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A New Sampling Scheme for High Sensitivity, Extended Dynamic Range CMOS Imaging Pixel Sensors

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1. Introduction

CMOS image sensors, compared with CCD, becomes popular due to their low operation voltage, low power consumption and compatibility with standard CMOS processes [1][2]. However, the advances in process technology for logic circuits often result in degradation in CMOS image sensors' performance. For example, self-align silicide technology reduces photo-sensitivity of imager significantly. A transfer gate that isolates the sensing diode and readout diode was proposed [3] to improve charge inversion gain decades ago. However, the standard 4-T pixel suffers from low dynamic range and high dark signal. In this work, we revisit the 4-T pixel with a photodiode sensor and a transfer gate which is implemented in a standard 0.35-um CMOS logic process. The sensing diode is designed to maximize the quantum efficiency with resist protection oxide (RPO) photo/etch process while the readout diode is covered with silicide. Operation schemes and cell structure design are investigated to optimize the pixel's performance. A novel readout scheme proposed to extends dynamic range of pixel is analyzed and optimized.

2. Pixel Structure and Operation

The CMOS active pixel sensor was fabricated by the TSMC silicided 0.35-um standard CMOS logic process and was operated at 3.3V power supply. A 3200K tungsten-halogen lamp and integration sphere were used to provide uniform source of illumination. Besides, a color-compensating filter was employed to suppress infrared signal.

The circuit schematic of the conventional 4-T[3] pixel is shown in Fig.1. The transfer gate isolating the sensing diode from the readout diode (described as a junction capacitor) is biased by TX. The operating timing diagram is illustrated in Fig.2. At first, the reset pulse and the TX pulse are applied at the same time to reset both the sensing diode and the readout diode. The sensing diode is reset to V_{TX}-V_{th}. After an integration period, t_p, TX is high again at the same level. The charges stored in the sensing diode then transfer to the readout diode and result in a large voltage drop on the readout diode. The readout signal will saturate due to the limited voltage swing. With the conventional readout scheme, the voltage drop ΔV_2 saturates at a very low light intensity. As optical response shown in Fig.3, the pixel exhibits a poor dynamic range.

3. New Readout Scheme

During measurement, it is observed that the readout diode, although covered with silicide to prevent light penetration, also response to illumination (shown in Fig.2). Even though the sensitivity of the voltage drop is very low, this information can provide us the light response after ΔV_2 saturates. Thus, a new readout scheme for improving D.R. is proposed. Here we adopt a ratiometric signal processing circuit [4] illustrated in Fig.4. In Fig.5, the simulation results demonstrate the circuit can operated as designed in three supply voltages. New readout timing diagram is described in Fig.6. The output signal can be written as follows:

$$V_{out} = (\Delta V_1 + \Delta V_2)/2$$

At low luminance, ΔV_2 dominates; at high luminance, ΔV_2 saturates and ΔV_1 dominates.

4. Experimental Results & Discussions

With an additional transfer gate, the fill factor of this cell is expected to be less than the basic 3T photodiode pixel. Fig.7 compares the optical response after using new readout scheme. The maximum nonsaturating light intensity can be extended by 2.5x. Fig.8 illustrate optical response for different readout diode sizes. Small readout diode provides high conversion gain but suffers disadvantages of high sensitivity to reset noise and a larger dark signal. The sensitivity of the two readout diodes (ΔV_1 drop) are not the same is due to their almost the same light absorption coming from diffraction light for small diode size. Maximum nonsaturating input signal of the 4T pixel with and without sum output under different integration time are shown in Fig.9. It is obvious that the new readout scheme can extend the dynamic range of 4T pixels. Fig.10 shows the maximum nonsaturating input signal and dark signal of 4T pixels with two readout diode sizes. In our measurement, the dark signal is the dominant noise source and was defined as the voltage drop per second. Thus the dark signal is proportional to the integration time. Fig.11 shows the dependence of dynamic range on readout diode size and integration time compared with basic 3T pixel. Smaller integration time reaches higher dynamic range at the cost of lower sensitivity. Hence, we can optimize the readout diode size and integration time for various imaging specification.

5. Conclusions

In this paper, we report a high sensitivity CMOS photodiode image pixel by using a transfer gate. A new readout method and a ratiometric processing circuit are proposed to improve dynamic range of this pixel about 10dB. The experimental results demonstrate the pixel can achieve both high sensitivity at low illumination and extended dynamic range for high illumination.

Acknowledgement

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References

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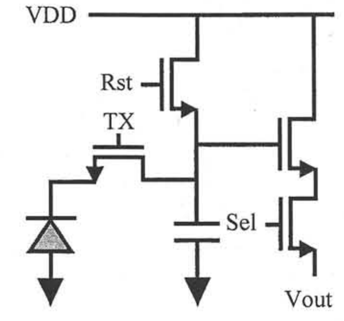

Fig.1 Circuit schematic of phtodiode pixel with transfer gate.

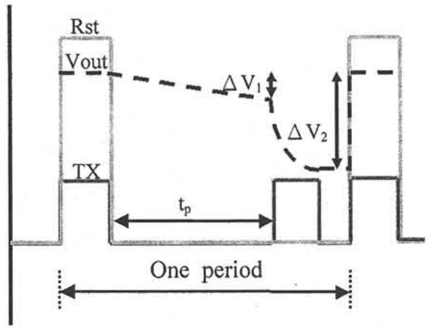

Fig.2 Timing diagram of reset pulse and TX pulse.

