High Bandwidth APD based on BiCMOS Technology

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Abstract

A high responsivity APD based on 0.18μm bipolar complementary metal-oxide-semiconductor (BiCMOS) process has been designed. With the standard 0.18μm BiCMOS technology, the proposed APD is designed with two P+/N-well type pn junction to form two avalanche region in order to produce avalanche multiplication current, and the guard-ring structure is with STI (Shallow Trench Isolation) structure on both sides of the avalanche region, which restrain the edge-breakdown effectively. A deep N-well structure has been applied in the APD to absorb a large number of carrier before they spread to the substrate, which screened the excessed noise and improved the responsivity of the device. Though theoretical analysis, the optical receiving area is of 10μm×10μm, other structure and process parameters of the BiCMOS-APD are also confirmed. The simulation result show that at wavelength of 480nm, the quantum efficiency reaches up to 90%. The avalanche gain is about 72, the responsivity was 2.96 A/W and 3 dB bandwidth is about 4.8GHz when the bias voltage is -15V.

Keywords

Bicmos-APD; Avalanche Gain; Responsivity; Bandwidth.

1. Introduction

As a photoelectric conversion device, Avalanche photodiode has the advantages of big internal gain, small volume and low operating voltage. It has been research hot spot in field of Optical communication, especially short distance optical communication system in recent years[1]. The APD based on BiCMOS process used Si as the material, in which electrons and holes had big difference of collision ionization rate, and can easily integrated with subsequent amplification circuit. It has been Widely used in optical communication system and optical interconnection equipment[2]

2. Structure design of APD device

Figure 1 shows the structure of APD based on 0.18μm BiCMOS process. Based on the hole injection type APD which is rise in literature [3], we put forward a new structure of BiCMOS-APD. At first, we added a deep N-well structure on the basis of the original structure, which is used for shielding substrate noise. Then, according to the analysis of the literature [4], we determined the optical window of 10μm x 10μm. According to the bandwidth and the current analysis of different P well, N well, STI width and doping concentrations in literature on [5], and combined with literature [6], we determined the APD structure as shown in figure 1

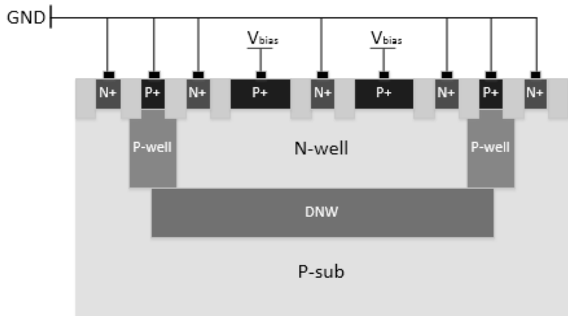

Figure.1 The structure of a new APD

The APD is P+/N-well/DNW/P-sub structure, Light incident from the top of the device, the avalanche area is formed by P+/N well structure of pn junction. It used the P+ ion implantation and N type diffusion process, the P+ connected the cathode, which make the pn junction reverse bias and provide conditions to produce avalanche effect. The STI formed a guard-ring at both ends, increased the pressure resistance of the device and improve the bandwidth to a certain extent. The deep N-well formed by N ion diffusion, the electrode collected to the substrate, which stopped the spread of the carrier on the P-substrate, improve the responsivity.

3. Performance analysis of APD device

3.1 i-v character

Figure 2 shows the I-V characteristic curve of APD we designed under the condition of the light wavelength is 480 nm and the light intensity is 1W/cm^2,

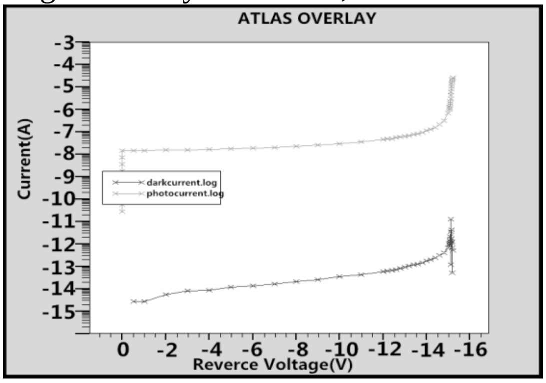

Fig.2 Current-Voltage characteristic curve of APD

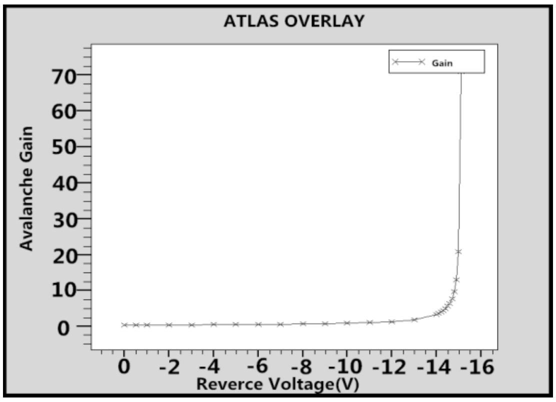

Fig.3 Voltage-Gain characteristic curve of APD

As can be seen from the figure 2, the dark current at zero bias is about 3×10^{-15}A, when the reverse bias voltage is more than -14V, electric current began to dramatically increase, and the avalanche breakdown voltage at around 15.4 V. Under the condition of light, the dark current at zero bias is about 2×10^{-8}A, and the photocurrent is almost the same when the reverse bias voltage is under -10V. While, when the reverse bias voltage is beyond -14V, the photocurrent began to increase rapidly. When V=15.4V, the avalanche breakdown happens and the avalanche breakdown occurs in the contact area of P+ region N-well. Compared to the breakdown voltage (about 7V) in literature [7], the APD we designed has higher breakdown voltage. It is because we use the STI asthe guard-ring, which allowing devices work under the higher bias. The width of the depletion can be calculated through the type (1):

