Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.342-343

E-5-3

Improved Efficiency-Bandwidth Product of Modified Uni-Traveling Carrier Photodiode Structures Utilizing an Undoped Photo-Absorption Layer

Dong-Hwan Jun[1], Jae-Hyung Jang[1], Ilesanmi Adesida[2], and Jong-In Song[1]

[1]Dept. of Information and Communications, GIST,
1 Oryong-dong Buk-gu, Gwangju, 500-712, Korea
+82-62-970-2208, +82-62-970-2204, e-mail: jisong@gist.ac.kr
[2]Micro and Nanotechnology Laboratory, University of Illinois,
208 North Wright St. Urbana, IL 61801, USA

1. Introduction

Researches on high-speed photodiodes have been focused on reduction of the transit time of photo-excited carriers through photo-absorption layer. In Schottky-type or pin-type photodetectors, for example, the drift time of hole has to be minimized since the low mobility of hole is a factor limiting the speed of the photodetectors [1]. On the other hand, for uni-traveling carrier photodiodes the electron diffusion time through the p-type photo-absorption layer should be minimized. [2]. Since the diffusion limited transit time is proportional to the square of the p-type photo-absorption layer thickness, the thickness of the p-type photo-absorption layer is limited to less than 0.2 μm for the bandwidth larger than 100 GHz [2]. While the uni-traveling carrier photodiodes have an advantage of a large bandwidth, they have an important drawback of low efficiency due to the very thin p-type photo-absorption layer. In order to improve the efficiency, modified uni-traveling carrier photodiode structures having an undoped photo-absorption layer have been proposed and theoretically analyzed [3].

In this work, effects of the undoped photo-absorption layer in modified uni-traveling carrier photodiode structures on efficiency and bandwidth are experimentally investigated

2. Experiments

Figure 1 shows schematic cross sections of photodiode epi-structures. The PD1 is a generic uni-traveling carrier photodiode structure having a 380 nm-thick undoped InP uni-traveling depletion layer. The PD2 and PD3 have 200 nm- and 400 nm-thick undoped photo-absorption layer (hole-electron drift) below the p-type photo-absorption layer, respectively. The photodiode epi-structures have been designed to have an identical total active layer thickness for performance comparison. Photodiodes having the diameters of 64 μm and 11 μm were fabricated for DC and high-frequency measurements, respectively, using identical process steps except for mesa etching.

3. Results and discussion

Responsivities of photodiodes as a function of the input optical power under -1 V reverse bias are shown in Fig. 2. As expected, the PD2 and 3 had a substantially larger efficiency compared with that of the generic uni-traveling carrier photodiode structure (PD1).

Frequency response of the PDs was measured by using an optical heterodyne method (100% modulation depth) with the calibration of losses from cables, a bias tee, and attenuators. Figure 3 shows the frequency response of the PDs having the mesa-diameter of 11 μm measured at the input optical power of -6 dBm. The PD2 and PD3 had a larger bandwidth compared with PD1, which agrees well with the theoretical study reported in [3]. This is associated with the undoped photo-absorption layer that generates photo-excited carriers and they also contribute to the total photo-current. At the same time, the drift time of carriers through the undoped photo-absorption layer is shorter than that of electron diffusion time in the p-type photo-absorption layer. Thus, a frequency compensation effect can be occurred by the serially connected undoped photo-absorption layer with p-type photo-absorption layer. The rather small bandwidth of the PD1 is ascribed to the low electron mobility (~1,000 cm^2/Vs) in the p-type photo-absorption layer that was extracted from the frequency response measurements of the PD1 [4].

Figure 4 shows measured and calculated efficiency-bandwidth product of the PDs as a function of the undoped photo-absorption layer thickness. As can be seen in the Fig. 4, the measured data agrees well with the calculated results at low input optical power. The PD 2 and 3 had a substantially larger efficiency-bandwidth product than that of the PD1 due to the presence of the undoped photo-absorption layer.

4. Conclusions

Effects of the undoped photo-absorption layers in modified uni-traveling carrier photodiode structures on efficiency and bandwidth were investigated. The undoped photo-absorption layers combined with a p-type photo-absorption layer were effective in increasing the efficiency-bandwidth product. The results indicate the possibility of improving the efficiency-bandwidth product of the uni-traveling carrier photodiode structures through further optimizations of structure and quality of the photodiode epitaxial layer.

Acknowledgements

This work was supported, in part, ITRC(MIC, Korea) -CHOAN, the BK21, and the ERC-UFON at Gwangju Institute of Science and Technology.

