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[Invited] Wide spectral response and highly robust Si image sensor technology

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Abstract An image sensor technology based on flattened Si surface is summarized that enables a wide spectral response of 200-1000 nm and high robustness of light sensitivity toward ultraviolet light exposure. Performances and opportunities of the light detectors and image sensors using the developed technology are demonstrated.

Keywords: photodiode, spectral response, ultraviolet light, spectrometer

1. Introduction

Light sensors and image sensors with wide spectral response to UV/VIS/NIR waveband are employed in various types of analytical instruments and imaging instruments used in a variety of scientific and engineering fields [1-2]. Sensors used in these fields are required to have a high sensitivity for 200-1000 nm as well as a high robustness of light sensitivity and dark current toward strong UV-light irradiation. This paper describes an advanced wide spectral response and highly robust imaging technology based on flattened Si-surface for photodiodes, photodiode array (PDA) sensors and image sensors.

2. Developed technology and sensor performances

Fig. 1 shows the light penetration depth in Si as a function of wavelength. In order to achieve high quantum efficiency (QE) in Si for a wide waveband, the light sensitive region with regards to Si depth must range from a few angstrom from the light receiving surface to several tens of micron meter. Fig. 2 shows the cross sectional illustration of a CMOS image sensor pixel with the key developed structures for a wide spectral response and high robustness to UV-light exposure. A high concentration p^+ layer is formed with a steep dopant concentration profile on the flattened Si surface region. This structure improves the UV-light sensitivity while achieving a high robustness of light sensitivity toward the fixed charge and interface state generations due to UV-light exposure [3-5]. A relatively thick p-type epitaxial layer is utilized in order to enhance the NIR-light sensitivity. The process technologies to form this structure are explained in detail elsewhere [3-5]. Furthermore, recently the atomically flattening technology when applied to the gate insulator/Si interface was shown to be effective to reduce random telegraph noise of source follower transistors based on the statistical evaluation of over 100 K samples [6].

Photodiode array (PDA) sensors and a CMOS image sensor were fabricated based on a 0.18 μm 1P3M CIS process technology [7]. Fig. 3 shows the chip micrograph of the developed PDA. Two types of PD structures were formed, i.e., p^+np type with the developed technology and np type as a reference. Fig. 4 shows the PD structures and photo-electric conversion characteristics. A higher FWC is obtained for p^+np type due to the increased PD capacitance. A better QE characteristic and its robustness were obtained for p^+np type than np type.

Fig. 6 shows the schematic image of a typical detector of spectrometers and the conceptual image of one of the proposed structures of PDA. Here, to improve the light transmittance to Si, PDA light receiving regions are divided into several regions and a high transmittance optical layer corresponding to the receiving light waveband is formed above Si in each region. The concept was verified by evaluating the fabricated seven types of PDs with different optical layers composed of only SiO_2 and SiN_x films as shown in Fig. 7 [8]. A very high QE is expected to be obtained by this PDA technology.

Fig. 8 shows the spectral sensitivity of the developed CMOS image sensor before and after UV-light exposure stress [4-5, 9-10]. High sensitivity is obtained for a wide spectral range and almost no degradation of light sensitivity occurs due to the strong light exposure stress that accounts for over 10 years-use. Fig. 9 shows some sample images captured by the developed CMOS image sensor under visible and UV-light illumination conditions. More information is obtained in the UV-light illumination condition than visible light case. This implies a usefulness of the UV-light imaging for the life-scientific and the agricultural applications.

3. Conclusion

In this paper, Si image sensor technologies featuring the PD pn junction and the optical layer above Si surface are summarized and their impacts on the spectral sensitivity and the sensitivity robustness and opportunities are demonstrated.

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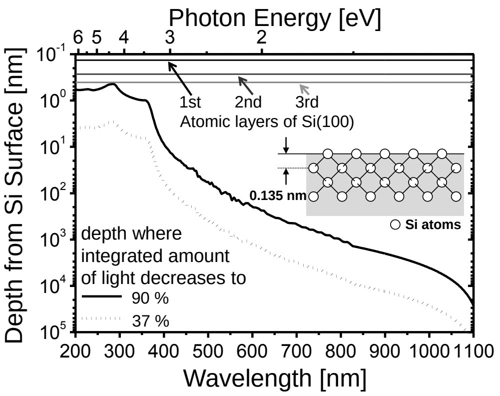


Fig. 1 Light penetration depth in Si as a function of wavelength.

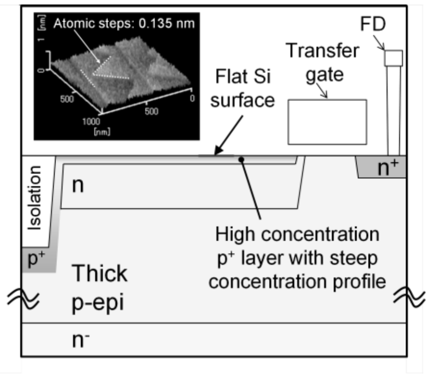


Fig. 2 Cross sectional illustration of a CMOS image sensor pixel with key structures to achieve the wide spectral response and the high robustness to UV-light exposure.