$$w=\left[\frac{2\varepsilon_s\left(V_{bi}+V_R\right)}{e}\left(\frac{N_a+N_d}{N_aN_d}\right)\right]^{\frac{1}{2}} \quad (1)$$

Figure 3 shows the avalanche gain under reverse bias voltage. As can be seen in figure 3 that when the reverse bias voltage is about 15V, the avalanche gain get a value of 72.The avalanche gain can be expressed as type (2):

$$M = \frac{I(V) - I_d(V)}{I(0) - I_d(0)} \tag{2}$$

3.2 Responsivity

Figure 4 shows the spectral response of different wavelengths. From the picture, we can see that the spectral response ranges from 0.1-1.0μm. The responsivity defined by the power can be expressed as type (3):

$$R = \frac{I_p}{P_{opt}} = \frac{\eta q}{h\nu} \tag{3}$$

We improve the response by kinds of methods. Kazuaki Maekita [8] put forward that add a deep n-type buried layer can make the large number carriers be absorbed before spreading to the substrate, which can improve the responsivity. Zhou Xiang [9] put forward that make the APD work at best gain point and Improve the SNR can obtain high responsivity. The responsivity we get is higher than literature [4] and literature [10].As can be seen from figure 4 that the responsivity of APD we designed is about 2.96A/W when the reverse bias voltage is equal to 15V.

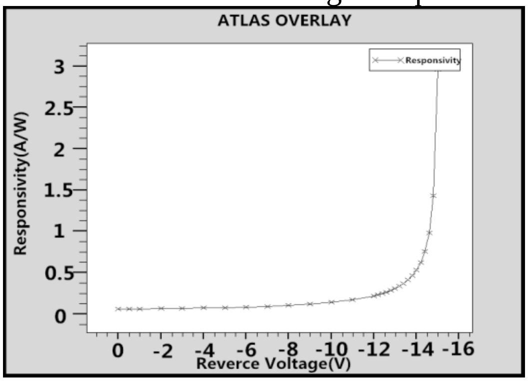

Fig.4 Voltage-Responsivity characteristic curve of APD Literature References

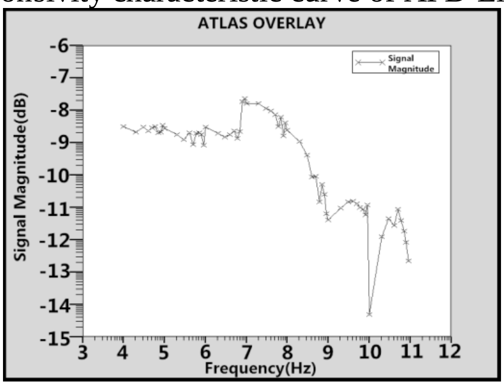

Fig.5 Frequency Response of APD

3.3 Frequency response

Frequency response is an important indicator of APD performance. From the frequency response curve of the device we can intuitive see the 3dB bandwidth. The bandwidth of the APD can be expressed in type (4):

$$BW = \frac{1}{\sqrt{(\frac{2\pi}{\omega_{RC}})^2 + (\frac{2\pi}{\omega_t})^2}} \tag{4}$$

Myung-Jae Lee[4] found that the smaller the window area, the smaller the capacitance of the Depletion region, and the better the frequency response of the device through analysis different window area. Koichi Iiyama[11] found that decrease the interval between electrodes can reduce carrier transit time and increase the bandwidth. In this paper, we use the optical window as 10μm×10μm, Figure 5 shows the frequency response in the light of 480nm under different bias.

As can be seen from the figure 5, the 3dB bandwidth of about 4.8 GHz when v=15V. When the bias increases, on one hand, the electric field enhanced and larger carrier drift effect lead to decrease of carrier transit time, the bandwidth become lager[1]. On the other hand, the avalanche gain become lager and the bandwidth get lager[4].

4. Conclusion

A new type of BiCMOS–APD has been designed in this paper. The optical window of the structure is 10μm×10μm. We add a deep N-well structure under the pn junction and contact the deep N-well to p substrate, prevents the carriers diffusion to P substrate and produce noise. The deep N-well structure increase the RC time constant and decrease the increase the RC time constant, which can improve the responsivity and increase the bandwidth at the same time. The device simulation results show that when the reverse bias voltage is equal to 15V, avalanche breakdown occurs. The avalanche gain is about 72, the responsivity is of 2.96 A/W and the 3dB bandwidth is of about 4.8GHz.

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