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A high-responsivity of 4.1 A/W Si PD with BJT amplifier in standard CMOS process

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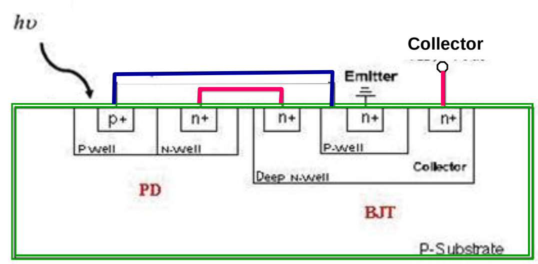
1. Introduction

Nowadays, integrated complementary metal-oxide-semiconductor (CMOS) PDs become popular in the application of near-infrared wavelengths (e.g. 850nm) due to its low cost, integration with receiver and systems-on-chip [1]. However, the low absorption coefficient of Si leads to low quantum efficiency (low responsivity) for a surface pn photodiode. The low responsivity can be improved by biasing Si PD in the avalanche region to increase the photo-generated carriers. In addition, many studies on the photodetectors made of Ge-related commercial process have been published in response to this demand. Polleux *et al.* [2] used a commercial SiGe BiCMOS process to fabricate an heterojunction photo-transistor (HPT) with a biasing base current of 60 μA. A responsivity of 1.49 A/W at 940 nm was obtained. Yin *et al.* [3] employed a commercial 0.25-μm SiGe BiCMOS process to realize an HPT. When the base current was biased at 5 μA, the responsivity for 850 nm light was measured as 2.7 A/W. When the base current was zero, the responsivity dropped to about 0.36 A/W.

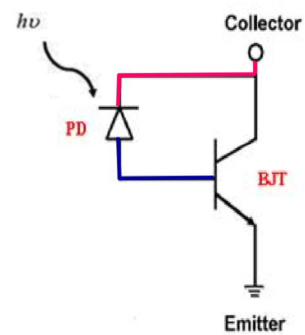
In this work, we propose a new PD/BJT which is a Si PD with parasitic BJT amplifier fabricated in standard 0.18-μm CMOS process. A high responsivity of 4.1 A/W for 850 nm light was obtained while biasing PD/BJT in the avalanche range.

2. Device Design

The proposed device is to integrate a Si PD with parasitic vertical npn transistor in bulk CMOS process. The basic operation is similar to HPT which the base-collector junction diode is used for illumination and transistor is biased to amplify the photo-generated carriers. Fig.1 (a) shows cross section of a Si PD with parasitic vertical npn transistor. Fig. 1(b) shows the equivalent model and basic operation of PD/BJT. The Si PD is composed of multiple p-n diodes with shallow trench isolation oxide in between p- and n-region. The total active area of Si PD is 50×50 μm^2, which consists of nineteen p-n diodes. The npn BJT is formed by the n-diffusion, p-well, and deep-n-well structures. The emitter area of the npn BJT is 10×10 μm^2. An image of Si PD with BJT layout is shown in Fig.2. As shown in Fig. 1(b), n-contact of PD is connected with the collector of BJT and the p-connect is with the base of BJT. The emitter of BJT is grounded for 850nm illumination..



(a)



(b)

Fig.1 (a) Cross section of a Si PD with parasitic vertical npn transistor in bulk CMOS process. (b) Equivalent circuit model of the proposed PD/BJT

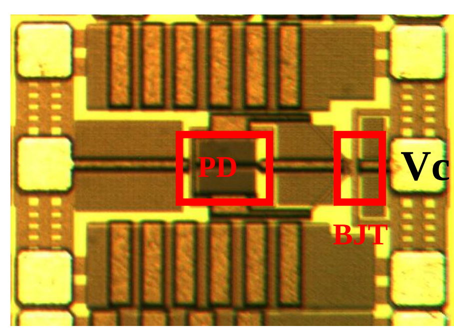


Fig.2 The image of the chip showing integrated PD and BJT.

3. Characteristics of BJT and PD

The parasitic vertical npn BJT amplifier was characterized in the common emitter mode. Fig.3 shows the common-emitter I-V characteristics and demonstrates a high early-voltage. Fig.4 shows the current gain (β) from the measured Gummel plot. The measured β of BJT is about 20 for the collector current in the range of 1μA to 3mA.

The Si PD with p-n diodes leads to generate large number of photocarriers by operating at the avalanche range before breakdown. In the avalanche bias, the proportion of the photo-generated carriers in drift to carriers in diffusion is significantly increased and a higher bandwidth and responsivity can be observed simultaneously. In this case, the integrated BJT amplifies the photo-generated currents from the p-n diodes of Si PD and generates the output signal at the collector. Therefore, the responsivity is enhanced consequently.

