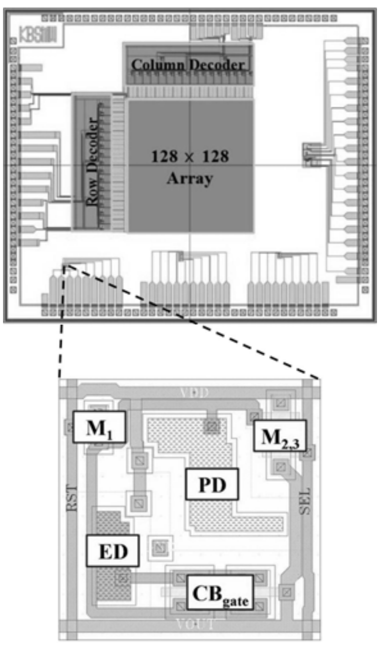

Fig. 2 Chip micrograph of the prototype.

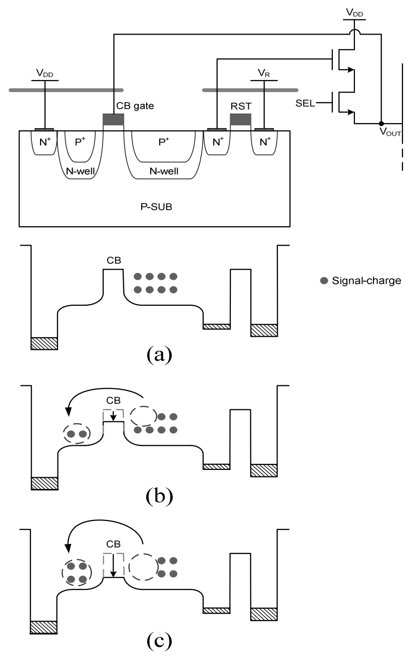

Fig. 3 Direction of photo-charge flows when the feedback voltage is transferred.
(a) at the initial state
(b) at the low light intensity
(c) at the high light intensity.

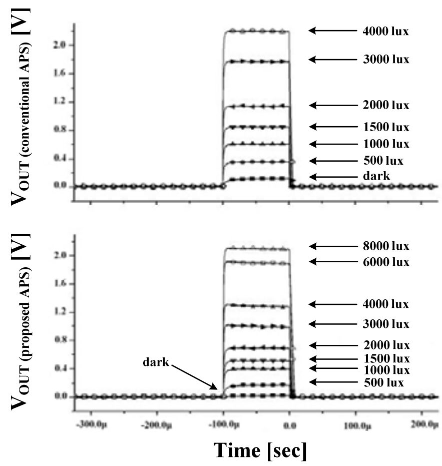

Fig. 4 Measured output voltage waveforms as incident light intensity varies.

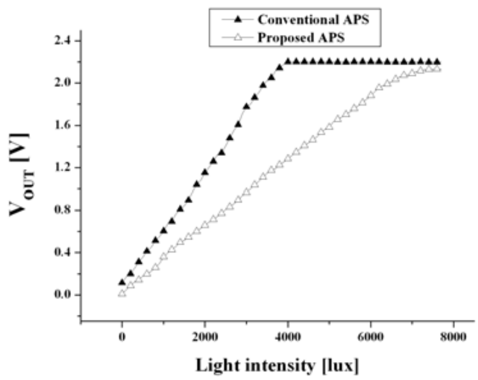

Fig. 5 Photo-electric conversion characteristics.