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Improvement of power consumption and SNR of self-reset pixels for an implantable CMOS image sensor

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Abstract

We have developed a self-reset pixel for an implantable CMOS image sensor to measure fluorescence image with a high signal-to-noise ratio (SNR). In a self-reset pixel, more number of reset actions occur than in a conventional pixel. This may cause the increase of power consumption in the sensor and thus increase temperature. Since heat degrades SNR drastically, it is essential to reduce power consumption in self-reset architecture.

In this paper, we have optimized self-reset circuits in low voltage operation of 1.7 V, and successfully achieved 1/100 decrease of power consumption and increase of SNR by 10 dB compared with 3.3 V operation.

1. Introduction

An Implantable complementary metal-oxide semiconductor (CMOS) image sensor can measure brain function under freely moving condition by observing blood flow correlated with neural activities [1] as shown in Figure 1. A self-reset CMOS image sensor with high signal-to-noise ratio (SNR) is expected to detect weak signals of neural activity such as fluorescence change of Ca^{2+} indicator or voltage-sensitive dye (VSD) expressed in neural cells.

Although the self-reset sensor achieved SNR of over 60 dB with a frame rate of over 200 fps in our previous work [2], power consumption per surface area of the sensor was relatively high compared with a conventional image sensor. Therefore, the sensor heated up at nearly 100°C in the surface of brain tissue. The heat causes serious damage in brain tissue and deteriorates SNR in the sensor.

In this paper, we developed a low power consumption self-reset pixel of an implantable CMOS image sensor for decreasing heat level. The newly designed sensor achieved higher SNR than the previous sensor.

2. Self-reset pixel for implantable image sensor

2.1 Circuit schematic and layout of self-reset pixels

A self-reset function avoids pixel saturations by resetting its pixel output level when the level reaches to a threshold value. As shown in Figs. 2(a) and (b), the pixel circuits are consisted of a 3-Tr active pixel sensor (APS), a 4-Tr Schmitt trigger inverter and reset transistors. The pixel was miniaturized to 15 × 15 µm, because spatial resolution will be determined by the pixel size of the image sensor in the use of contact imaging of the brain. The inverter detects voltage level of a photo diode V_{PD}, and the inverter output connected to the reset transistor inverts its output level when V_{PD} reaches the threshold value. This action triggers the self-resetting, while conventional resetting per a frame is triggered by another reset transistor.

2. 2 Power consumption of self-reset pixel

In the previous self-reset pixel as shown in Fig. 2(a), penetration current was occurred in the Schmitt trigger inverter at the transitional condition of the self-resetting. To avoid this shoot-through current, we designed a pixel circuit to decrease the power supply voltage of the Schmitt trigger inverter. Fig. 2(b) shows the pixel circuit of the self-reset pixel for decreasing power supply voltage VDD2 of the Schmitt trigger inverter.

Fig. 3 shows a simulation result of power supply voltage versus power consumption amount of the 4-Tr Schmitt trigger inverter. We found that the power consumption amount decreased exponentially as decreasing the power supply voltage.

Fig. 4 shows a photograph of the newly designed self-reset CMOS image sensor chip. The power supply voltage of the inverter was set to 1.70 V while previous voltage was 3.3 V. Actual measurement value of the total power consumption amount of the Schmitt trigger inverters in the sensor was 0.8 mW, while the previous sensor was 75.6 mW. The major improvement was achieved in the power consumption.

2.3 SNR of self-reset pixels

Figs. 5(a)-(c) show illuminated light energy versus pixel output intensity, noise intensity, and SNR, respectively. The values obtained in the previous and newly designed self-reset pixel were plotted with black and red dots, respectively. Green LEDs (central wavelength: 525 nm) were used as a light source. Fig. 5(a) shows that the sensitivity of the newly designed self-reset sensor was lower than the previous sensor. In contrast, Fig. 5(b) shows that the noise intensity of the newly designed pixel was drastically reduced in the region of high exposure light energy. The dark noise intensity in Fig. 5(b) is almost the same between the newly designed pixel and the previous pixel. On the other hand, noise intensity around the self-resetting is remarkably lower in the newly designed pixel than the previous pixel. Consequently, as shown in Fig. 5(c), the peak SNR of the newly designed sensor was successfully achieved over 70 dB at exposure light energy of over 5×10^{-6} J/cm^2. The heat reduction probably contributed to the increase of the SNR.

