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InP/InGaAs Leaky Waveguide Photodiode with a Partially p-Doped Absorption Layer and a Distributed-Bragg-Reflector (DBR) for High-Power and High-Bandwidth-Responsivity Product Performance

Wei-Yu Chiu[1], Wen-Kai Wang[1], Yen-Shiang Wu[1], Fan-Hsiu Huang[1], Dong-Ming Lin[1], Yi-Jen Chan[1] and Jin-Wei Shi[1*]

[*]Department of Electrical Engineering, National Central University, Chung-li, Taiwan 32001, R.O.C 320
Phone: 886-3-4227151-34466 Fax: 886-3-4255830 E-mail:jwshi@ee.ncu.edu.tw

1. Introduction

The performance of microwave and millimeter-wave photonic systems would benefit from the use of photodiodes (PDs) with high saturation power, high-speed and high responsivity performance [1]. There are two major ways to satisfy these three requirements of PDs. One is to distribute and uniform the photocurrents along the edge-coupled PDs by improving the structure of optical and electrical waveguides [2]; the other is to minimize the space-charge effect by changing the structure of epitaxial layers [3]. In this work, we combined a partially p-doped photo-absorption layer with a leaky optical waveguide and a distributed-bragg-reflector (DBR) in the structure of an edge-coupled photodiode. The integrated DBR mirror can fold the injected optical path and enhance the responsivity performance without increasing the length of active region. The demonstrated device can achieve superior performance in terms of bandwidth, saturation power, and quantum efficiency for the control, without DBR mirrors.

2. Device structures and fabrication

Figure 1 shows the cross-sectional view, top-view, and fabricated DBR mirror of demonstrated device. In order to determine the influence of DBR mirrors on the responsivity performance of photodiodes, two kinds of device, with the same geometry and epi-layer structures, but with and without DBR mirrors, were fabricated. The pattern of the DBR mirrors with periods of 240nm was written into the photo-resist (PMMA) layer by electron-beam lithography, and then transferred to the Si_3N_4 layer. The DBR mirror device has twice the reflected input optical power and absorption of the folded optical power. Thus, compared with the DBR device, the control device requires a much longer device-absorption-length, which results in poorer speed performance. The used leaky optical waveguide is composed of the two bottom undoped InGaAsP core layers ($In_{0.9}Ga_{0.1}As_{0.21}P_{0.79}$ 2.5μm and $In_{0.68}Ga_{0.32}As_{0.69}P_{0.31}$ 0.65μm), a thin heavily doped n-type InP etching stop layer, a $In_{0.53}Ga_{0.47}As$ based photo-absorption layer with 0.3μm undoped and 0.2μm p-doped layer thickness, and topmost p-type InP cladding layer with 0.5μm thickness. The partially p-doped photo-absorption layer will shorten the depletion layer thickness and increase the saturation current of PD significantly.

In this paper, except for the DBR structures, both devices were fabricated by use of the standard photolithography, metallization, lift-off, and dry etching processes. Then the fabricated devices were integrated with the Co-Planar Waveguide (CPW) for on-wafer high-speed measurement.

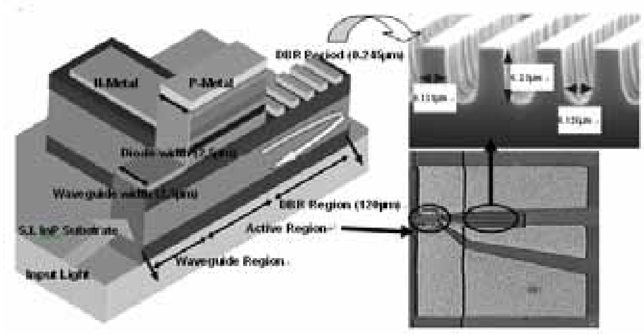

Fig. 1 The cross-sectional and top views of the demonstrated devices. The inset pictures the fabricated DBR mirrors.

3. Measurement Results

In order to study the influence of DBR mirrors on device performance, we have fabricated the control-device without DBR mirrors. Both devices have similar epi-layer and geometry structure. We employed a tunable semiconductor laser as the light source for the dc photocurrent measurement. Figure 2 shows the measured responsivity of both devices vs. active diode lengths with different waveguide widths (2μm and 5μm) under a fixed dc bias voltage (-3V). We can clearly see the devices with DBR mirrors can have significant higher responsivity than that of control-device with similar active length. For the device with DBR mirror and 32μm active length, the achieved responsivity is as high as 0.9A/W. Furthermore, our demonstrated device does not exhibit serious wavelength selectivity, which is a serious problem for the resonant-cavity-enhanced PD (RCEPD) [4]. The measurement result was shown in the figure 3. This is because our cavity length is much longer than the operating wavelength and that an AR coating is applied to the input facet.