References

[1] K.-H, Oh, et al., 3rd Japan-Korea Joint Workshop on Microwave and Millimeter-wave photonics, 2002, pp. 131-134

[2] H. Ito, et al., Selected Topics in Quantum Electronics, Vol. 10, 2004, pp. 709-727

[3] D.-H. Jun, et al., International Semiconductor Device Research Symposium, 2003, pp. 86-87

[4] N. Shimizu, et al., International Topical Meeting on Microwave Photonics, 1998, pp.193-194

Layer	Doping	PD1	PD2	PD3
$In_{0.53}Ga_{0.47}As$	P:1x10^{19}cm^{-3}	60nm		
$In_{0.53}Al_{0.03}Ga_{0.44}As$	P:1x10^{19}cm^{-3}	15nm		
$In_{0.53}Ga_{0.47}As$: photo-absorbption layer	P:1x10^{18}cm^{-3}	300nm		
	undoped	10nm	200nm	400nm
$In_{0.53}Al_{0.03}Ga_{0.44}As$	undoped	10nm	10nm	10nm*
InP	undoped	380nm	190nm	0nm
InP	N:5x10^{18}cm^{-3}	50nm		
$In_{0.53}Ga_{0.47}As$	N:1x10^{19}cm^{-3}	20nm		
InP	N:1x10^{19}cm^{-3}	400nm		
Semi-insulated InP Substrate				

Figure 1. Schematic cross sections of photodiode epi-structures (* - N: 5x10^{18} cm^{-3})

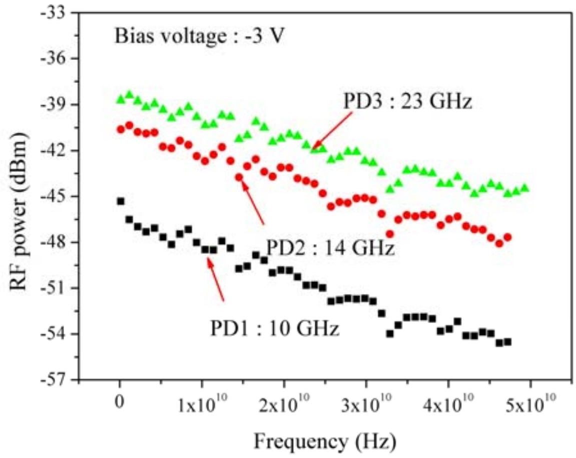

Figure 3. Frequency response of the PDs having the mesa-diameter of 11 μm measured at the input optical power of -6 dBm

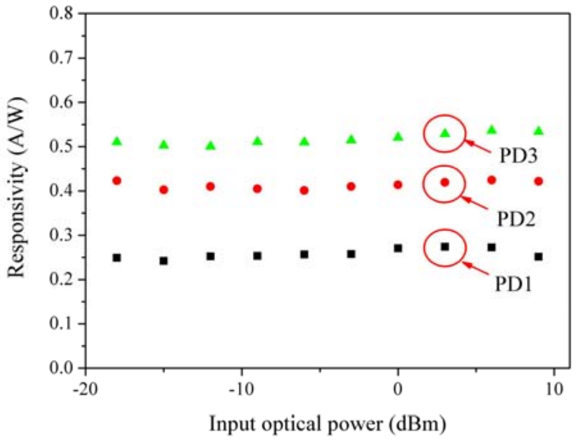

Figure 2. Responsivities of photodiodes as a function of the input optical power at -1 V bias voltage

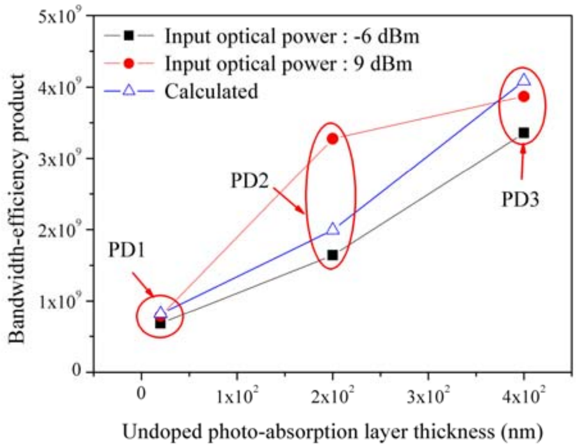

Figure 4. Measured and calculated efficiency-bandwidth product as a function of the undopded photo-absorption layer thickness at bias voltate -3 V