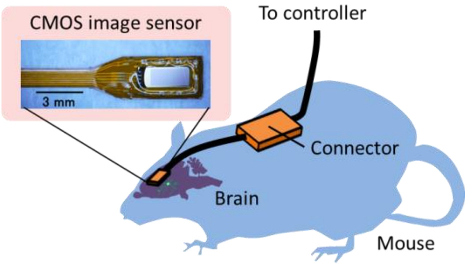

Figure 1 Schematics of brain functional imaging using an implantable CMOS image sensor.

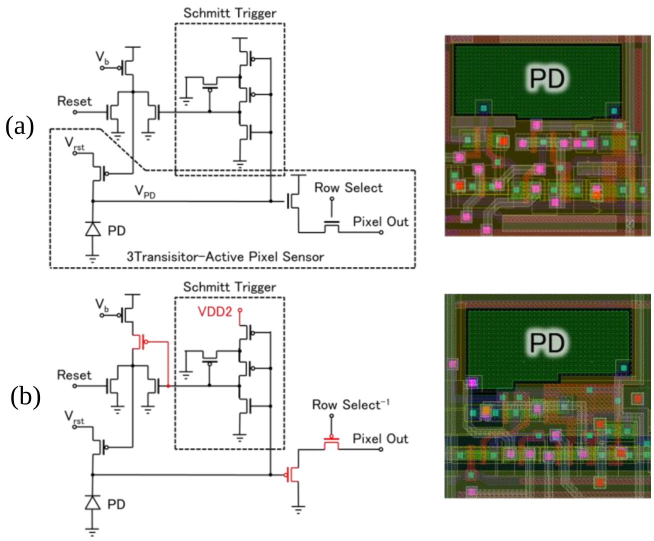

Fig. 2 (a) Pixel circuit and layout of the previous self-reset CMOS image sensor. (b) Pixel circuit and layout of newly designed self-reset CMOS image sensor. Changed points in the circuit were highlighted in red color.

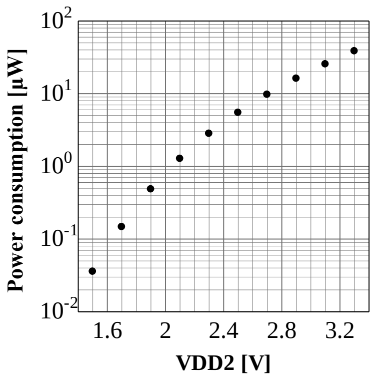

Fig. 3 Simulation result of power supply voltage versus power consumption of the 4-Tr Schmitt trigger inverter.

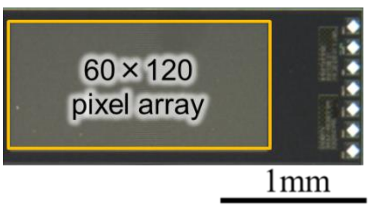

Fig. 4 Photograph of newly designed self-reset image sensor chip. The sensor is small enough for implantation into a mouse brain.

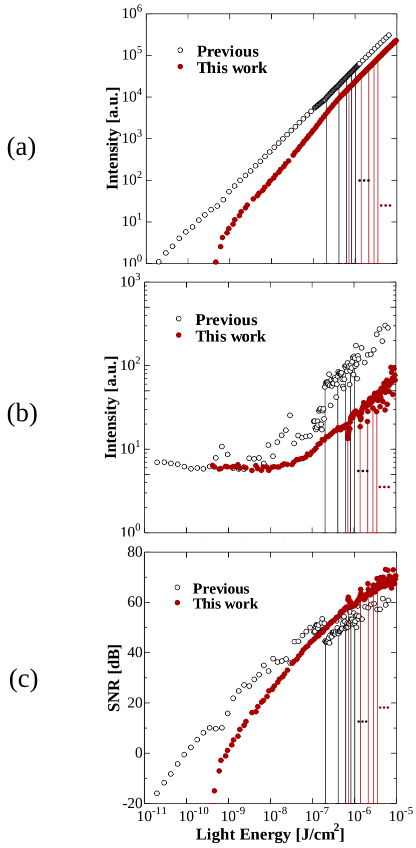

Fig. 5 Characteristics of previous and newly designed self-reset pixels. Solid lines indicate the first five self-resetting points. (a) Exposed light energy versus pixel output intensity. Each point was converted by self-reset counts. (b) Exposed light energy versus noise intensity. (c) Exposed light energy versus SNR calculated from (a) and (b).

3. Conclusions

We developed a high SNR self-reset CMOS image sensor for brain functional imaging. In this paper, the higher SNR self-reset CMOS image sensor than previous sensor was developed by reducing the power consumption of the sensor. The newly designed sensor is expected to be used for detecting weak signals of neural activity in the brain research.

Acknowledgements

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