Extended Abstracts of the 2016 International Conference on Solid State Devices and Materials, Tsukuba, 2016, pp809-810

PS-7-12

Wavelength Dependent Photodetection Characteristics of Avalanche Photodiode Fabricated by Standard CMOS Process

Zul Atfyi Fauzan Mohammed Napiah[1,2], Takuya Hishiki[1] and Koichi Iiyama[1]

[1] School of Electrical and Computer Engineering
Kanazawa University, Kanazawa 920-1192, Japan
Phone: +81-76-234-4887 E-mail: iiyama@se.kanazawa-u.ac.jp
[2] Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
76100 Melaka, Malaysia

Abstract

Avalanche photodiodes fabricated by CMOS process (CMOS-APDs) have features of high avalanche gain below 10 V, wide bandwidth over 5 GHz, and easy integration with electronic circuits. In CMOS-APDs, guard ring structure is introduced for high-speed operation by cancelling photo-generated carriers in the substrate. We describe here wavelength dependence of the responsivity and the bandwidth of the CMOS-APDs with and without the guard ring structure.

1. Introduction

Optical communication has been realized mainly in long-haul communication, and recently board-to-board and chip-to-chip optical interconnection have been actively studied. In order to realize the optical interconnection, it is necessary to integrate light sources, optical waveguides, photodetectors, and electronic circuits. A number of researches on Ge photodetectors on Si substrate have been studied for a long wavelength band, while a number of researches on photodetectors fabricated by CMOS process are also studied for short wavelength band [1,2], and optical receivers have been demonstrated [3,4]. By using CMOS process, it is possible to easily integrate photodetectors and electronic circuits on same Si substrate with low-cost because CMOS process is mature process. Photodetectors fabricated by CMOS process have high avalanche amplification below 10 V bias.

We have already designed and prototyped avalanche photodetectors by using CMOS process (CMOS-APD) in [5,6]. Our CMOS-APD structure achieved the highest bandwidth of 10 GHz at a wavelength of 830 nm band [7,8]. In addition, as an application of the optical disk, we also reported characteristics of the CMOS-APD at a wavelength of 405 nm band [9]. Here, we report experimental results of wavelength dependence of the responsivity and frequency response for the CMOS-APD with and without the guard ring structure.

2. Structure, Result and Discussion

Structure

Figure 1 shows a photograph of a CMOS-APD fabricated by 0.18 μm CMOS process. The anode and cathode electrodes are interdigitally formed on the photo-detection area with 20 × 20 μm^2 area. It also has an electrode pads for the DC biasing and probing high frequency signal. Figure 2 shows a cross-sectional structure of a pMOS-type CMOS-APD also known as a hole-injection-type APD as we describe in [6]. The electrode of the p-type substrate (P-substrate) is connected to the ground to form a guard ring, while if the electrodes of the P-substrate is opened, the device is without a guard ring. The light is illuminated from the top of the CMOS-APD. The electrode spacing L_S is L_S = 1 μm.

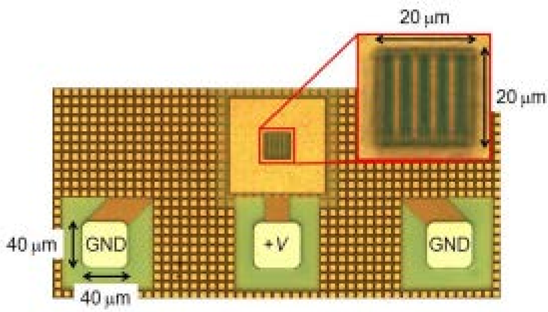


Fig. 1. Photograph of the CMOS-APD.

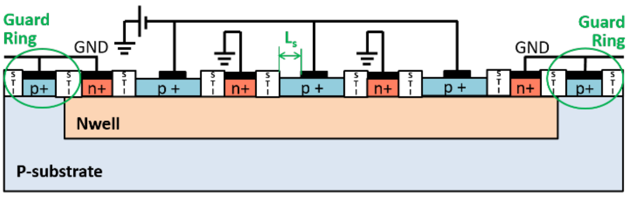


Fig. 2. Cross-section of the pMOS-type CMOS-APD.

Responsivity

Figure 3 shows the wavelength dependence of the responsivity at the bias voltage of 2 V and 7 V. There is no difference in responsivity due to the presence of the guard ring at a wavelength of 405 nm for both bias voltage, but the difference increases with increasing the wavelength. This is because optical absorption of Si is very strong for 405 nm wavelength, and then all the incident light is absorbed in the p$^+$ layer and Nwell and consequently it cannot reach the P-substrate region. At a wavelength of 520 nm, most of the incident light is absorbed in the p$^+$ layer and Nwell and then responsivity is almost same with or without the guard ring. Since the responsivity is proportional to the wavelength for constant quantum efficiency, the responsivity at 520 nm wavelength is higher than that at 405 nm wavelength because the

