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Abstract

A silicon avalanche photodiode fabricated by CMOS process was characterized at 405 nm wavelength for Blu-ray applications. The avalanche gain of 36, the maximum responsivity of 2.61 A/W, and the bandwidth of 300 MHz were achieved.

I. Introduction

A silicon (Si) avalanche photodiode (APD) fabricated by complementary metal oxide semiconductor process (referred to as a CMOS-APD) has been developed for optical interconnection applications [1-5]. The CMOS-APD has been characterized in 830 nm wavelength region, and the typical performances are the bandwidth of over 1 GHz and the avalanche gain of more than 100 at less than 10 V bias voltage. Since high avalanche gain is achieved in low bias voltage, the CMOS-APD can be easily integrated with electronic circuits such as transimpedance amplifiers, limiting amplifiers and the following electronic circuits.

The other possible application of the CMOS-APD is Blu-ray systems. In Blu-ray systems, a laser diode emitting at 400 nm wavelength range is used as the light source, and a Si PIN photodiode (PIN-PD) is used as the photodetector. In future Blu-ray systems, multi-layer optical disks will be used to increase the disk capacity. In this case, the reflected optical power from the disk is very low because the disk is transparent. Then highly sensitive photodiodes at 400 nm wavelength range are required for photodetection. Although an APD is a promising device, a conventional APD requires high voltage (about 150 V) to achieve large avalanche gain, and then integration with electronic circuits is difficult. The CMOS-APD has a feature of high avalanche gain at low bias voltage, and therefore, is very attractive in multi-layer Blu-ray systems.

In this paper, we characterize the CMOS-APD in blue wavelength region. The CMOS-APD has the avalanche gain of 36, the maximum responsivity of 2.61 A/W, and the bandwidth of about 300 MHz.

II. Structure

The structure of the CMOS-APD is shown in Fig. 1. The CMOS-APD was fabricated by a standard 0.18 μm CMOS process. The thickness and the doping concentration of the deep Nwell, the Nwell, the Pwell, the n^+-layer and the p^+-layer are not disclosed. The light is

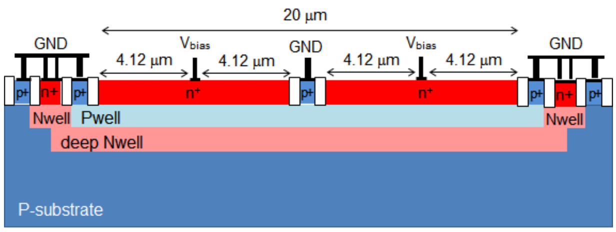

Fig.1: Structure of a CMOS-APD.

illuminated from the top of the device. Since the P-substrate and the deep Nwell are electrically shorted, the photogenerated holes generated there move to the p^+-layers on the P-substrate, and the photogenerated electrons generated there move to the n^+-layers on the Nwell, which are recombined and don't contribute to the photocurrent. As a result, the photogenerated carriers generated in n^+-layers on the Pwell and the Pwell contribute to the photocurrent.

In the CMOS-APD, silicides are formed only below the V_{bias} electrodes for the n^+-layers on the Pwell, and most part of the n^+-layer is silicide-free. Then the illuminated light is efficiently absorbed without being absorbed in the silicides. The detection area is 20 x 20 μm^2.

III. Characterization

Figure 2 shows the I-V characteristics of the CMOS-APD. The dark current is about 1 nA, and is drastically increased when the bias voltage exceeds 8 V, and the breakdown voltage is 9.2 V. Under light illumination, the current is almost constant when the bias voltage is below 6 V, and is gradually increased; especially when the bias voltage is above 8 V, the current is significantly increased due to avalanche amplification, which occurs around the interface between the Pwell and the n^+-layers on the Pwell. The current is also found to be increased for shorter wavelength, which is due to the decreased absorption length of Si. For 830 nm wavelength, a large portion of the illuminated light reaches the P-substrate and the carriers are generated there. However the carriers generated in the P-substrate are canceled because the P-substrate and the deep Nwell are electrically shorted, and then the small current is measured.

