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Improvement of Color Separation Characteristics of a Side-Illuminated Color Photo Sensor

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Abstract

Superior color separation characteristic could be obtained by using an improved side-illuminated color photosensor.

1. Introduction

Silicon imagers can detect visible light separately from near-infrared light. For color imaging, the Bayer method using color filters is applied [1]. However, in the process used to obtain the color information, there are problems with the generation of false colors and moiré patterns. The Foveon method is a color imaging technique that does not use color filters [2]. However, because the signal electrode is not independent of each of the PN junction layers, it is necessary to perform an extraction operation to separate the color signals. Additionally, a special process is required for precise formation of the three-layer NPN silicon region.

We proposed a side-illuminated color photo sensor which allows light to be injected from the side of the silicon substrate. The proposed method uses a standard silicon CMOS process, which reduces fabrication costs and enables color imaging without the use of color filters. Also, because each of the PN junctions is isolated from the others, the color information can be separated easily. We evaluated the color separation characteristics by using a test device, and have confirmed the effectiveness of this side-illuminated color photo sensor [3]. In this study, we confirmed that superior color separation characteristics can be obtained by improving the sensor's pixel structure.

2. Improvement of Side-Illuminated Color Photo Sensor

Figure 1 shows a cross section of the pixel structure of our proposed side-illuminated color photo sensor. On the P-type silicon substrate surface, four photodetection areas (first, second, third, and fourth areas) are formed in turn from the side in the direction of light incidence. The incident blue, green, red, and near-infrared light beams are detected by the first, second, third, and fourth photodetection areas. Also, to minimize incident light attenuation, the side area is removed to a depth *d*. It is also desirable that the silicon width from the chip side to the edge of the photodiode, denoted by *r*, is small.

Figure 2 shows the pixel layout of our previously proposed side-illuminated type color photo sensor. The pixel was designed using a 0.35 μm CMOS rule. The pixel pitch, the depth *d*, and the side silicon width *r* were 9.0, 80, and 1.0 μm, respectively. The photodetection area width of 7.0 μm was buried in the n^+S/D area without a gap so that each photodetection area detected light without loss. The lengths of the first, second, third, and fourth areas were 0.7, 0.7, 2.0, and 40 μm, respectively, and the spacing between the photodetection areas was 0.6 μm. Figure 3 shows the color separation characteristics obtained using this pixel structure [3]. A wide spectrum characteristic was detected as a whole, but four colors, i.e. blue, green, red, and near-infrared, could be separated. However, the peak wavelengths of the *B*, *G*, *R*, and *IR* were 480, 650, 775, and 925 nm, respectively, and for both *G* and *R*, the peak wavelengths shifted to the longer wavelength side of the real color range. This is because the photodetection areas that were designed in 0.35 μm CMOS technology are long and the spacing between these areas is wide. Therefore, as shown in Fig. 4, we proposed a new pixel structure to shorten each photodetection area without violating the design rule. By removing part of the edge of the photodetection areas, it was possible to shorten each of the photodetection areas. The lengths of the first, second, third, and fourth areas are then 0.3, 0.5, 1.4, and 40 μm, respectively, and the space between the photodetection areas is 0.6 μm.

3. Fabrication of Test Chip

Figure 5 shows a microphotograph of the test chip, which was fabricated using a 1-poly 4-metal 0.35 μm CMOS process. The chip dimensions are 5000×5000 μm^2, and the silicon substrate thickness is 730 μm. Three types of line sensor circuit with various margins *r* from the photodiode edge were located in this test chip. The values of *r* in sensor circuits A, B, and C were 0.5, 1.0, and 0.5 μm, respectively. The pixel layout of sensor C was as shown in Fig. 4, and was used for the measurement in this case. Each sensor was formed using a 128-pixel array with a pixel pitch of 9.0 μm. Additionally, the sensor surfaces were coated with a metal layer for shading. The sensors can therefore only detect the light that is incident from the side. The metal layer that is used to shade the circuit also acts as a mask when the side area is removed.

The side area of the test chip shown in Fig. 5 is 1000 μm wide and 5000 μm long. This area was constructed by using the SiO_2 layer on the Si substrate. We etched this area to an approximate depth *d*=16 μm by a combination of reactive ion etching (RIE) for the SiO_2 layer and a conventional deep-RIE process for the Si substrate. The etching mask was formed using the resist mask used in the lithography machine to cover the chip patterns. We etched by dividing the process into 3 stages for resist mask durability. After etching, the SEM image of the chip cross section was as shown in Fig. 6. The side of the sensor was etched vertically.

The pixel circuit configuration is shown in Fig. 7. The supply voltage is 3.0 V. The bias voltage, PixVb, provides the photodiode reset voltage, and was set as 1.5 V for these measurements. The light is irradiated along the four photodiodes from the side towards the tip. The AMI Tr. converts the photodiode potential into a current. The *I*–*V* conversion circuit then converts the current, which is selected by a 2 bit decoder, into a voltage signal. The signals are then output in order from the first area to the fourth area.

4. Measurement Results

A light irradiation experiment was performed on the test chip, and color separation characteristics were obtained for a range of colors from visible to near-infrared light. Figure 8 shows the measurement results for fixed pattern noise (FPN) and random noise (RN) for sensor circuit C before and after removal of the side area. The horizontal axis in the figure represents the photodetection areas, and the vertical axis represents the standard deviations for each type of noise voltage. The results for both noise patterns remained largely unchanged after the RIE process, which indicates that little damage was caused during RIE.