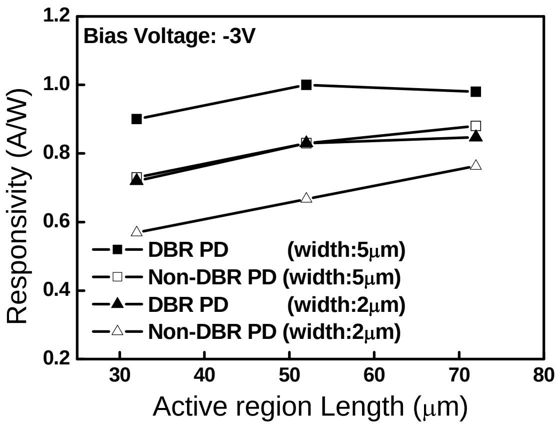

Fig. 2 The measured responsivity versus lengths of active diodes with and without DBR mirrors.

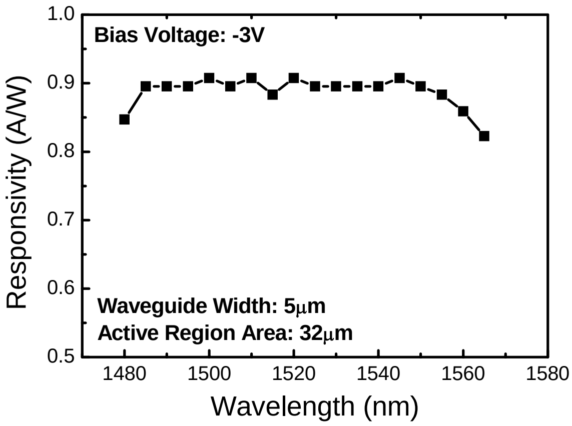

Fig. 3 The measured responsivity versus different input wavelength of device with DBR mirrors.

The bandwidth and saturation current were measured with a heterodyne beating setup. Figure 4 shows the measured frequency responses of both device with different active areas and almost similar responsivity performance (0.9 vs. 0.8A/W).

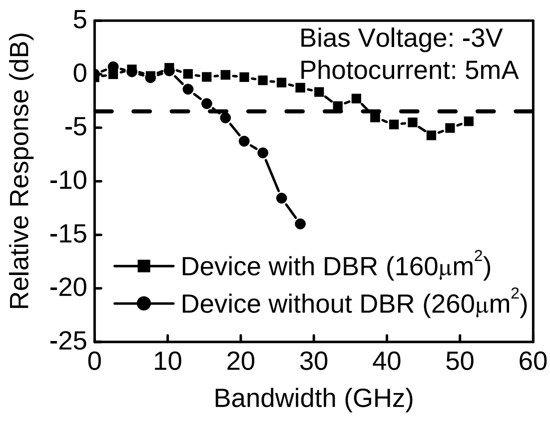

Fig. 4 The measured frequency responses of devices with and without DBR mirrors.

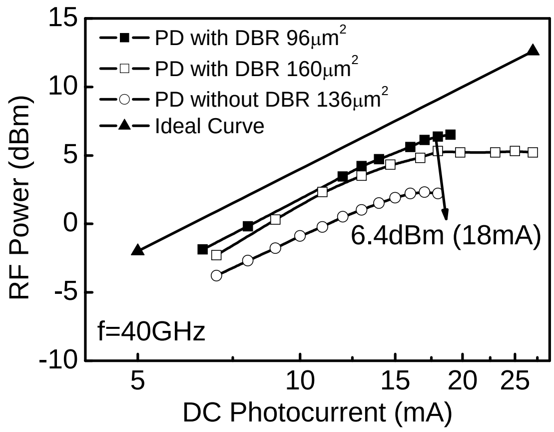

Fig. 5 RF power versus dc photocurrent of devices under a fixed 40GHz operating frequency and dc bias voltage (-3V).

Compared with the control-device, the device with DBR mirrors can not only have much higher electrical bandwidth performance (~37GHz vs. ~17GHz) due to its smaller geometry size but also much higher bandwidth responsivity product (33.3GHz-A/W vs. 13.3GHz-A/W). Figure 5 represents the photo-generated RF power versus dc photocurrent of devices with and without DBR mirrors and different active areas under a fixed dc bias voltage (-3V). The operating frequency is fixed at 40GHz. The ideal relation between the RF power of a 100% modulated large-signal and the average current with a 50Ω load is also plotted as a straight line for reference. As shown in this figure, DBR devices with a smaller geometric size (96μm^2 vs. 160μm^2) can have a slightly larger photo-generated RF power under the same photocurrent, due to having a larger RC limited bandwidth. Furthermore, we can clearly see that the two DBR devices have a higher saturation current (~18mA vs. ~15mA) and RF power (6.4dBm vs. 2dBm) than that of the control devices without DBR structure.

4. Conclusions

In conclusion, we developed a novel edge-coupled photodiode structure, which is composed of DBR mirrors, a leaky optical waveguide, and a partially depleted absorber. With this device the dependence of the responsivity on the cleaved length of the passive optical waveguide is greatly relaxed, leading to significant improvement in terms of speed, power, and responsivity performance.

Acknowledgments

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