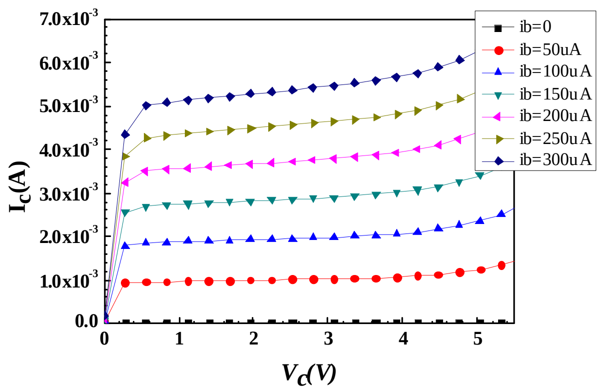


Fig.3 I-V characteristics of a 10×10 μm² BJT.

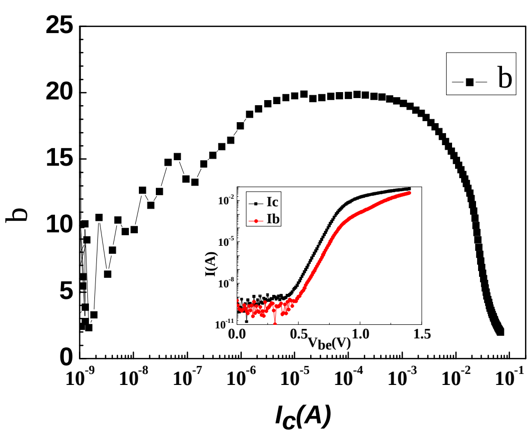


Fig.4 The current gain of a 10×10 μm² BJT. Inset shows the Gummel plot.

Fig.5 shows the measured dark current of Si PD and PD/BJT, respectively, and demonstrates that the breakdown voltage of Si/BJT up-PD is decreased to 6.7 V (at 1 μA) compared to the 14 V of Si PD. The basic reason is due the lower breakdown characteristics from BJT.

As shown in Fig.6, the responsivity for Si PD is 0.06 A/W at low bias but increased to 0.37 A/W while biasing up to 13.9 V. The responsivity of the proposed PD/BJT is improved to 1.6 A/W at low bias and up to 4.1 A/W at 6.7 V before breakdown. The responsivity of PD/BJT is significantly improved by adding a BJT amplifier without extra process and cost. Moreover, the same size of Si PD is connected to smaller size of BJT (5×5 μm²), the responsivity is decreased to 3 A/W. Therefore, the BJT amplify the photo-generated carriers and output current is function of the size of BJT.

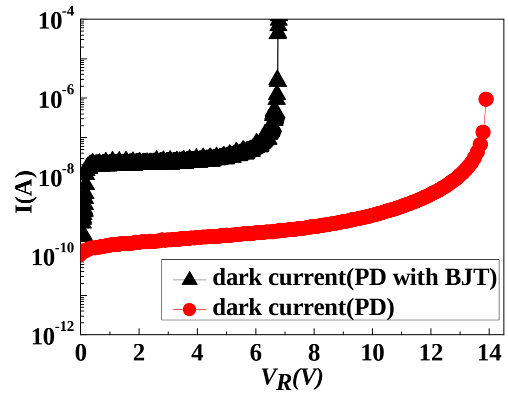


Fig.5 The measured dark currents of Si PD and PD/BJT.

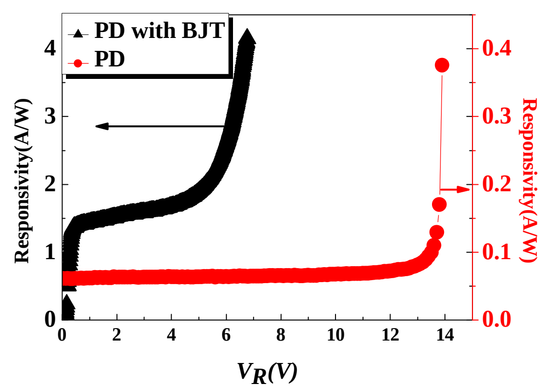


Fig.6 The responsivities of Si PD and PD/BJT at 850nm.

4. Conclusion

Without altering any step of the commercial 0.18 μm CMOS process, a high responsivity Si PD with BJT amplifier has been realized. The responsibility of the PD is improved from 0.37 A/W to 4.1 A/W while basing at the avalanche range. Under the regular bias, the proposed PD/BJT demonstrates a high responsivity of 1.6A/W.

5. References

[1] Wei-Kuo Huang, Yu-Chang Liu and Yue-Ming Hsin, "A high speed and high responsivity photodiode in standard CMOS technology," *IEEE Photonics Technology Letters*, Vol. 19, No. 4, pp. 197-199, 2007

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