Improvement of saturation characteristics of a frequency-demodulation CMOS image sensor

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Abstract - This paper demonstrates improvement of image quality in a frequency-demodulation CMOS image sensor. We have already demonstrated fundamental characteristics of a frequency-demodulation function but the sensor shows relatively poor saturation characteristics due to a crosstalk effect. By introducing sweeping out residual carriers in a photogate and discharging 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.

I. Introduction

A frequency-demodulation CMOS image sensor for capturing images only by the modulated light has been proposed and demonstrated [1]. In each pixel the sensor has two FD (floating diffusion) regions for accumulating signal charges and one photo-gate (PG) for detecting the modulated light and the background light as shown in Fig. 1. 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 FDs, images produced only by the modulated light can be obtained. Based on the proposed circuit, we have demonstrated that an image can capture modulated image. However, the saturation characteristics of the sensor were relatively poor mainly due to a crosstalk between the two FDs.

In this summary, we propose a method to alleviate the effect of the crosstalk on the saturation characteristics.

II. Improvement of saturation characteristics

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 the curve referred as "original" of Fig. 2. Figure 3(a) clearly shows the effect, where the modulated light spot is captured by the sensor; the extracted spot image has a hole in the center, because the intensity of the center is saturated. This effect is caused from a crosstalk of carriers and explained as follows; when carriers originated from modulation light diffuse and then flow into the FD to be stored only carriers from background illumination.

We have suppressed the effect by introducing an overflow drain combined with adding a reset timing of the PG. The PG reset causes residual carriers to be swept. If carriers originated from the modulated light are left in the PG, they are transferred into the FD for only background light accumulation. Based on the improvement, we have fabricated a 64x64-pixel array using 0.6 μm CMOS technology. Figure 4 shows the chip photomicrograph and the pixel layout. The specification of the fabricated chip is summarized in Table 1.

Figure 2 shows the experimental results 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 the original one. Figure 3(b) shows a captured image of the modulated light spot by the improved sensor. The spot figure is correctly captured as compared with one taken by the original sensor as shown in Fig. 3(a). Figure 5 shows the captured images of a gray-scale chart before and after the improvements. In the experiment, there is no background image, but the crosstalk image of the gray-scale chart appeared in the background image before the improvements and thus the gray-scale level in the modulated image is not displayed correctly as shown in Fig. 5 (a). Figure 5 (b) clearly demonstrates the correct gray-scale level in the modulated image. This improvement in the gray-scale level clearly reflects the image quality of a captured object as shown in Fig. 6.

III. Summary and Conclusions
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. The output at the saturation region increases 30 times larger than the original one.

References

Figure 1: Pixel structure.

Figure 2: Modulation signal as a function of a modulation light intensity before and after improvement of characteristics. OFD: overflow drain, PG reset: operation of photogate reset action.

Figure 3: 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 4: A fabricated 64x64 sensor chip. (a) chip photomicrograph, (b) Pixel layout. NTUB means an overflow drain composed of NTUB layer.

Figure 5: Captured images of gray-scale chart. (a) before improvement, (b) after improvement. MOD and BACK are the same notation as in Fig. 3.

Figure 6: Captured image by the improved sensor. (a) Output from modulation and background illumination, (b) Output only from modulation.

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

<table>
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<tr>
<th>Specification</th>
<th>Value</th>
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<tbody>
<tr>
<td>Technology</td>
<td>0.6μm CMOS 2-poly 3-metal</td>
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<tr>
<td>Chip size</td>
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<tr>
<td>Pixel number</td>
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<tr>
<td>Pixel size</td>
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<tr>
<td>Photogate size</td>
<td>349.2 μm²</td>
</tr>
<tr>
<td>Floating diffusion size</td>
<td>12 μm x 3 μm</td>
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<tr>
<td>Fill factor</td>
<td>19.8%</td>
</tr>
<tr>
<td>Power supply voltage</td>
<td>5 V</td>
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</tbody>
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