

Proceedings of the 13th Conference on
Optoelectronics and
Optical Communications

ISSN 1738-2661

COOC 2006

제13회

VOL.13 NO.1

광전자 및 광통신 학술회의 논문집

일시 2005년 5월 10일(수) ~ 5월12일(금)

장소 일성부곡콘도

(http://ilsung.ilsungcondo.co.kr/condo/bugok_main.html)

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Bias Voltage Optimization of Vertical PN-Junction Photodetectors Fabricated in Standard CMOS Technology

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Abstract

We present vertical PN-junction photodetectors fabricated from standard 130nm complementary metal-oxide-semiconductor (CMOS) process for applications in optical data transmission and optical interconnects. We experimentally observe that the bandwidth and responsivity of the photodetector are enhanced when the applied bias voltage is close to the reverse break-down voltage. The fabricated photodetector has 3-dB bandwidth of 2.3 GHz and responsivity of 0.11 A/W at the optimum bias voltage.

I. Introduction

With increasing bitrates, optical interconnects and short-distance optical access networks are widely investigated. High volume and wide deployment of optical links indispensably require low-cost optical transceivers. For the optical transmitters, low-cost 850nm AlGaAs/GaAs vertical-cavity surface-emitting lasers (VCSELs) are readily available. As a counter part, CMOS-based optical receivers are a strong candidate because low-cost, high-volume manufacturability is available and monolithic integration of a photodetector and receiver circuits is possible [1].

In this paper, we report vertical PN-junction photodetectors fabricated by DongbuAnam 130 nm CMOS process and examine the bias voltage dependence of photodetector performance.

II. Photodetector structure

Fig. 1 shows cross-sectional diagram of the fabricated photodetector. There are two PN-junctions in the device, P+/n-well and n-well/p-substrate junction. However, we only use vertical P+/n-well junction to eliminate slow diffusion currents [2]. In addition, the multi-finger electrode and narrow finger space of $0.5 \mu\text{m}$ are formed to collect the photogenerated carriers effectively without going

through the lateral diffusion path. The active area of photodetector is about $30 \times 30 \mu\text{m}^2$ and the salicide process is blocked for the optical window.

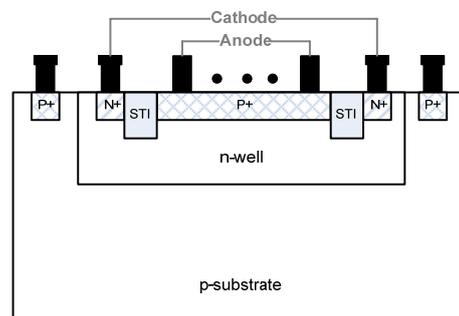


Fig. 1. Schematic cross-section of fabricated photodetector.

III. Experimental results

For the characterization of the photodetector performance, all experiments were done on wafer and 850nm optical signal was injected to the device using a lensed-fiber. Fig. 2 shows I-V characteristics with and without optical illumination and calculated photocurrents and external responsivity, which includes optical coupling loss. In general, CMOS compatible photodetectors have low responsivity because of the narrow depletion region and large penetration depth, which is about $14 \mu\text{m}$, of Si under 850 nm optical illumination [1]. In Fig. 2, it can be

seen that photocurrent and responsivity increases with the increasing reverse bias voltage due to enhanced depletion width of PN-junction. At the reverse voltage above 10.3V, reverse breakdown occurs and responsivity has the maximum value of 0.11 A/W as shown in Fig. 2 (b). This high responsivity can be explained by the avalanche gain process, which is attributed to the increased carrier concentration under optical illumination.

