Demonstration of a frequency-demodulation CMOS image sensor and its improvement of image quality

K. Yamamoto, Y. Oya, K. Kagawa, J. Ohta, M. Nunoshita, K. Watanabe*
Nara Institute of Science and Technology, 8916-5 Ikoma, Nara 630-0101, Japan
Tel: +81-743-72-6051, Fax: +81-743-72-6059, Email: ohta@ms.aist-nara.ac.jp
** Mirocsingal Co. Ltd.*

Abstract

This paper describes a frequency-demodulation CMOS image sensor to improve its image quality. We have already demonstrated the fundamental characteristics of a frequency-demodulation function but the sensor shows relatively poor saturation characteristics. By introducing to sweep out residual carriers in a photogate and to discharge them into an overflow drain, a fabricated image sensor using a standard 0.6 μm CMOS technology exhibits better saturation characteristics. The output at the saturation region increases 30 times larger than the original one.

1. Introduction

Image sensors to detect only images to be illuminated with modulation light are very effective to machine vision, ITS (intelligent transportation system), surveillance and so on, because they make possible to acquire images little affected by background illumination condition. Several sensors with such functions have been reported so far [1]-[4].

We have proposed and demonstrated a frequency-demodulation CMOS image sensor for capturing images only by the modulated light is proposed and demonstrated [5]. The pixel circuit as shown in Fig. 1 has two FD (floating diffusion) for accumulating signal charges and one photo-gate (PG) for detecting the modulated light and the background light. By operating the image sensor synchronously with a frequency and a phase of the modulated light, signal charges generated by the modulated light and the background light are accumulated at FD of one side, while signal charges generated only by the background light are accumulated at another FD, respectively. By subtracting outputs of two FD with the off-chip subtraction circuits, images produced only by the modulated light can be obtained.

Based on the proposed circuit, we have fabricated an image sensor with 64 x 64 pixels by using 0.6 μm CMOS technology and demonstrated that the sensor can capture images only by modulated light as shown in Fig. 2. In this figure, a marker attached to an object is modulated in its intensity and correctly captured by the sensor. This suggests that the sensor can be applied to use of target tracking and motion capturing.

2. Improvement of saturation characteristics

Although we demonstrate the effectiveness of the sensor, we have found that the sensor shows anomalous saturation characteristics when the modulated light is too strong; the modulated output saturates and then decreases when the modulated input light intensity increases as shown in Fig. 3. Figure 4 clearly demonstrates the effect, where the modulated light spot is captured by sensor; the extracted spot image has a hole in the center, because the intensity of the center is saturated. This effect is caused as follows; when carriers originated form modulation light diffuse with some reason and then flow into the FD to be stored only carriers from background illumination. It noted that two FDs essentially arises the problem, thus a conventional image sensor is not generally suffered from the effect.

We have suppressed the effect by introducing an overflow drain combined with adding a reset timing of the PG. The PG reset confirms to sweep out residual carriers. If carriers originated from the modulated light are left in the PG, they are transferred into the FD for only background light accumulation. We have fabricated a 64x64-pixel array using 0.6 μm CMOS technology. Figure 5 shows the pixel layout and Figure 6 shows the chip photo-micrograph. Device specifications are shown in Table 1.

Figure 7 shows the experimental result of the output characteristics in modulated light and clearly demonstrates the improvements. The anomalous saturation is suppressed by introducing both the overflow drain and PG reset. The output at the saturation region increases 30 times larger than one before the improvement. Figure 8 also shows a captured image of the modulated light spot by the improved sensor under the same condition as in Fig. 4. The spot figure is correctly captured. Figure 9 shows an image captured by the improved sensor.

Finally, we address another issue to be solved. In Fig. 3, when the background level is zero, the output does not increase even if the modulated light increases. This is presumably due to the effect of the "parasitic ndiff region" which lies between the PG and the transfer gates, where initial charges are trapped and cannot contribute to the output voltage. When charges created by background light completely fill the "parasitic ndiff region", then the following charges can flow into the FD and thus the output is appeared. By simulating the potential profile using a device simulation, we have confirmed that the potential valley exists between PG and FD, and acts as the trap for the transferred charges. Once the region is filled, then the threshold mismatch increases the error of the subtraction and thus reduces the sensitivity.

