修士学位論文要約（平成29年３月）

シリコン受光素子の分光感度差を用いた太陽光紫外線検出技術に関する研究

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A Study on a Solar Ultraviolet Radiation Measurement Technology Using Differential Spectral Response of Silicon Photodiodes

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This thesis proposes a novel ultraviolet (UV) radiation measurement technology that uses the differential spectral response of several silicon (Si) photodiodes for developing a bulk-silicon solar UV sensor with selective sensitivity only in the UV waveband and almost no response to the background visible and near-infrared radiations. Several photodiodes were designed, manufactured and evaluated. Also, an UV sensor system composed by the photodiodes and a differential signal extraction board was developed, for confirming the sensor operation principle. The proposed measurement technology is based on the extraction of the differential spectral response between a highly UV sensitive photodiode (PD1) and a lowly UV sensitive photodiode (PD2), in order to cancel out the visible and NIR wavebands sensitivity and to obtain a resultant response only to the UV waveband. Since this approach uses only bulk Si devices, it can be employed for the fabrication of very small solar UV sensors, with low cost and low power consumption to be integrated in wearable devices.

1. Introduction

Ultraviolet (UV) radiation sensing is used nowadays in several applications in industries for machine control, safety systems, flame detection and so on. At a consumer level, it has applications for healthcare purposes, because overexposure to solar UV light leads to several health problems, varying from skin cancer and cataract to premature skin aging and sunburns. Thus, it is necessary to develop reliable, low cost, low power and small sensors to be integrated into wearable devices for continuous measurement of UV exposure and to alert the user about overexposure dangers in the right timing.

In this research, a bulk silicon (Si) UV sensor with selective sensitivity to the UV waveband and almost no sensitivity to background visible and NIR light is presented. [1] Due to its low sensitivity to background non-UV radiation, the developed sensor is suitable for solar UV measurement applications. Also, since it uses only bulk-Si technology, it is suitable for miniaturization and integration in wearable devices.

2. Differential spectral response sensing method and UV sensor photodiodes design.

Detecting UV radiation under background illumination conditions with only bulk-Si technology is challenging because, due to the Si bandgap of 1.12 eV, Si photodiodes (PDs) have sensitivity to visible and NIR light. Current UV sensors use compound semiconductors with a wide band-gap [2] or a SOI structure with a thin detection layer [3]. No bulk-Si UV sensor capable of measure UV radiation under background light conditions has been reported so far.

In recent years, it has been reported a Si photodiode (PD) with high UV sensitivity and high reliability to continuous UV light exposure [4]. However, because it has sensitivity to UV, visible and NIR wavebands, it is not suitable for applications that require detection of UV light under background light conditions, such as for solar UV radiation measurement. UV band pass filters can be combined with this technology for detection of only UV light, but those filters are expensive, bulky and difficult to fabricate.

To overcome this issue, in this research it was proposed the differential spectral response UV sensing method, as shown in Fig 1. In this method, two types of PDs with different sensitivities for UV light, but with the same sensitivity in the visible and NIR wavebands are employed. In the Fig 1, PD1 and PD2 represent, respectively, the PDs with high and low UV sensitivity. By extracting the differential spectral response PD1 – PD2, it is possible to cancel out the sensitivity to visible and NIR lights, resulting in the detection of only the signal generated from UV light. To improve the differential signal extraction accuracy, both PD1 and PD2 are developed to have low sensitivity to visible and NIR lights, thus reducing the detection of undesired signal.

To obtain the photodiodes PD1 and PD2, the characteristics of light penetration depth in Si was used. More than 90% of the incident UV light is absorbed within dozens of nanometers from the Si surface, while less than 10% of the incident NIR light is absorbed within the first hundreds of nanometers. Thus, by adjusting the P-well layer depth to create potential barrier hundreds of nanometers from the surface, it is possible to reduce sensitivity to visible and NIR wavebands in the PD. Furthermore, by implanting a thin surface N+ layer near the Si surface, a potential barrier is formed with the surface P+ layer and the generated electrons aren't drifted to the buried-N layer. Thus, it functions as a dead zone that drains out or recombines electrons generated within the layer reducing drastically UV sensitivity, with minor effects in the visible and NIR sensitivities. The thin P-well layer was employed in both PDs, and the surface N+ layer only in PD2, as shown in Fig 2.