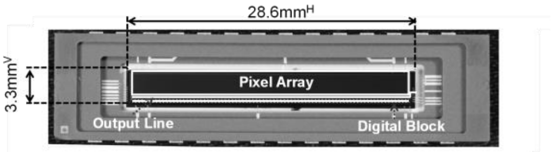
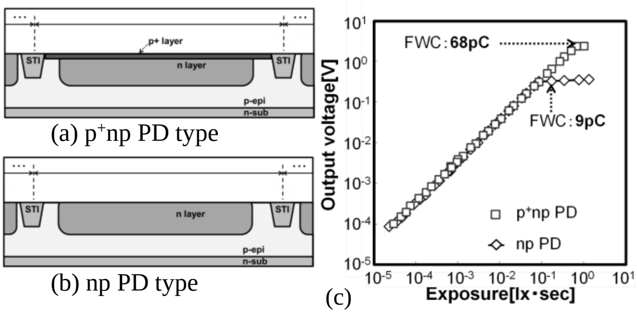


Fig. 3 Chip micrograph of developed PDA. Pixel size is 20 μm by 2500 μm and the number of pixels is 1024.

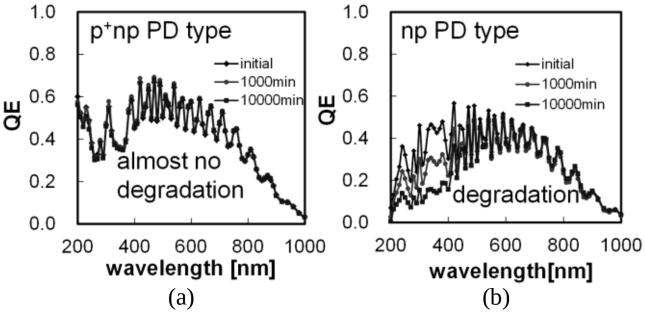


(a) p^+np PD type

(b) np PD type

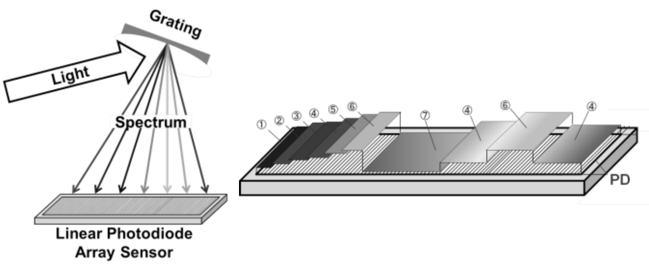
(c)

Fig. 4 (a-b) Cross sectional illustrations of fabricated PD types and (c) photo-electric conversion characteristics of the fabricated PDAs.



(a) (b)

Fig. 5 Spectral QE for the developed PDAs before and after UV-light exposure stress. (a) p^+np PD type and (b) np PD type. The inter-metal layer SiO_2 film has 3.8μm thickness.



(a) (b)

Fig. 6 (a) Schematic image of the typical detector of a spectrometer using PDA and (b) conceptual illustration of the proposed PDA structure with optimum optical layers for multiply divided pixel regions.

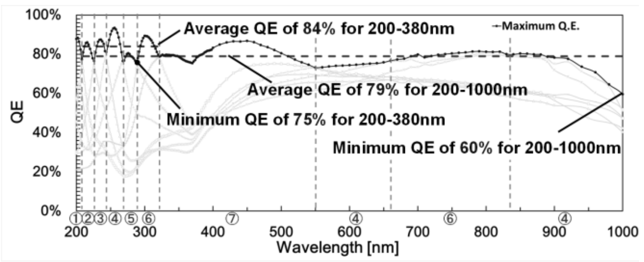


Fig. 7 QE as a function of wavelength for the seven types of PDs with different optical layers above Si formed by SiO_2 and SiN_x films only (gray lines) and the expected QE performance (black line) for the proposed PDA structure in Fig.6 (b).

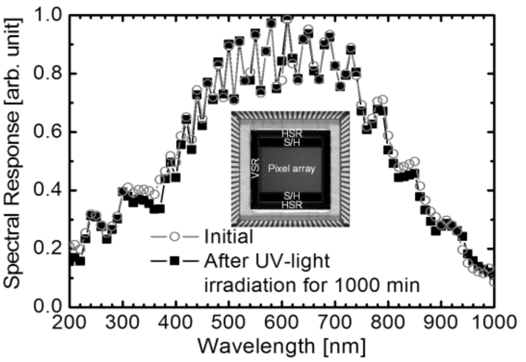


Fig. 8 Spectral response as a function of wavelength for the developed CMOS image sensor before and after UV-light exposure stress. The pixel pitch is 5.6 μm and the number of pixels is $1280^H \times 960^V$.

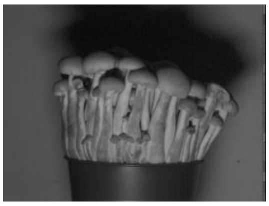
	Visible light	UV-light
(a)		
(b)		

Fig. 9 Sample images of (a) Rudobekia flower and (b) Shimeji mushroom captured by the developed CMOS image sensor under visible light source and UV-light source (360 nm).