Figure 9 shows the color separation characteristics obtained using sensor circuit C. Four colors can be separated. The peak wavelengths for *B*, *G*, *R*, and *IR* are 450, 525, 625, and 875 nm, respectively, and these values can be put in a real color range. Simulations indicate that the widths of the color separation characteristics can be measured more narrowly by using 0.18 µm CMOS technology, which would easily reduce the size of the photodetection areas [3].

5. Conclusions

By remodeling the pixel structure of the side-illuminated photo sensor proposed in our study, the color separation characteristics can be placed in a real color range. The proposed method can only be used to form line sensors. However, an image sensor could be formed by first thinning the substrate used for the proposed sensor, and then laminating several of these sensors together to form the image sensor structure [3].

Acknowledgements

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References

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[2] Richard Billings Merrill, U. S. Patent 5,965,875, October 1999 (filed 1998).
[3] T.Ariyoshi, A.Baba, and Y.Arima, Jpn. J. Appl. Phys. 52 (2013) 04CE10.

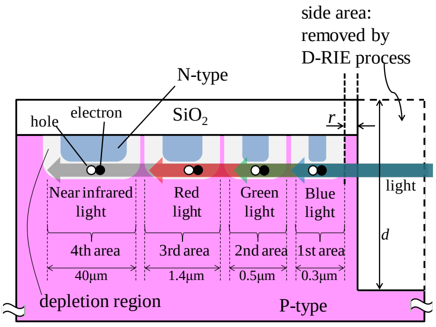

Fig. 1 Pixel structure of the side-illuminated color photo sensor.

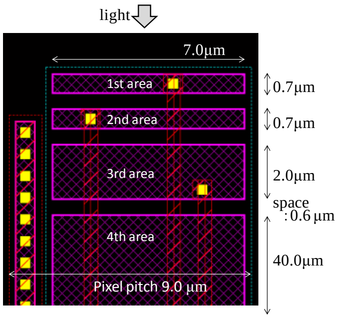

Fig. 2 Previous pixel layout.

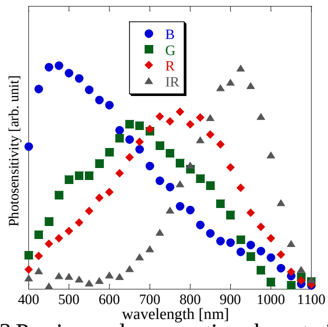

Fig. 3 Previous color separation characteristics.

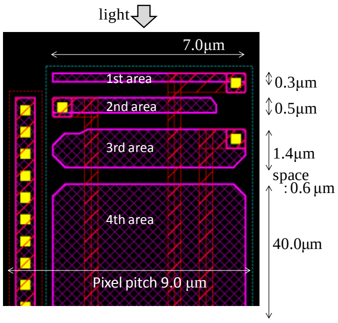

Fig. 4 Proposed new pixel layout.

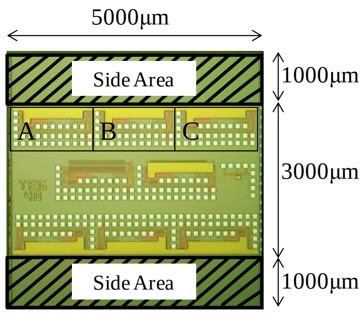

Fig. 5 Microphotograph of the test chip.

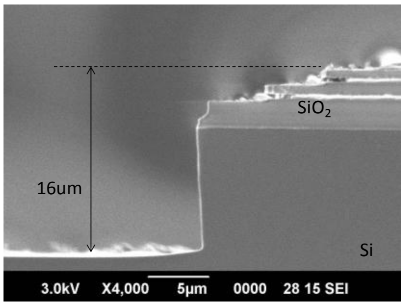

Fig. 6 SEM image of chip cross section.

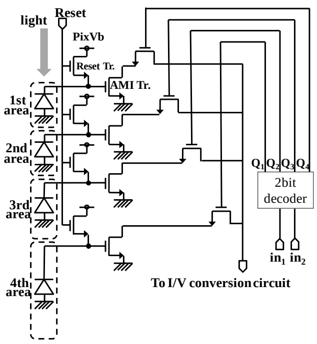

Fig. 7 Measurement circuit.

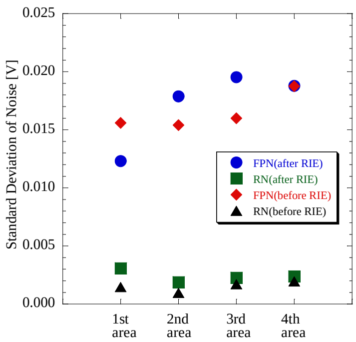

Fig. 8 Measured noise.

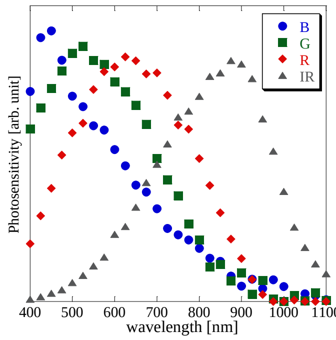

Fig. 9 Measurement results for the color separation characteristics.