Effects of Aperture Width on the Performance of Monochrome CMOS Image Sensor Using Offset Pixel Aperture Technique for Depth Extraction

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Abstract This paper presents the effects of aperture width on the performance of monochrome CMOS image sensor using offset pixel aperture technique for depth extraction. The offset pixel aperture pattern comprises two types: left-offset pixel aperture and right-offset pixel aperture. The two types of offset pixel aperture are divided into odd and even rows and integrated in a pixel array. The aperture width of the offset pixel aperture in the proposed monochrome CMOS image sensor has a variation from 0.3-μm to 0.5-μm. The disparity of the image increases as the aperture width decreases, but the sensitivity decreases. The depth information could be obtained by the disparity which is acquired from the proposed monochrome CMOS image sensor using offset pixel aperture technique, without requiring external light source. Therefore, the proposed monochrome CMOS image sensor using offset pixel aperture technique is easy to apply to miniaturized devices. The proposed monochrome CMOS image sensor using offset pixel aperture technique was designed and manufactured using 0.11-μm CMOS image sensor process. Experimental results have been compared with simulation results.

Keywords: aperture width, monochrome, CMOS image sensor, offset pixel aperture, depth extraction

1. Introduction

Images are essential data in modern society. A human acquires more detailed information easily from the visual data. Since ordinary images have only two-dimensional (2D) data, it is difficult to obtain depth information. Therefore, extraction of depth information is important process to implement the three-dimensional (3D) imaging system. In the techniques for depth extraction, there are a time-of-flight (TOF), a light field, and a stereo vision [1-4]. The TOF is a technique that uses an interlocked high-power light source with a camera. It measures the time when the emitted light is reflected by the object and returns, and obtains the depth information accordingly. The stereo vision technique acquires depth information by reproducing binocular parallax phenomenon using two cameras. The structured light is a technique for analysis depth information using a pattern of light projected onto the object at an angle. However, the above described techniques for depth extraction are required the additional elements on the outside of the image sensor. This is a demerit to miniaturization of the image sensor system.

In the proposed monochrome (MONO) CMOS image sensor (CIS) using offset pixel aperture (OPA) technique, the depth information could be acquired by using a simple structure in which two types of OPA pixels are integrated in pixel array. The proposed MONO CIS using OPA technique was designed and manufactured using 0.11-μm CIS process.

2. Architecture

The structure of the proposed MONO CIS using OPA technique is shown in Fig.1. The structure is based on a pinned photodiode and four-transistors. The STI is a shallow trench isolation and the FD node is a floating diffusion node. In previously proposed CIS using OPA technique, the red, blue, LOPA, and ROPA are used for color pattern [5-7]. However, in the proposed MONO CIS, the color filters are not integrated and the OPA patterns are integrated in the pixel array.

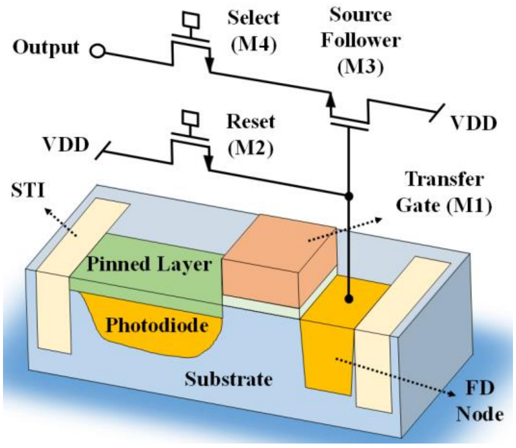

Fig. 1. The structure of the proposed MONO CIS using OPA technique.

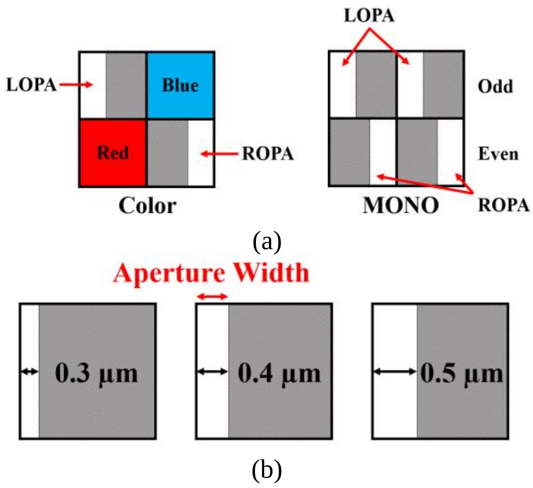

Fig. 2. (a) Comparison of the OPA patterns between color and MONO CIS using OPA technique, and (b) the variation of OPA width for the measurement of performance difference.

