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InP-based OEIC Photoreceivers using Shared Layer Integration Technology of Heterojunction Bipolar Transistors and Refracting-Facet Photodiodes

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1. Introduction

The optoelectronic integration of photodetectors and transistor preamplifiers has been the issue in the high-speed optical fiber communication systems. The photoreceivers based on the p-i-n/HBT shared layer integration scheme have advantages of simple fabrication, one-step epitaxy and high yield. However, the shared collector layer thickness causes the tradeoff relation between the HBT transit time and the optical responsivity of the photodetector [1].

In this paper, we report on the new monolithic integration technology of RFPDs and HBTs. The refracting-facet photodiode (RFPD), featuring high optical responsivity with a rather thin absorption layer [2], was fabricated using the base-collector junction of the HBT. The self-aligned 2×10 μm^2 emitter InP/InGaAs HBT was fabricated and characterized. Based on the RFPD/HBT shared layer integration scheme, monolithic OEIC photoreceivers consisting of the transimpedance amplifier (TIA) and the RFPD were fabricated and measured for the first time.

2. Structure and Fabrication

The InP/InGaAs single HBT epitaxial layer structure is used for the RFPD/HBT monolithic integration. It consists of a 800 Å $n^+(2 \times 10^{19}$ cm$^{-3})$ InGaAs emitter cap layer, a 500 Å $n^+(2 \times 10^{19}$ cm$^{-3})$ InP, a 1000 Å $n(4 \times 10^{17}$ cm$^{-3})$ InP emitter, a 50 Å undoped InGaAs spacer, a 450 Å $p^+(4 \times 10^{19}$ cm$^{-3})$ InGaAs base, a 6000 Å $n^-(2 \times 10^{16}$ cm$^{-3})$ InGaAs collector, a 100 Å $n^+(2 \times 10^{19}$ cm$^{-3})$ InP etchstop, a 5000 Å $n^+(2 \times 10^{19}$ cm$^{-3})$ InGaAs subcollector layer and a 1000 Å undoped InP buffer layer on a semi-insulating InP substrate. Fig. 1 shows a schematic cross section of the fabricated RFPD and HBT using the InP/InGaAs single HBT structure. The key feature in this monolithic integration is to use the base-collector InGaAs junction to fabricate the RFPD. A 6000 Å InGaAs collector layer was used as an absorption layer of the RFPD at a wavelength of 1.55 μm. An InGaAs subcollector layer for the n-ohmic contact was used as the etch mask to form the refracting facet of the RFPD. InP refracting facets with an angle of 55° were formed by a selective wet chemical etching process using a $1HBr{:}1H_3PO_4$ solution with the InGaAs subcollector mask. The HBTs for the monolithic OEIC photoreceiver were fabricated using a self-aligned emitter-base process with nonalloyed metallization for the ohmic contacts [3]. For the

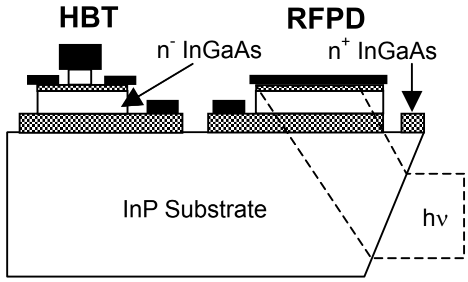

Fig. 1. Schematic cross section of the fabricated HBT and RFPD using the InP/InGaAs single HBT structure.

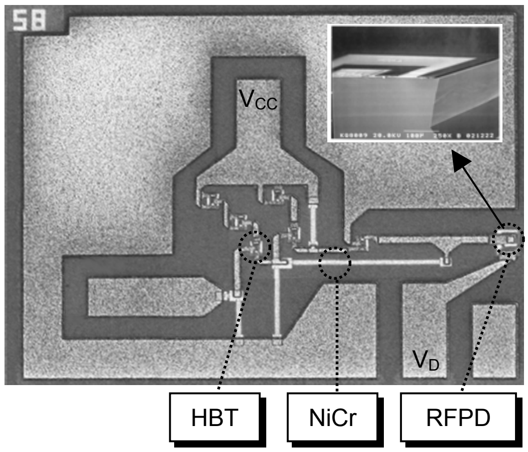

Fig. 2. Microphotograph of the OEIC photoreceiver fabricated using the RFPD/HBT shared layer integration scheme. The inset shows a SEM image of refracting facet formed by a selective wet chemical etching.

emitter and collector ohmic contacts, Ti/Pt/Au was evaporated and Pt/Ti/Pt/Au was evaporated to form the base contact. The mesa was defined by wet chemical etching. The fabrication of the RFPD were simultaneously obtained through the fabrication process of the base-collector junction of the HBT. A 430 Å NiCr layer was evaporated to form thin-film resistors with a sheet resistance of 25Ω/□. For device passivation, the polyimide was spin-coated and cured at 200°C. The monolithic OEIC photoreceiver was fabricated using the integration scheme of the HBT and RFPD as shown in Fig. 1. A SEM image of refracting facet and a microphotograph of the fabricated monolithic photoreceiver using the RFPD/HBT shared layer integration scheme were shown in Fig. 2. The TIA for the OEIC photoreceiver is composed of a common emitter gain stage, two emitter-follower buffer stages, and a feedback resistor [4].

