Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp1031-1032

Improved Near-Infrared Sensitivity for a Side-Illuminated Photo Sensor

Tetsuya ARIYOSHI, Noriyuki URYU, Akiyoshi BABA, and Yutaka ARIMA

Center for Microelectronic Systems, Kyushu Institute of Technology
680-4, Kawazu, Iizuka, Fukuoka 820-8502, Japan
TEL: +81-948-29-7590, FAX: +81-948-29-7586, E-Mail: ariyoshi@cms.kyutech.ac.jp

1. Introduction

Conventional silicon sensors can detect near-infrared light at wavelengths up to 1.1 μm. However, the absorption ratio of near-infrared light for silicon is lower than that for visible light [1]. Moreover, the structure of conventional image sensors causes decreased sensitivity to near-infrared light. To solve this problem, attempts have been made to improve the near-infrared sensitivity of the sensors by creating a doping concentration gradient that increases with depth [2]. In addition, a study investigated making columns on the silicon surface and injecting sulfur into the substrate [3].

We proposed a side-illuminated photo sensor which allows near-infrared light to be injected from the side of the silicon substrate. The proposed method uses a standard silicon CMOS process, which reduces costs and improves sensitivity. Our method enables an image to be produced with a short exposure time, which is beneficial for applications, such as night vision cameras, that require high-speed imaging at a reasonable price. To confirm the effectiveness of this side-illuminated photo sensor, we fabricated a test chip and evaluated it.

2. Pixel Structure of a Side-Illuminated Photo Sensor

Figure 1 shows a cross section of a photodiode from a conventional pixel circuit. Generated charges (electron–hole pairs) are collected in the depletion region which forms at the PN junction. The PN junction, which was fabricated using a standard CMOS process, formed a few micrometers below the surface. However, near-infrared light, which has wavelengths ranging from 780 to 1000 nm, penetrates into the silicon substrate 10 to 100 μm. Thus, most of the generated charges are wasted.

Figure 2 shows the pixel structure of the proposed side-illuminated photo sensor. The key feature of this method is that the length of the photodiode (L) is similar to the penetration depth of the near-infrared light. This structure allows most signal charges generated by the injected near-infrared light to be collected, which leads to improved sensitivity. In addition, the side piece is removed to decrease the attenuation of the incident light (Figure 2).

3. Fabrication of a Test Chip

Figure 3 shows a microphotograph of the test chip fabricated using a 1-poly 3-metal 0.35 μm CMOS process. The chip dimensions are 4.2 x 3.3 mm, and the silicon substrate thickness is 520 μm. The test chip was equipped with three line-sensor circuits with different photodiode lengths (L) as described below. The lengths of line sensors A, B and C are 120, 90 and 60 μm, respectively. Each of the sensors was formed using a 128-pixel array with a pixel pitch of 7 μm. The photodiodes in sensor D are 30, 50, 70, 90, 110, 130, 150 and 160 μm in length. Each sensor was placed in a group of 16 for a total of 128 pixels. Also, the surfaces of line sensors A, B, C and D were coated with a metal layer for shading. This allows only light injected from the side to be received. Line sensor E, which has the same circuit as line sensor D, is not shaded and was used for the evaluation of conventional illumination methods.

Figures 4 and 5 show the pixel circuit and layout, respectively. The metal layer used to shade the circuit also works as a mask once the side piece is removed.

The hatching area (side piece) in the test chip is 610 μm in width and 4200 μm in length and is shown in Figure 3. The area was etched to a depth of about 40 μm with reactive ion etching (RIE). Figure 6 shows the test chip after the RIE process, and Figure 7 shows a photo of the processed surface at an increased magnification. The remaining width (W) of the side silicon from the end of the photodiode was about 15 μm.

4. Measurement Result

Light from an LED was used for the measurement of sensitivity characteristics. Four types of LEDs, which had peak wavelengths of 690, 780, 870 and 970 nm, were used as light sources.

Figure 8 shows the measurement results for fixed pattern noise (FPN) and random noise (RN) for line sensor D before/after removing side piece. The fact that the results for both noise patterns remained largely unchanged after the RIE process indicates there was little damage done during the RIE process.

Figure 9 shows the sensitivity ratio for side illumination versus surface illumination for the tested wavelength. The solid line shows the results for optical simulation. It shows that the sensitivity ratio is low for short wavelengths. This is because a short photodiode can collect a sufficient number of generated charges because shorter wavelengths have shorter penetration depths in silicon. For longer wavelengths, higher sensitivity ratios were obtained. The sensitivity ratio was more than ten at a wavelength of 870 nm. This confirms that the proposed side-illumination method is more effective at longer wavelengths. According to our simulation, the sensitivity is expected to double if the remaining silicon (width W) on the side of the photodiode is removed.

5. Conclusion

We confirmed that the near-infrared sensitivity of a silicon sensor can be improved by more than one order of magnitude via side illumination. The sensitivity ratio for the illumination methods can be increased to more than ten for a wavelength of

870 nm and a photodiode length of 90 μm. Currently, the proposed method can only be used to form line sensors. However, an image sensor can be formed by thinning the substrate used in the proposed senor and laminating several sensors. This is shown in Figure 10.

Acknowledgements

This work was supported in part by a grant from the Regional Innovation Cluster Program (Global Type [2nd Stage]), which was implemented by the Ministry of Education, Culture, Sports, Science & Technology (MEXT) of Japan.

References

[1] W. C. Dash and R. Newman, "Intrinsic Optical Absorption in Single-Crystal Germanium and Silicon at 77K and 300K," Physical review,vol. 99, no. 4, pp. 1151–1155, Aug. 1955.