To alleviate the effect of the "parasitic ndiff region", we propose a reset operation of the "parasitic ndiff region". By filling charges in the region by the reset operation, it is expected to reduce the difference between the two outputs. We fabricated a test circuit to confirm this idea. In the circuit, we added an NMOSFET between the "parasitic ndiff region" and GND. We have confirmed that the output characteristics in the low light intensity region are improved by introducing this proposed mechanism.

4. Conclusion

We have demonstrated a 64x64-pixel image sensor to detect only modulated light. The sensor is improved in the saturation characteristics by introducing an overflow drain and the PG reset action. Also an offset effect is discussed. "n-diff parasitic region" possibly causes the effect and ndiff reset is effective to alleviate the problem.

References

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Table 1: Specifications of a frequency-demodulation CMOS image sensor

Technology	0.6μm CMOS 2-poly 3-metal
Chip size	5.58 mm x 5.58 mm
Pixel number	64 x 64
Pixel size	42 μm x 42 μm
Photogate size	349.2 μm2
Floating diffusion size	12 μm x 3 μm
Fill factor	19.8%
Power supply voltage	5 V

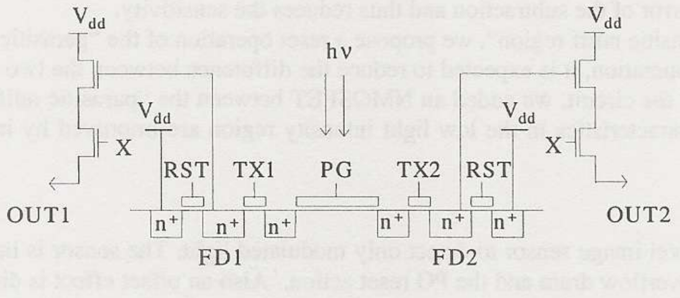


Figure 1: Pixel structure.

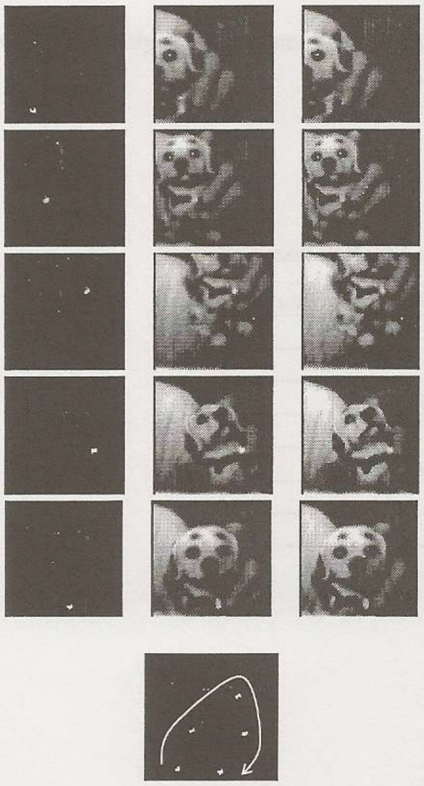


Figure 2: Demonstration of marker tracking.
The images are placed in order of time from the top to the bottom.
The left column: modulated light pattern extracted by the sensor. The middle column: the output from modulated light and background light. The right column: the output from only background light. The lowest figure shows the moving trace of the marker. For convenience, the moving direction or the track of the LED is superimposed.

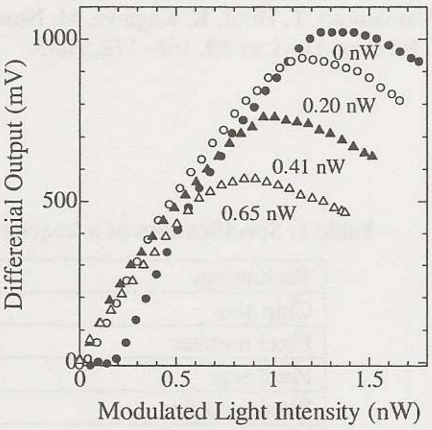
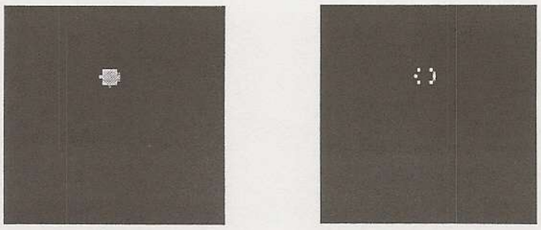


Figure 3: Output characteristics of the original sensor. The parameters are background illumination level.