For the measurement of optical modulation response, 20 GHz electro-optic modulator and vector network analyzer are used. Fig. 3 shows the optical modulation response of the fabricated photodetector at different bias voltages. When applied reverse voltage increases, the detected power increases as in the I-V characteristics of the photodetector. Interestingly, it can be observed that, bandwidth and responsivity are maximized at the bias voltage close to the reverse breakdown voltage as shown in Fig. 3 (b). This enhanced bandwidth is believed due to

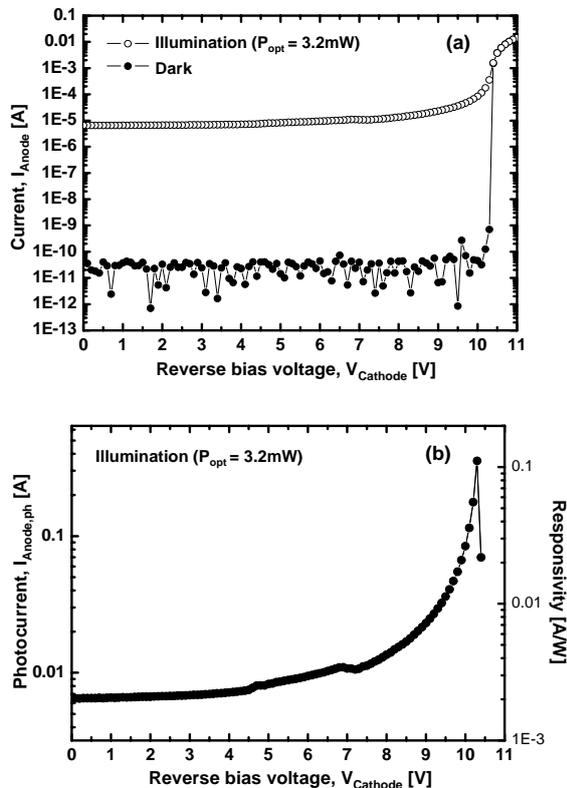


Fig. 2. (a) I-V characteristics of the photodetector under dark and illumination condition. The incident optical power is 3.2 mW. (b) Photocurrent and responsivity as a function of applied bias voltages.

reduced transit-time in the high electric field region.

IV. Conclusion

We fabricated CMOS-compatible vertical PN-junction photodetectors and optimize the bias voltage for high bandwidth and responsivity. At the bias voltage close to the reverse breakdown voltage, 3-dB bandwidth of 2.3 GHz and responsivity of 0.11 A/W are obtained.

We acknowledge the support of IDEC (IC Design Education Center) for EDA software used for designing the photodetector.

Reference

[1] T. K. Woodward, et al, *IEEE JSTQE*, Vol. 5, No. 2, pp. 146-156, 1999.
 [2] P. Bhadri, et al, *Proc. LEOS*, Vol. 2, pp. 683-684, 2002

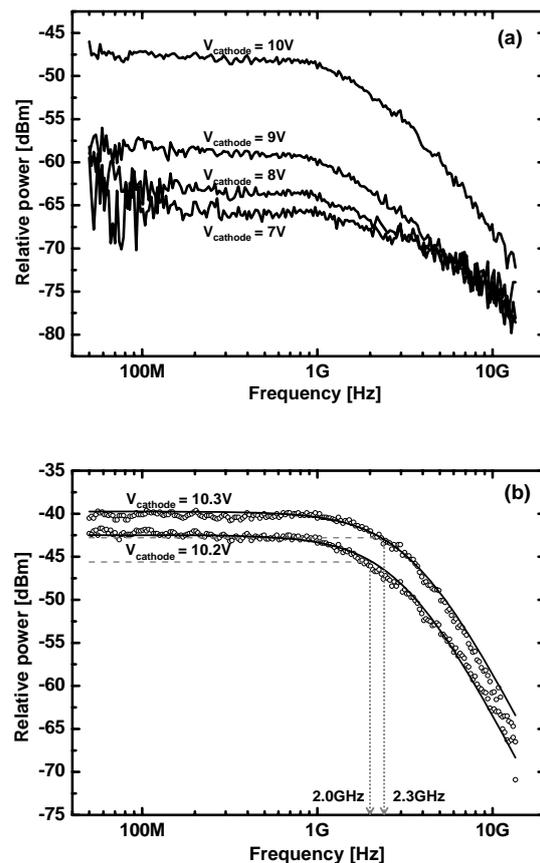


Fig. 3. Optical modulation responses of the photodetector (a) at different bias voltages and (b) around the reverse breakdown voltages. The hollow circles represent measured data and solid lines indicate fitting results.