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Using selective Zn diffusion to enhance the performance of the PD in monolithically integrated InP/InGaAs p-i-n PD/HBT

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1. Introduction

Monolithically integrated front-end photoreciever based on InP/InGaAs material system is very attractive because of the potential for high-speed operation in long-wavelength optical communication systems. Using same layer structure for photodiode (PD) and heterojunction bipolar transistor (HBT) provides the advantages of one-step epitaxy and simpler fabrication. An example of the shared layer integration scheme in this design is the p-i-n PD/HBT photoreceiver in which the p-i-n PD is made with the base-collector layers of the HBT structure without any complex growth and fabrication sequence [1].

In the top-illuminated p-i-n PD [1], the light illuminates the absorption layer directly and thus the large proportion of the photons is absorbed in the surface as well as the generated electron-hole pairs. However these photo-carriers will be accumulated at the edge of the depletion region to screen the given reverse bias and saturate the PD's output power [2]. In this paper, the additional Zn diffusion process is proposed and applied in InP/InGaAs p-i-n PD/HBT integrated structure to enhance the PD's performance.

2. Layer Structure and Devices Performance

The InP/InGaAs p-i-n PD/SHBT is grown by molecular beam epitaxy (MBE) and the epitaxial structure is described in Table I.

Table I Layer Structure of SHBT

SHBT Layer Structure

	Material / Thickness (Å)	
Emiter cap	InGaAs / 2000	
Emitter	InP / 500	
Spacer	InAlGaAs / 30	
Base	x=0.03-0.05 $In(Al_xGa_{1-x})As$ / 500	
Collector	InGaAs / 5000	PD
Subcollector	InP / 4000	
Substrate	S.I. InP	

The graded p^+-$In(Al_XGa_{1-X})As$ (x = 0.05-0.03) with Be dopant is used for the base layer with built in electric field and performs as an illuminated window at λ = 1.55 μm. After considering the trade-off problem between the transistor speed and the PD's responsivity, the collector (PD's absorption layer) of the SHBT is a 5000 Å InGaAs with doping of 1×10^{16} cm^{-3}. The HBT is fabricated in conventional triple mesa-type process technology by using optical lithography and selective wet etching. The InP/InGaAs p-i-n PD is fabricated simultaneously by removing the emitter layer. The non-annealed electron beam evaporation of Ti/Pt/Au metallization is used for ohmic contacts for both p-type and n-type layers.

The emitter size of the base-emitter self-aligned HBT is 4×12 μm^2. The measured f_T and f_{MAX} are 97 and 60 GHz, respectively. The active region of the PD for vertical illumination is 20×23 μm^2. The measured optical-electrical conversion bandwidth is 15.8 GHz (V_R = 1 V, I_{PH} = 1 mA), as shown in Fig. 1.

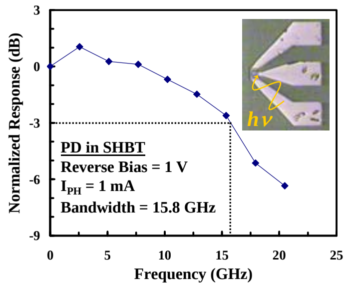


Fig. 1 Frequency response of the fabricated PD.

3. Zn Diffusion

The selective Zn diffusion process is applied after the p-i-n PD/SHBT fabrication with passivation. The diffused region is defined only for the PD, as shown in Fig. 2. Other region is passivated by the plasma enhanced chemical vapor deposition (PECVD) SiN_X.

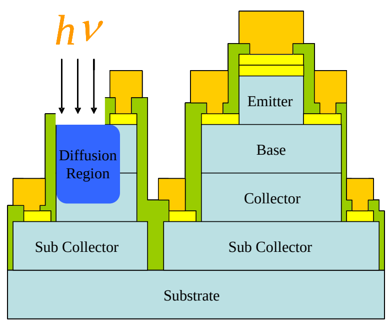


Fig. 2 Schematic cross-section of the Zn diffused p-i-n PD and HBT.