3. Photodiodes fabrication and evaluation

Several photodiodes with different ion implantation profiles were fabricated and evaluated for the spectral response and robustness to continuous UV light exposure. Also, to suppress the effects of oblique light and non-uniform light incident over the sensor light receiving area, a checkered pattern containing several photodiodes PD1 and PD2 was employed, as shows the chip micrograph in Fig 3.

The measurement results for the sensitivity adjusted for the internal quantum efficiency (Internal Q.E.) of PD1, PD2 and their differential spectral response (PD1 – PD2) are shown in Fig 4. A high sensitivity to UV light and almost no residual sensitivity to visible and NIR lights was obtained. Also, no sensitivity degradation was observed after continuous strong UV light exposure. The developed UV sensor is shown in Fig 5.

4. Conclusion

In this paper, a novel differential spectral response UV sensing method was proposed and used to fabricate a bulk-Si UV sensor with high UV sensitivity and almost no sensitivity to background visible and NIR radiation. The developed sensor is suitable for fabricating highly integrated, small and cost-effective ultraviolet sensors that can be used in health care applications by measuring solar UV light.

References

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3) R. Hamada et al., SICE Annual Conference, pp.317-320, 2008.
4) R. Kuroda et al., ITE Trans. on MTA, Vol. 2, No. 2, pp. 123-130, 2014.

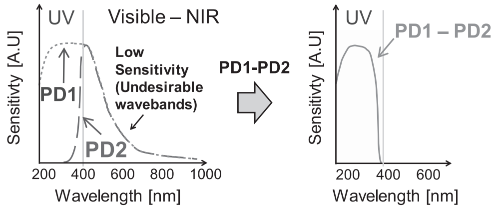

Fig. 1: Differential spectral response UV sensing method conceptual diagram.

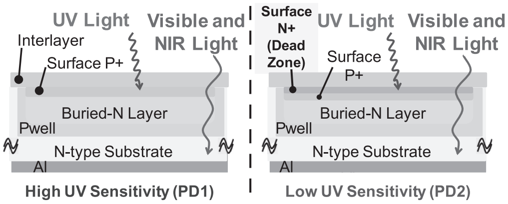

Fig. 2: Conceptual image showing the photodiodes (PD1 and PD2) structure and the penetration depth of different wavebands.

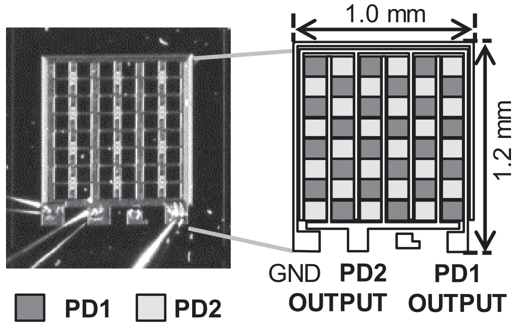

Fig. 3: Chip micrograph and the checkered pattern extructure explanation.

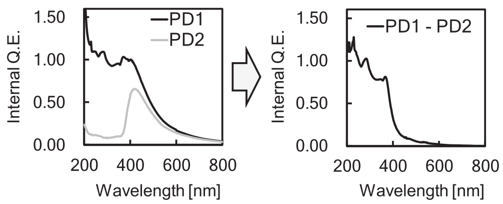

Fig. 4: Spectral response measurement results.

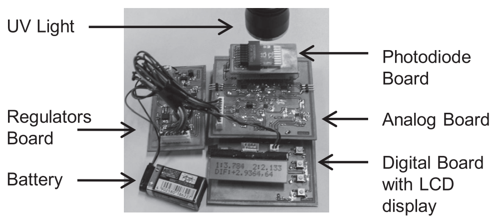

Fig. 5: Developed UV sensor picture.