Figure 3 shows the responsivity against the bias voltage. The responsivity is increased for shorter wavelength according to the increased current shown in

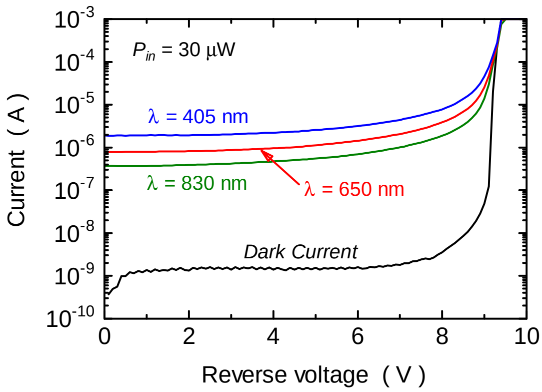

Fig. 2: I-V characteristic of a CMOS-APD.

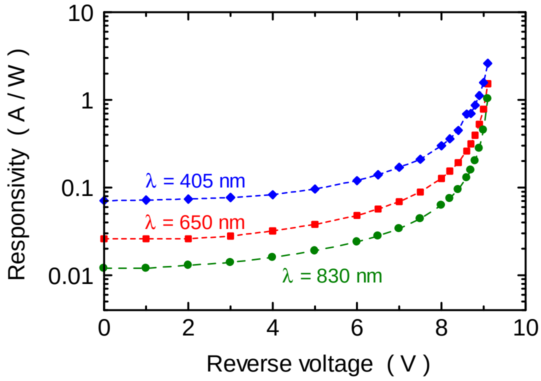

Fig. 3: Responsivity of a CMOS-APD.

Fig. 2. Typical responsivity and the correspondent avalanche gain are tabulated in Table 1. In a commercial Si PIN-PD, the responsivity at 400 nm wavelength is about 0.2 A/W. The measured responsivity at 405 nm wavelength at 0 V bias voltage is lower than a commercial PIN-PD due to recombination of photo-generated carriers in the n^+-layer on the Pwell, and the responsivity at 9.1 V bias voltage is about 10 times higher than a commercial PIN-PD due to avalanche amplification.

Table 1: Responsivity and the avalanche gain.

Wavelength	405 nm	650 nm	830 nm
Responsivity at 0 V (A/W)	0.071	0.026	0.012
Responsivity at 9.1 V (A/W)	2.61	1.53	1.03
Avalanche gain at 9.1 V	36.8	58.8	85.8

Figure 4 shows the frequency response of the CMOS-APD at 9 V bias voltage. The bandwidth at 405 nm wavelength is about 300 MHz, while the bandwidths at 650 nm and 830 nm wavelength are about 1 GHz. The narrow bandwidth at 405 nm wavelength is due to that most of the illuminated light is absorbed in the n^+-layer

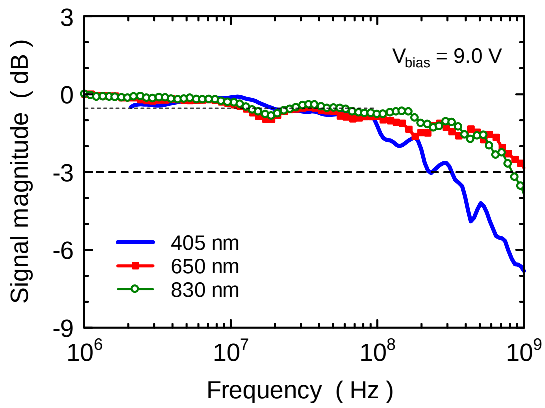

Fig. 4: Frequency response of a CMOS-APD.

on the Pwell, where the carrier transit time is long due to high doping concentration.

IV. Conclusions

In conclusion, a Si CMOS-APD was fabricated by standard 0.18 µm CMOS process, and was characterized at 405 nm wavelength for Blu-ray applications. The responsivity is 0.071 A/W at 0 V bias voltage and is increased to 2.61 A/W at 9.1 V bias voltage due to avalanche amplification. The bandwidth was about 300 MHz, which is narrower than the bandwidth at 650 nm and 830 nm wavelength. However, the bandwidth of 300 MHz is enough for Blu-ray applications because the bandwidth of the current photodetection electronics for Blu-ray systems is about 250 MHz.

Acknowledgment

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.

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