[2] B. Dierickx, J. Bogaerts: Electronic Imaging, San Jose, 21 Jan 2004; SPIE Proceedings vol. 5301, p. 204, 2004.

[3] Zhihong Huang, James E. Carey, Mingguo Liu, Xiangyi Guo, Eric Mazur, and Joe C. Campbell: Appl. Phys. Lett. 89, 033506 (2006)

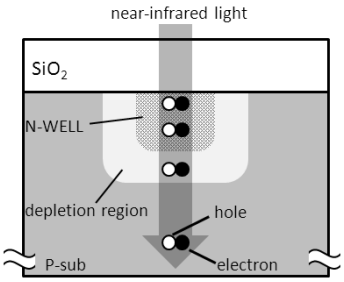

Fig.1 Cross-section of a conventional photodiode pixel circuit.

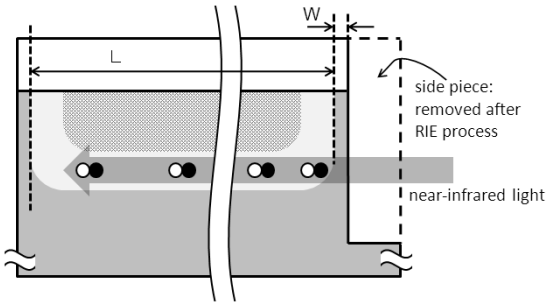

Fig.2 Cross-section of the proposed side-illuminated photodiode.

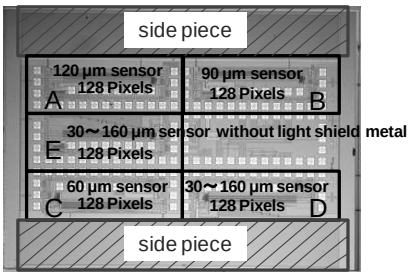

Fig.3 Microphotograph of the test chip.

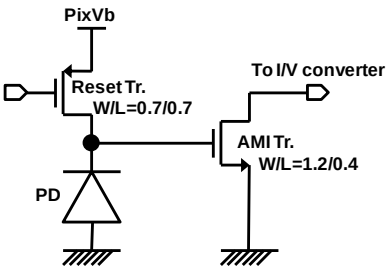

Fig. 4 Pixel circuit.

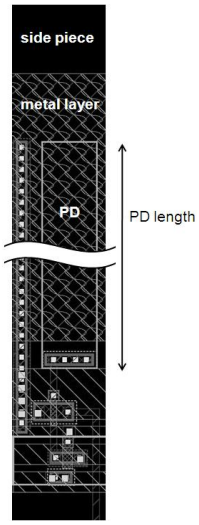

Fig.5 Pixel layout.

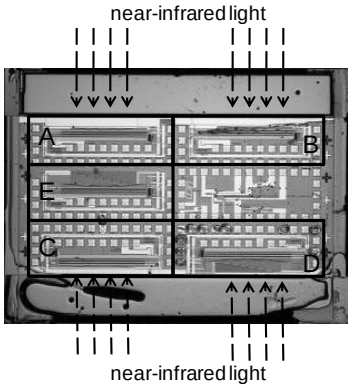

Fig.6 Test chip after RIE process.

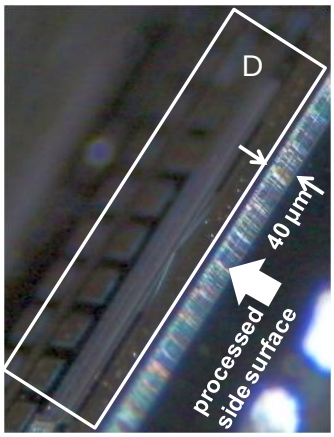

Fig.7 Side view of the photodiode.

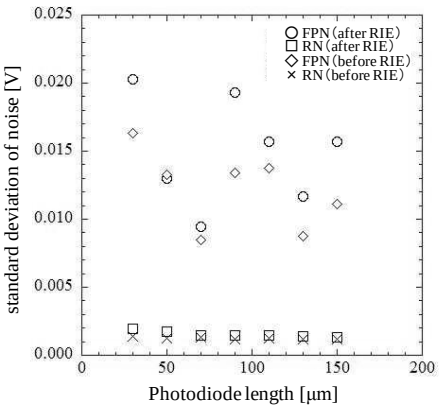

Fig.8 Measured noise.

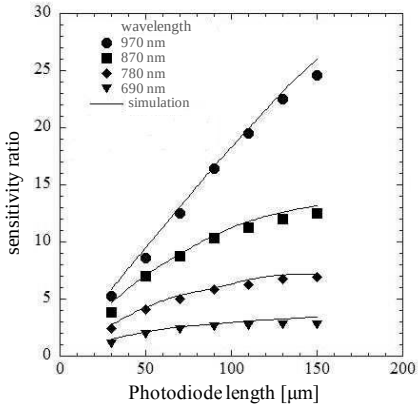

Fig.9 Sensitivity ratio of the side-illumination method to conventional front-face illumi-nation.

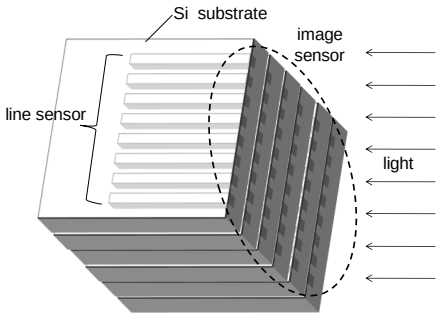

Fig.10 Image sensor formed through the lamination of multiple chips.