3. Measurement and Discussion

The fabricated self-aligned 2 × 10 μm^2 emitter HBTs exhibited a maximum current gain of 40. The peak f_T and f_{max} of the fabricated HBT were measured to be 79 GHz and 143 GHz at I_C = 19 mA and V_{CE} = 1.5 V, respectively. The fabricated three-stage TIA with a feedback resistor of 600 Ω shows a transimpedance gain of 46 dBΩ and a –3 dB bandwidth of 12 GHz. The gain-frequency characteristics of the fabricated HBT and the transimpedance characteristics of the TIA are shown in Fig. 3. The fabricated RFPD with a 30 × 30 μm^2 mesa size has a 37% increased optical responsivity of 0.48 A/W compared to the fabricated surface-illuminated photodiode (S-PD) as shown in Fig. 4. The effective increment of optical path in a thin absorption layer, due to the refraction of light beam, improves the responsivity of the fabricated RFPD. A full width at half maximum (FWHM) of the fabricated RFPD was 24 ps and the dark currents were measured to be less than 25 nA up to a reverse bias of 4 V. The fabricated monolithic RFPD/HBT OEIC photoreceiver has demonstrated a –3 dB optical bandwidth of 6.9 GHz at λ = 1.55 μm, due to the mesa area (30 × 30 μm^2) of the RFPD designed for 10 Gb/s photoreceiver applications with a high responsivity. Fig. 5 shows the optical frequency response of the fabricated photoreceiver and impulse response of the RFPD. The sensitivity of the fabricated photoreceiver is now under investigation to confirm the effect of the responsivity of the RFPD.

4. Conclusion

The RFPD featuring a high optical responsivity and the self-aligned emitter InP/InGaAs HBT were monolithically integrated, for the first time to our knowledge, based on the shared layer integration scheme. The fabricated HBT shows f_T = 79 GHz and f_{max} = 143 GHz at I_C = 19 mA and V_{CE} = 1.5 V, respectively. The fabricated RFPD, which was simultaneously obtained through the fabrication process of the base-collector junction of the HBT, shows 37% increased optical responsivity compared to the fabricated S-PD. Based on the RFPD/HBT monolithic integration scheme, OEIC photoreceivers were successfully fabricated and characterized at a wavelength of 1.55 μm, promising for realization of low-cost and high-speed photoreceiver for dense WDM applications.

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Acknowledgement

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References

[1] D. Huber, et al., Journal of Lightwave Technology, vol. 18, no. 7, pp. 992-1000, 2000.

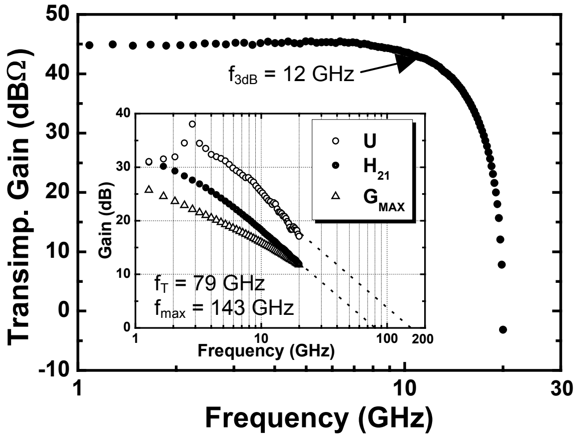

Fig. 3. Measured electrical frequency response of the fabricated monolithic transimpedance amplifier. The inset shows measured gain-frequency characteristics of the fabricated HBT with a 2 × 10 μm^2 emitter size.

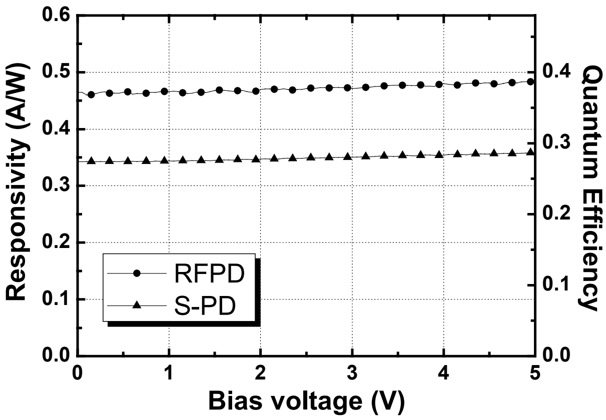

Fig. 4. Measured optical responsivity of the fabricated 30 × 30 μm^2 mesa RFPD and S-PD at λ = 1.55 μm.

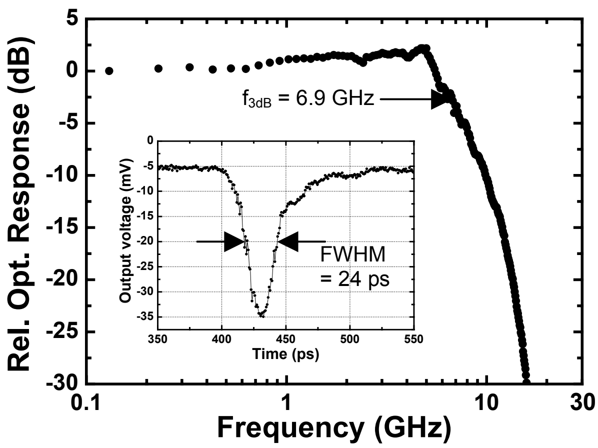

Fig. 5. Measured optical frequency response of the fabricated RFPD/HBT photoreceiver. The inset shows measured impulse response of the fabricated RFPD with a 30 × 30 μm^2 mesa size.

[2] H. Fukano, et al., Electronics Letters, vol. 32, no. 25, pp. 2346-2348, 1996.

[3] Y. Song, et al., Journal of Semiconductor Technology and Science, vol. 3, no. 1, pp. 33-41, 2003.

[4] K. Yang, et al., Journal of Lightwave Technology, vol. 14, no. 8, pp. 1831-1839, 1986.