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Effect of Absorption region in 850-nm Si Avalanche Photodiodes by standard CMOS Technology

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1. Introduction

In this work, we present a lateral avalanche photodetector (APD) by standard 0.18 μm CMOS process with three different absorption region widths (0.43, 0.86, and 3.44 μm). The responsivity is 4.63 A/W at reverse bias 11.67 V for the APD with 0.43μm absorption region width, and the best 3-dB bandwidth is 5.4 GHz at reverse bias 11.4 V for the structure with 3.44 μm absorption region width.

2. Device Structure and Measurement Results

Fig. 1 shows the schematic cross-section of proposed APD, which was fabricated by Taiwan Semiconductor Manufacturing Company (TSMC) 0.18-μm CMOS technology without process modifications.[1] We use metals to distinguish the avalanche region and the absorption (illumination) region. The avalanche region is formed by n-implant/p-well junction and the p- substrate is used for the absorption region. APDs with three different absorption region width, 0.43 μm, 0.86 μm and 3.44 μm, were studied in this report. The size of avalanche region is kept at 0.86 μm. The n-implant region is positively biased (V_R) to reverse bias the p-n diodes and collect the photo-generated carriers. The p-implant region is connected to ground. The total active area of APD is 50×50 μm^2, due to the difference in the absorption region width, the ratios of avalanche region to absorption region in this study are 2, 1, 0.25.

Fig. 2 shows the characteristic of dark current and photo current of three APDs. The breakdown voltage (V_{BK}) is slightly decreased as the absorption region width increases, which is 11.67 V for the structure with 0.43 μm absorption region width, 11.5 V for the structure with 0.86 μm absorption region width and 11.4 V for the structure with 3.44 μm absorption region width. Fig. 3 shows the responsivity of three structures. The responsivity increase due to more photocurrent generated from the n-implant (avalanche region). The maximum responsivity of the three APDs is 4.63, 2.34, 1.53 A/W. In the mean time, the M-factor is about 397.96 with quantum efficiency about 675 % for the structure with 0.43 μm absorption region width, which is showing in Fig. 4 and Fig. 5.

Fig. 6 shows the measured frequency response of three structures. Since more photocurrent generate from the n-implant region, more diffusion component carrier collected, the 3-dB bandwidth decrease as the avalanche region/absorption region ratio increased. The 3-dB bandwidth is 5.4 GHz for the APD with 3.44 μm absorption region width, and decrease to 1.4 GHz for the APD with 0.43 μm absorption region width. This phenomenon also can be observed by the pulse measurement result showing in Fig. 7[2]. The FWHM of the absorption region width 3.44 μm is about 270 ps, and fall time is about 456 ps. And the FWHM of APD with absorption region width 0.43μm increases to 726 ps with fall time about 2350 ps. The detail parameters are listed in table I.

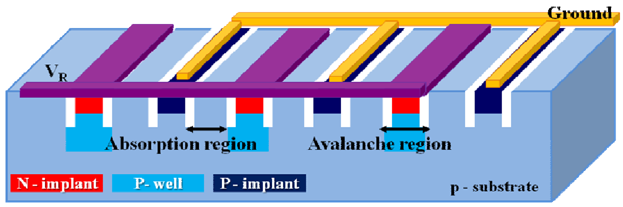

Fig. 1 The schematic cross-section of proposed APD with separated absorption and avalanche regions. The absorption region width varies from 0.43 μm, 0.86 μm to 3.44 μm, while avalanche region width is kept at 0.86 μm.

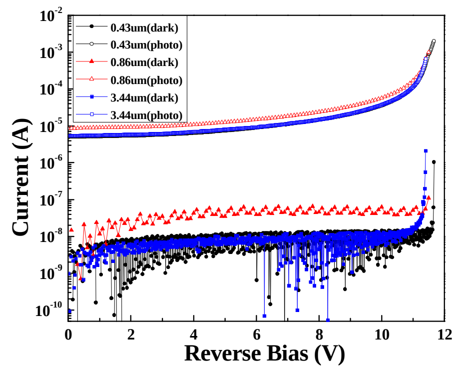

Fig. 2 Characteristic of the dark current and the photo current with different absorption region width.

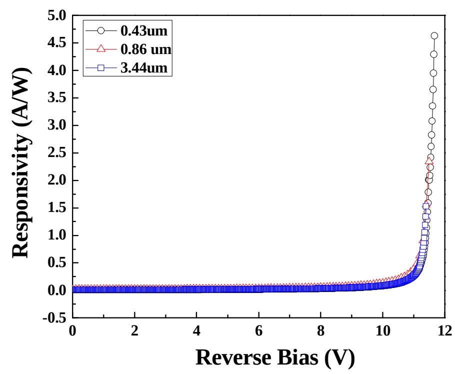

Fig. 3 Responsively of the proposed APDs with different absorption region width.

