Characterization of Heterojunction Bipolar Phototransistor with Integrated Two-Section Light-Emitting Transistors

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The III-V light-emitting transistor (LET) with direct bandgap and carrier injection has made itself as a three-port (an electrical input, an electrical output and a “third-port” optical output) device. Quantum-wells (QWs), as an optical collector, are incorporated in the p-type base layer in order to enhance the base recombination, thus the effective minority carrier lifetime can be progressively reduced to sub-100 ps [1]-[3]. The fast spontaneous recombination lifetime and dual outputs characteristics allow light-emitting transistors to operate as three-terminal high-speed devices and desirable electrical-to-optical converter. Heterojunction phototransistor (HPT) is an attractive component in lightwave systems due to its simultaneous photodetection and amplication in one device, especially in the high speed optical communication systems. The large internal gain, low noise and compatibility with LET in epitaxial layer and process allow a possibility to fabricate high performance and cost-effective optoelectronic integrated circuits (OEICs) [4].

In the present work, we demonstrate an integrated two-section phototransistor with a light-emitting transistor serving as the light source. We fabricate two InGaP/GaAs LETs with back to back orientation (Fig. 1.) and operate one device as light emitter (LET), where the other device as photon-absorption section (HPT). The phototransistor optical gain can be modulated by incident optical powers and different bias conditions.

Figure 1 shows the schematic device structure of the two-section edge-emitting light-emitting transistors where one of them is operated as the light source (LET), and the other one is served as the photodetector (HPT). The lengths of both LET and HPT are 400 μm. Two devices are saperated by 4.9 μm and electrically-isolated by ICP-RIE dry etch to form the cavity mirrior.

Figure 2(a) and 2(b) show the base and collector current of the HPT with illumination from LET (circles: 4.28 μW; triangles: 7.33 μW) and without illumination (squares). The reversal I_B shown in Fig. 2(b) with light illumination of 4.28 μW (circles) when V_{BE} < 0.96 V arise from the fact that during optical absorption photo-generated holes in the base-collector space charge region are injected into the base exceeding the need for hole injection from the base terminal connection, thus, producing a net flow of holes out the base connection, i.e. a negative base current. At high base-emitter biases (V_{BE} > 1 V), the hole injection due to optical absorption is negligible compared to that from the base contact. In this condition, the electrical base current dominates over the photo-generated current leading to a coincident curves between illuminated current and dark current. The notchs corresponding to the reversal in the base current move to a higher base-emitter bias (0.96 V to 0.98 V) with increasing optical power (4.28 μW to 7.33 μW) while the characteristic is unchanged at high biases. At low biases, the base current saturates at a value corresponding to the incident optical power. Similarly, Fig. 2(b) shows th collector current’s saturation value at low bias shifting to highercurrent levels with increasing optical power [5].

Figure 3(a) and 3(b) show the electrical characteristics of the HPT with incident optical power of 4.28 μW and 7.33 μW respectively. The base current (I_B) varies from 3 to 12 mA in 3 mA steps. The total optical collector current, $I_{C,opt}$, for a current-biased HPT under optical injection is given by [6]

$$I_{C,opt} = (\beta + 1) I_{ph} + \beta I_{Bdc} \tag{1}$$

where I_{ph} is photo-generated current, β is dc current gain, and I_{Bdc} is input base current. With the incident input power of 4.28 and 7.33 μW, the total optical collector currents increase 2.3 and 3.9 % respectively at V_{CE} of 3 V and I_B of 12 mA due to the increasing optical absorption.

Figure 4 shows the optical gain, G, of the HPT with different incident optical powers (P_{in} = 4.28 and 7.33 μW) and biases. The optical gain can be express as [7]

$$G = \frac{h\nu}{q} \frac{\Delta I_{C,opt}}{P_{in}} \tag{2}$$

The optical gain up to 450 when V_{CE} = 3 V and sensitive to voltage variation because more photo-generated carrers are produced with the increasing reversed base-collector voltage.

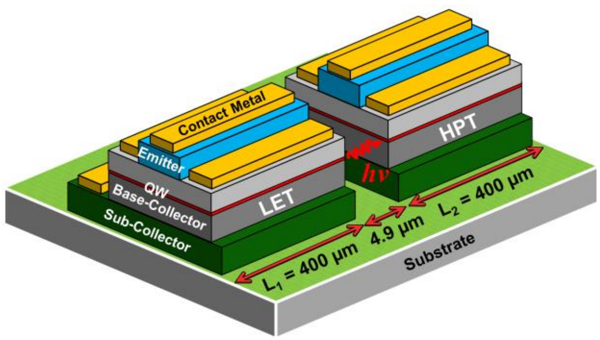

Fig. 1: Schematic device structure of two-section edge-emitting light-emitting transistor where one of them is operated as the light source (LET), and the other one is served as the photodetector (HPT).