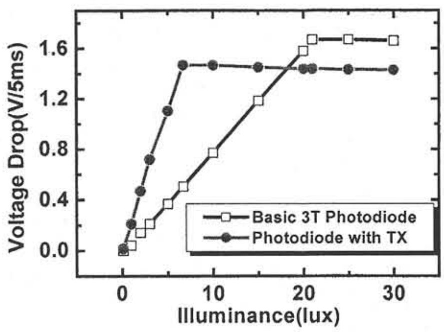

Fig.3 Optical response of TX-in photodiode and basic photodiode with integration time of 5ms.

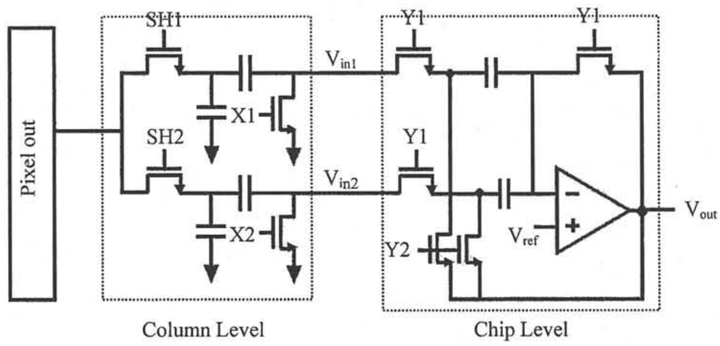

Fig.4 Schematic of readout circuit.

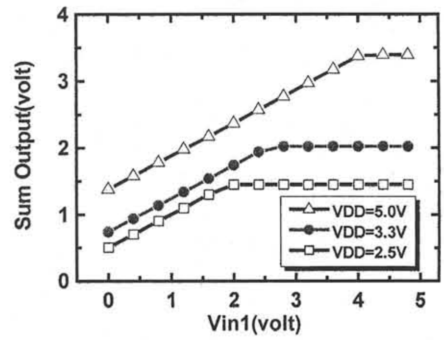

Fig.5 Simulation result of sum output circuit under different power supply with V_{in2}=Max.ΔV_2.

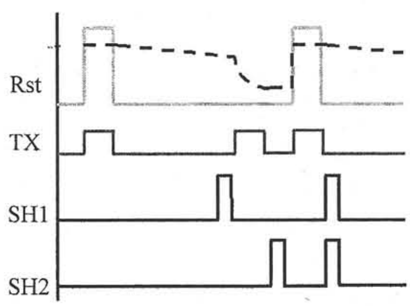

Fig.6 Timing diagram of readout operation.

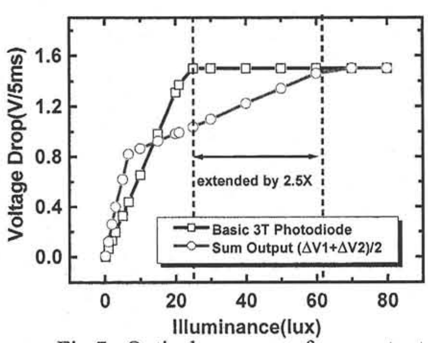

Fig.7 Optical response of sum output.

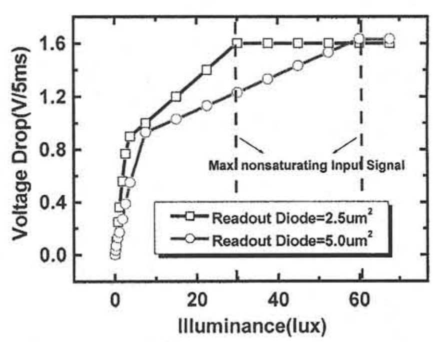

Fig.8 Optical response of 4T pixels with two different readout diode area.

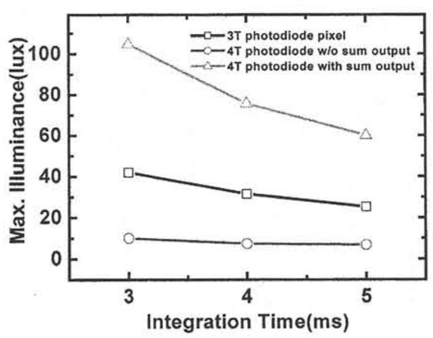

Fig.9 Max. nonsaturating input signal of 4T pixel at readout diode=5um^2 with and w/o sum output.

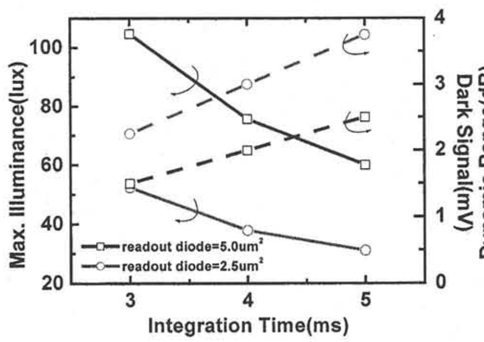

Fig.10 Max. nonsaturating input signal and dark signal of 4T pixels with different readout diode area.

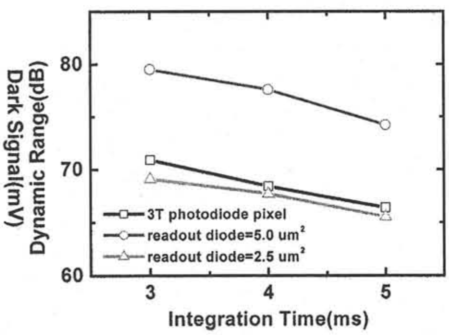

Fig.11 Dynamic range of 4T pixels dependent on integration time compared with basic 3T pixel.