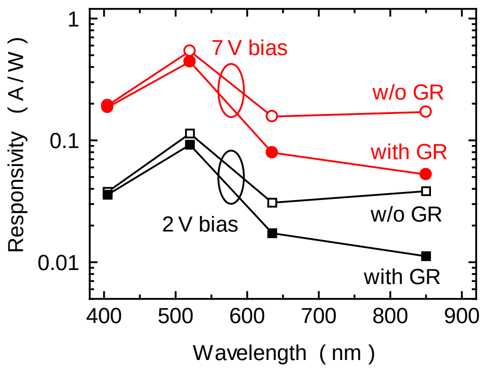
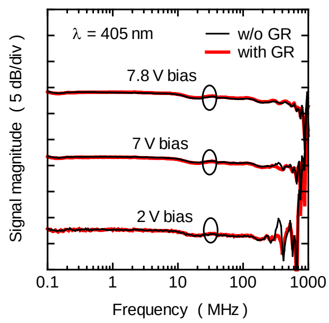
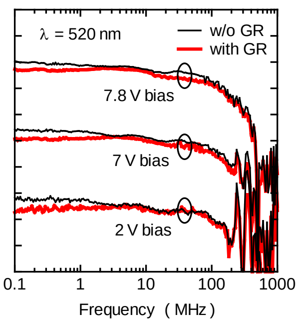


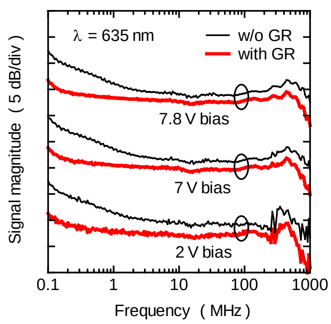
Fig. 3. Wavelength dependence of the responsivity.



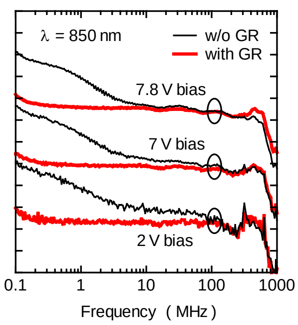
(a) λ = 405 nm



(b) λ = 520 nm



(c) λ = 635 nm



(d) λ = 850 nm

Fig. 4. Frequency responses for different wavelengths.

internal quantum efficiencies at 405 nm and 520 nm wavelengths are almost the same.

On the other hand, at wavelength of 635 nm or more, the incident light reaches the P-substrate and then the carrier is generated there, but it does not contribute to the photocurrent due to the guard ring. Then quantum efficiency is reduced and consequently the responsivity is decreased.

Frequency Response

Figure 4 shows the measurement results of the frequency response for various wavelength. At 405 nm wavelength, there is no difference in the frequency response with or without the guard ring, which is similar trend to the responsivity characteristics. At 520 nm wavelength, the signal magnitude of the device without the guard ring is slightly higher than that of the device with the guard ring in the low frequency region, and no difference in the signal magnitude is observed in the frequency range over 10 MHz. The difference in signal magnitude in the low frequency region is due to the difference in responsivity. On the other hand, at 635 nm wavelength, the signal magnitude of the device without the guard ring in the low frequency region is obviously greater than the device with the guard ring, and the difference is approximately 6 dB at 100 kHz. The difference is corresponding to the responsivity at a wavelength of 635 nm in Figure 3 which is about 2 times. Consequently, the difference in signal magnitude due to the presence of the guard ring in the low frequency region for the wavelength of 850 nm is even greater, about 10 dB at 100 kHz. This difference also corresponds to the difference in the responsivity in Figure 3, approximately 3 times. There is no difference in frequency response with or without the guard ring over 10 MHz for both 635 nm and 850 nm wavelength. It can be seen that the bandwidth is significantly improved by the guard ring structure.

3. Conclusions

The wavelength dependence of the responsivity and bandwidth of the CMOS-APDs with and without the guard ring has been successfully characterized. At wavelength shorter than 520 nm, there is no difference in the responsivity and the frequency response because all the illuminated light is absorbed in the p^+ layer and the Nwell due to strong light absorption of Si. On the other hand, a part of the illuminate light is absorbed in the substrate and the photo-generated carriers in the substrate is cancelled by the guard ring for the wavelength longer than 520 nm, and then bandwidth was remarkably enhanced at the sacrifice of the responsivity.

Acknowledgements

The CMOS-APD has been fabricated in the chip fabrication program of VLSI Design and Education Center (VDEC), the University of Tokyo, in collaboration with Rohm Corporation and Toppan Printing Corporation.

References

[1] S. Radovanović *et al.*, IEEE J. Solid-State Circuits, **40** (2005) 1706.

[2] F.P. Chou *et al.*, IEEE Photon. Technol.Lett., **25** (2013) 659.

[3] T.K. Woodward and A.V. Krishnamoorthy, IEEE J. Sel. Top. Quantum Electron. **5** (1999) 146.

[4] J.S. Youn *et al.*, IEEE J. Quantum Electron., **48** (2012) 229.

[5] K. Iiyama *et al.*, IEICE Trans. Electron., **E91-C** (2008) 1820.

[6] K. Iiyama *et al.*, IEEE Photon. Technol. Lett., **22** (2010) 932.

[7] T. Shimotori *et al.*, *Proc. Opto-Electronics and Communications Conference* (2013) 6.

[8] K. Iiyama *et al.*, *Proc. Opto-Electronics and Communications Conference* (2014) 243.

[9] T. Shimotori *et al.*, *Proc. Opto-Electronics and Communications Conference* (2012) 509.