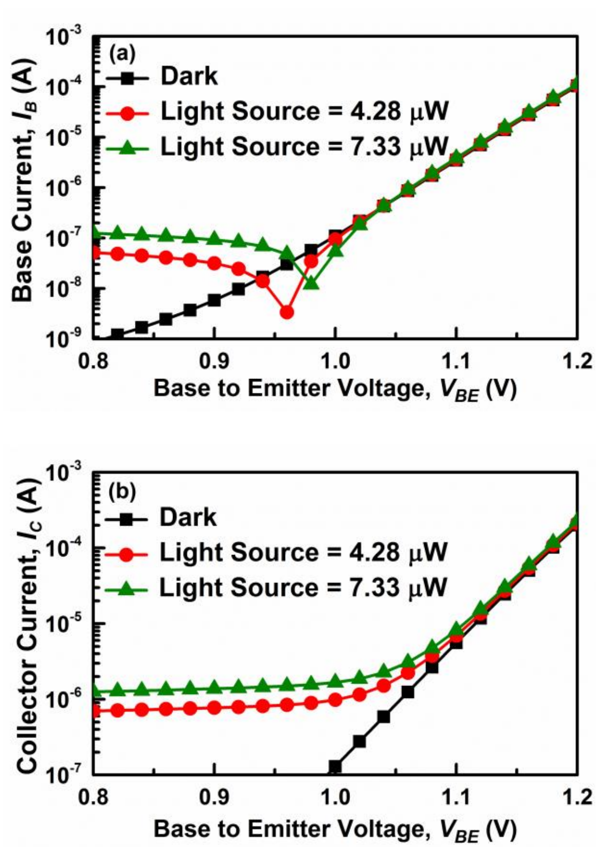

Fig. 2: (a) Base and (b) collector current of the HPT with illumination from LET (circles: 4.28 μW; triangles: 7.33 μW) and without illumination (squares).

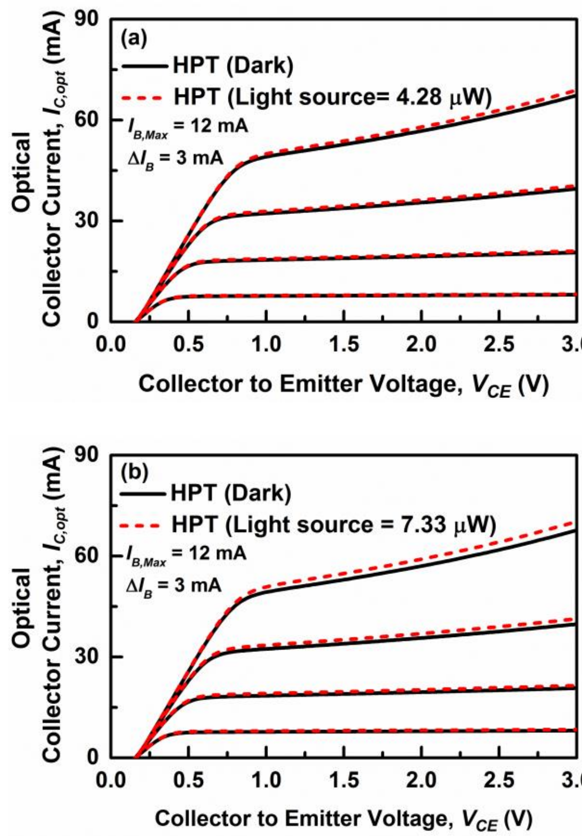

Fig. 3: The electrical characteristics of the HPT with incident optical power of (a) 4.28 μW and (b) 7.33 μW respectively.

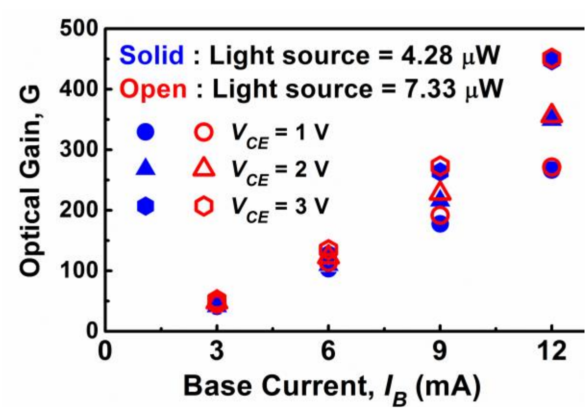

Fig. 4: The optical gain, *G*, of the HPT with different incident optical powers (P_{in} = 4.28 and 7.33 μW) and biases.

REFERENCES

[1] M. Feng, N. Holonyak, Jr., and W. Hafez, *Appl. Phys. Lett.*, 84, 151, 2004.
[2] M. Feng, N. Holonyak, Jr., and R. Chan, *Appl. Phys. Lett.*, 84, 1952, 2004.
[3] G. Walter, C. H. Wu, H. W. Then, M. Feng, and N. Holonyak, Jr., *Appl. Phys. Lett.*, 94, 241101, 2009.
[4] H. Kamitsuna, K. Ishii, T. Shibata, K. Kurishima, M. Ida, *IEEE J. of selected topics in quantum electronics.*, 10, 673, 2004.
[5] R. Sridhara, S. M. Frimel, K. P. Roenker, N. Pan, and J. Elliott, *J. Lightwave. Technol.*, 16, 1101, 1998.
[6] S. W. Tan, H. R. Chen, and W. S. Lour, *Appl. Phys. Lett.*, 97, 034502, 2005.
[7] D. C. Scott and H. R. Fetterman, *Indium Phosphide and Related Materials: Processing, Technology and Devices.* Boston, MA: Artech House, 1995, pp. 351–403.