Fig. 2 (a) shows the comparison of the OPA patterns between color and MONO CIS using OPA technique. The OPA pixels are divided into two types, left-OPA (LOPA) pixel and right-OPA (ROPA) pixel as shown in Fig. 2 (a). Patterns of the two OPA are arranged in odd row of LOPA and even row of ROPA.

Fig. 2 (b) is shows the variation of OPA width for the measurement of performance difference. The OPA pattern is designed with the first metal layer. The light enters through the microlens and transfer to the pixels. At this time, since the positions of the opening areas of LOPA and ROPA are opposite to each other, a difference occurs in the output signal due to the generated signal electrons by the amount of the light and an incidence angle. This difference is called disparity, and it is possible to calculate the distance from the object and obtain the depth information according to the degree of disparity.

3. Measurement and Results

Fig. 3 shows the measurement method of chief ray angle (CRA) for analyzing the performance difference depending on the OPA width. A collimator is connected to the light source, and the light is transmitted to the sensor. Then, angle of the sensor was measured with varying in the range of -30 to 30 degrees. This gives the same effect as changing the incident angle of the light transmitted to the sensor, and it is possible to confirm the disparity between LOPA pixel and ROPA pixel according to the incident angle. At this time, it is important to rotate the center axis of the sensor, which is the reference axis. If the center axis of the sensor does not match with the axis of rotation, the central axis of the light from the light source is off from the center of the sensor. In this case, the result of the measured CRA is not correct. The CRA measurement result depending on OPA width is shown in Fig. 4. The disparity is 40 degrees when the OPA width is 0.5-µm, and it is 42 degrees when the OPA width is 0.4-µm. Also, the proposed MONO CIS with 0.3-µm OPA width has the disparity of 44 degrees. As the width of OPA increases, the degree of the disparity decreases as shown in this result. However, the sensitivity increases as the width of OPA increases.

4. Conclusion

In this study, we measured characteristic difference of the proposed MONO CIS using OPA technique depending on the CRA. The proposed MONO CIS using OPA technique was designed and manufactured using the 0.11-µm CMOS process. The pixel array of the proposed MONO CIS using OPA technique was designed without a color filter pattern. OPA were designed using the first metal layer in the CIS process. The OPA pattern array consists LOPA and ROPA. And, two types of the OPA pattern are divided into odd and even row.

In the measurement results, the degree of the disparity increases with decrease of OPA width. Because, as the width of OPA increases, the extent of aperture offset decreases. And, the sensitivity increases with increase of OPA width. This is because the amount of light which is transmitted to the photodiode increases, as the width of OPA increases. The depth information could be obtained using the disparity that occurred by the OPA pattern, without requiring external factors such as light source having a high-power, the plurality of cameras and special algorithms. Pixel arrays using OPA technique with the inherent simple structure could be implemented using standard CIS process.

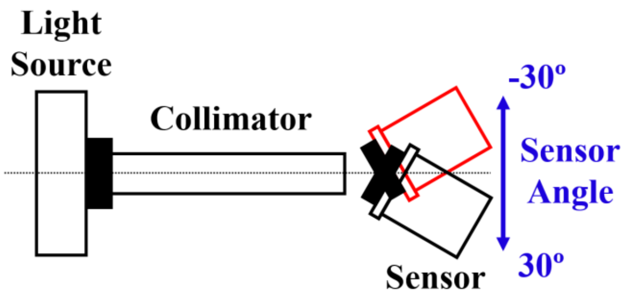

Fig. 3. Measurement method of CRA for analyzing the performance difference depending on the OPA width.

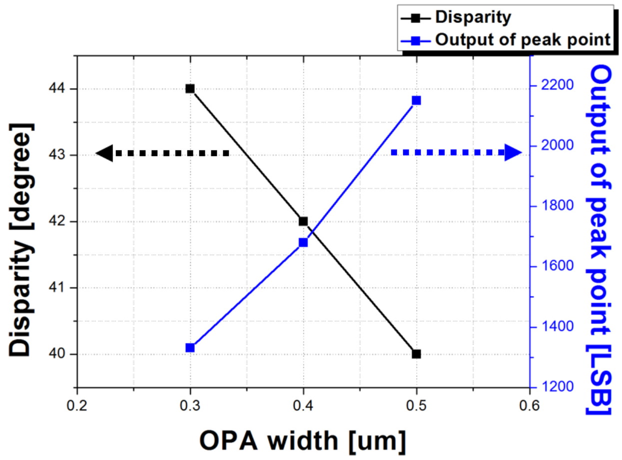

Fig. 4. The CRA measurement results depending on OPA width.

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