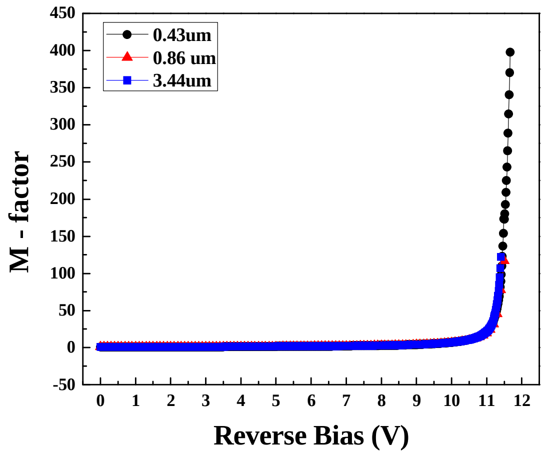

Fig. 4 Avalanche gain of proposed APDs with different absorption region width.

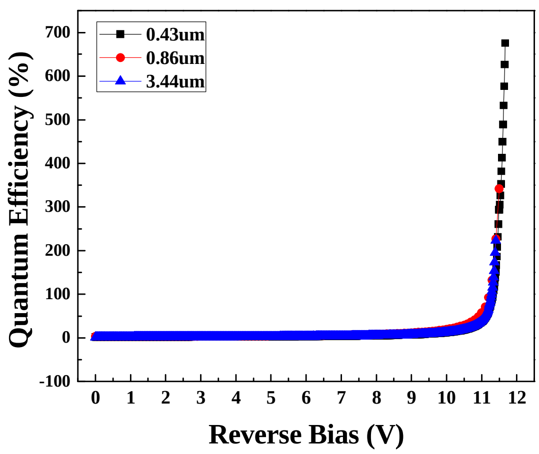

Fig. 5 Quantum efficiency of proposed APDs with different absorption region width.

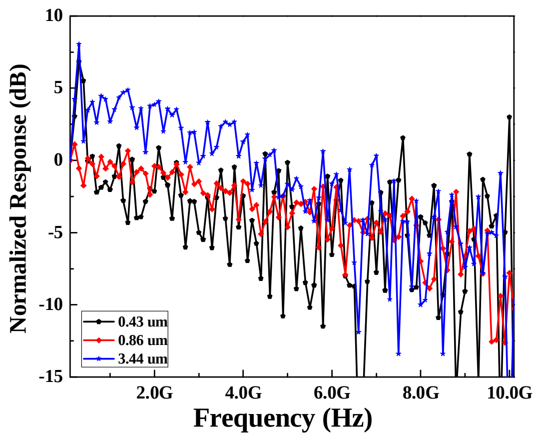

Fig. 6 Normalized frequency response of proposed APDs with different absorption region width.

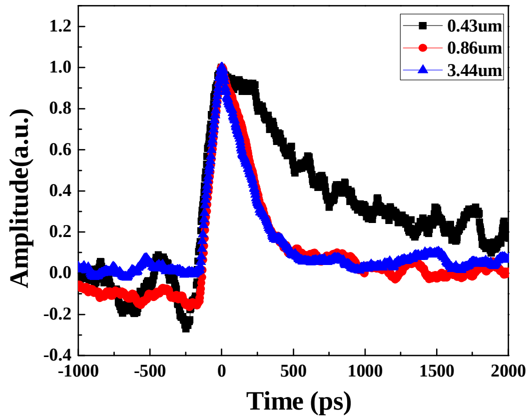

Fig. 7 Pulse response of proposed APDs with different absorption region width.

Table I Device Characteristics of APDs with three different absorption region width.

Absorption region width (μm)	**0.43**	**0.86**	**3.44**
Ratio of avalanche region to absorption region*1	2	1	0.25
V_{BK} (V)	11.67	11.5	11.4
R (A/W)*2	4.63	2.34	1.53
M	397.96	116.97	122.17
η(%)	675.4	341.6	223.1
3dB BW (GHz)	1.4	3.3	5.4
FWHM (ps)	726	289	270
Rise time (ps)	119	33	115
Fall time (ps)	2350	496	456

*1 avalanche region width is 0.86 μm

*2 Responsivity obtained at dark current of 1μA

3. Conclusions

We compared the dc and ac characteristics of lateral avalanche photodetectors with three different absorption region width. The APDs with shorter absorption region width demonstrates higher responsivity due to higher avalanche region ratio. And we also observed that diffusion current dominates the frequency response in lateral APDs with shorter absorption region width by pulse measurement result. The highest responsivity is 4.63 A/W at reverse bias 11.67 V for the APD with 0.43 μm absorption region width, and the best 3-dB bandwidth is 5.4 GHz at reverse bias 11.4 V for the structure with 3.44 μm absorption region width.

Acknowledgements

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References

[1] Z. Y. Li, et al., Opto-Electronics and Communications Conference, 2011

[2] W. K. Huang, et al., IEEE Photonics Technology Letters, 2007