(a) (b)

Figure 4: Example of anomalous output. (a): input modulated spot image, (b) extracted spot image.

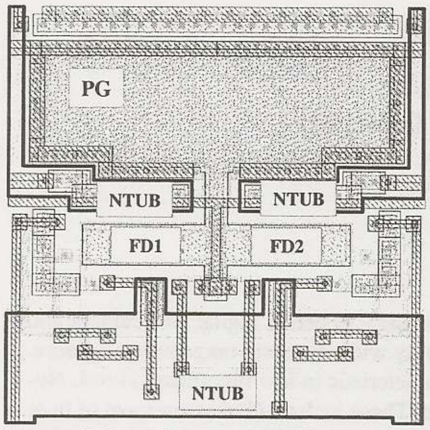


Figure 5: Pixel layout. NTUB means an overflow drain composed of NTUB layer.

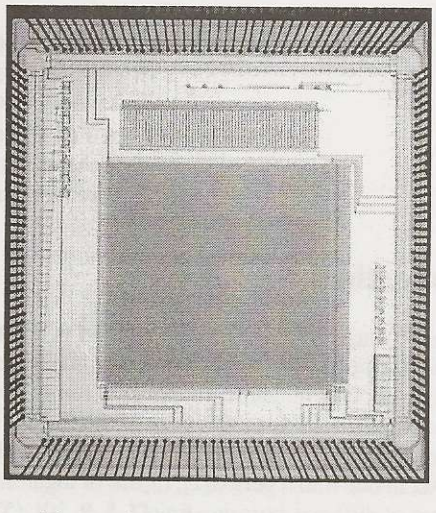


Figure 6: Chip photomicrograph.

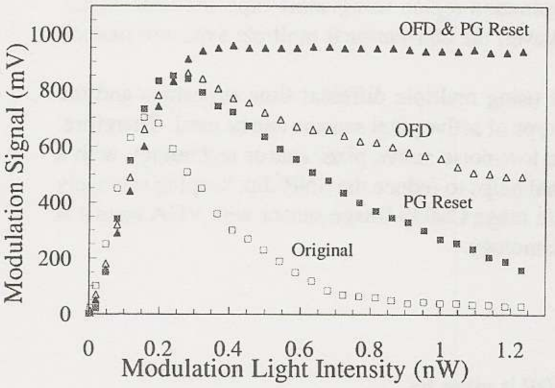


Figure 7: Improvement of saturation characteristics. OFD: overflow drain, PG reset: operation of photogate reset action.

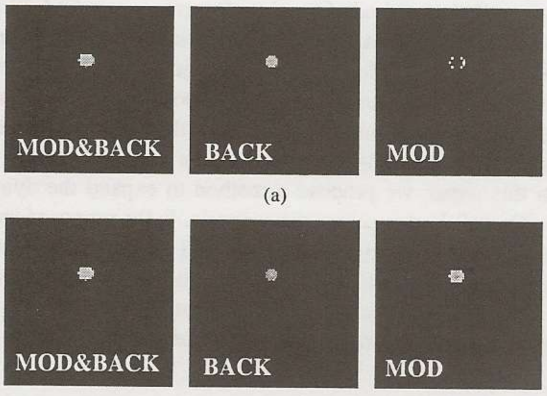


Figure 8: Extraction of a modulated spot light. (a) before improvement, (b) after improvement. MOD and BACK means the output from modulation and background illumination, respectively.

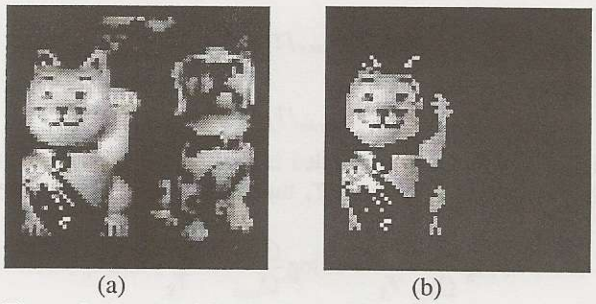


Figure 9: Captured image by the improved sensor. (a) Output from modulation and background illumination, (b) Output only from modulation.