The Zn diffusion is implemented at the temperature of

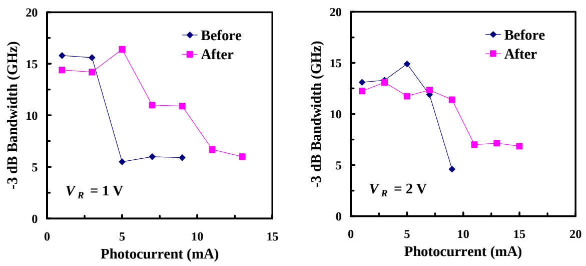
500 °C (3 minutes). The estimated depth of the Zn diffusion is about 3000 Å.

This Zn diffusion provides two main advantages for PD:

1. The upper portion of the collector (absorption) layer is transferred into p-type to be the main absorption region. The generated holes can be absorbed by p-electrode quickly which prevents from the accumulation. And the whole PD's speed will be almost dominated by the generated electrons with reducing the screening effect.
2. The Zn diffusion region acts as a gradient doping design. The gradient is expected to accelerate the generated photo-carriers.

4. Measurement and Discussion

Fig. 3 shows the comparison of the bandwidth versus different photocurrent levels before and after Zn diffusion process at (a) V_R = 1 V and (b) V_R = 2 V.



(a) (b)

Fig. 3 Comparison of the PD's -3 dB bandwidth before and after Zn diffusion at (a) V_R = 1 V and (b) V_R = 2 V.

When V_R is 1 V, the screening effect is observed and results in the bandwidth dramatically decreased to 5.5 GHz at I_{PH} of 5 mA before the process. After the process, the roll-off phenomenon of the bandwidth has been delayed successfully and it shows a bandwidth of 10.9 GHz (before the process: 5.9 GHz) at I_{PH} of 9 mA. When V_R is 2 V, although the screen effect can be improved at higher V_R, it still takes effect at I_{PH} of 9 mA after the process as shown in Fig. 4.

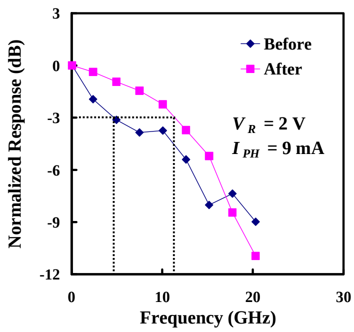


Fig. 4 Comparison of the PD's normalized responses between before and after Zn diffusion process at I_{PH} of 9 mA.

However, the temperature of the Zn diffusion process is high for the fabricated HBT. Such high temperature process causes Be dopant in base out-diffuses into Emitter. Consequently, the p-n junction is moved toward wide bandgap emitter of InP and causes the higher B-E turn-on voltage, as shown in Fig. 5.

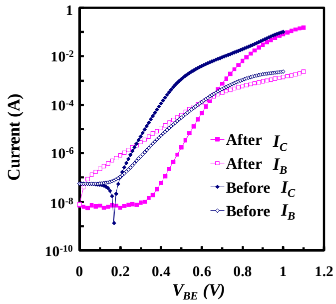


Fig. 5 Comparison of the gummel plots for HBT before and after Zn diffusion process.

The RF performance of the HBT is also affected. The f_T is decreased to 92 GHz with slightly shifted bias condition as shown in Fig. 6. And the f_{MAX} is also degraded to 52 GHz.

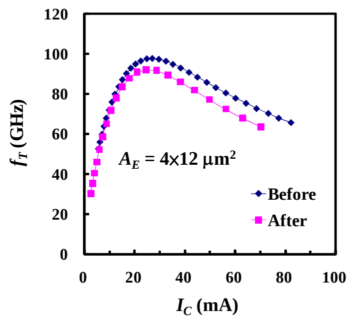


Fig. 6 Comparison of the f_T versus I_C performance for HBT before and after Zn diffusion process.

5. Conclusion

In this paper, the selective Zn diffusion process is applied in the conventional p-i-n PD/HBT structure to enhance the PD's performance. After the Zn diffusion process, the PD demonstrates a better -3 dB bandwidth at higher output current successfully.

However, the high temperature process results in the degradation of the HBT's characteristics. Lower temperature process or other base dopants of low diffusivity (such as C) are suggested in future work to avoid the degradation in HBT but improve PD performance.

6. References

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[2] G. Unterborsch, D. Trommer, A. Umbach, R. Ludwig, and H.G. Bach, Electronics Lett., **34** (1998) 493.