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Dynamic Behavior of 1.3-µm npn-AlGaInAs/InP Transistor Lasers under Collector-Base Voltage Loss-modulation

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Abstract

An intensity modulation of 1.3-µm wavelength *npn*-AlGaInAs/InP transistor laser was demonstrated by collector-base voltage loss-modulation at 1 GHz. A 150-ps wide pulse operation was observed with the peak intensity enhanced by approximately 6 times the CW intensity level.

I. Introduction

Today, internet traffic is rapidly increasing, so optical communication systems with higher bandwidth are penetrating toward shorter distance communication. For short to medium distance, direct modulation lasers (DMLs) are usually used in terms of its low power consumption and cost. However, the modulation speed of laser diodes (LDs) is limited to around 40 Gb/s owing to several factors, including damping effects related to carrier transport. To overcome this modulation limit, a transistor laser (TL) based on a heterojunction bipolar transistor with an active layer in the base region can be one of the solutions. The TL has two modulation schemes. One is current modulation by controlling emitter current, higher modulation bandwidth than that in conventional LDs is expected thank to carrier pulling out from the emitter to the collector [1]. The other is voltage modulation by controlling collector-base voltage [2]. Recently, we realized the RT-CW operation of *npn*-TL emitting at 1.3-µm wavelength using an AlGaInAs/InP material system [3]. In this paper, we demonstrated collector-base voltage loss-modulation of the 1.3-µm TL for the first time.

II. Device Structure and Fabrication Process

The structure of the TL is shown in Fig. 1. We used AlGaInAs as the active layer material since AlGaInAs/InP lasers are better than GaInAsP/InP lasers in terms of thermal characteristic. A buried hetero (BH) structure was used from an aspect of effective confinements of both carriers and optical mode [4].

The fabrication process flow of the TL is as follows. Firstly, an initial wafer was grown on a (100) n-InP substrate by using an organo-metallic vapor-phase-epitaxy (OMVPE). It consists of an *n*-AlGaInAs optical confinement layer (OCL), five fully strain-compensated AlGaInAs quantum-wells (QWs; λ_g = 1.3-µm), a *p*-AlGaInAs upper OCL, and a *p*-GaInAsP etch stop layer. A

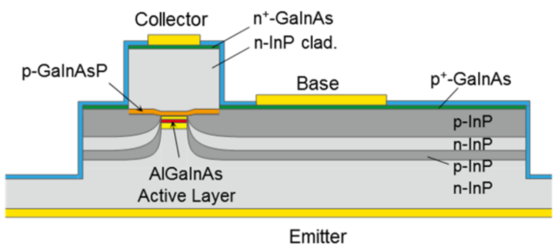

Fig.1. The structure of a fabricated npn-AlGaInAs/InP TL.

BH structure with *n*/*p*/*n*/*p*-InP current blocking layers were formed by wet etching and selective regrowth. Then, *p*-GaInAsP base layer, an *n*-GaInAsP collector layer, an *n*-InP sub-collector layer, an n^+-GaInAs collector contact layer, and a p^+-GaInAs base contact layer at the side were formed through three steps regrowth processes. By using a reactive-ion-etching and wet etching, the collector and base mesas were formed. Finally, the collector, base, and emitter (backside) electrodes were formed by evaporating Ti/Au onto the device. Laser cavities were formed by cleavage without high reflection coating.

III. Modulation Principle and CW Characteristics

Using the fabricated devices, we carried out collector-base voltage loss-modulation under common base configuration. Fig. 2 illustrates the circuit diagram to perform collector-base voltage loss-modulation. When collector-base voltage V_{CB} is applied, the optical absorption in the *p*-GaInAsP base layer increases due to Franz-Keldysh effect, and the light output power decreases. By modulating V_{CB}, we could expect high modulation bandwidth with less effect of carrier transport issue unlike current modulation.

Fig. 3 shows the emitter current-output power (I_E-P) characteristic of the TL under a common base configuration with a cavity length of 500-µm and a stripe width of 1.5-µm. A threshold current and an external differential quantum efficiency were 29 mA and 18%, respectively, when V_{CB} = 1.0 V, and were 34 mA and 16%, respectively, when V_{CB} = 3.0 V. By setting the emitter current I_E = 40 mA, the modulation of the collector-base

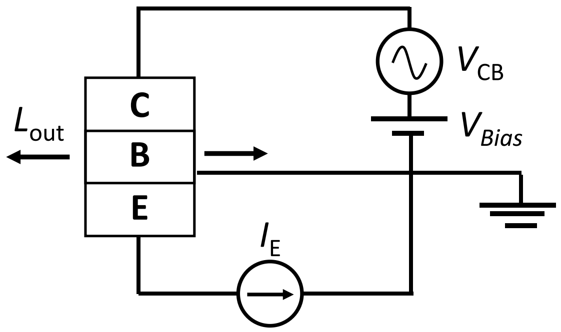

Fig. 2. The circuit diagram used for collector-base voltage loss-modulation.

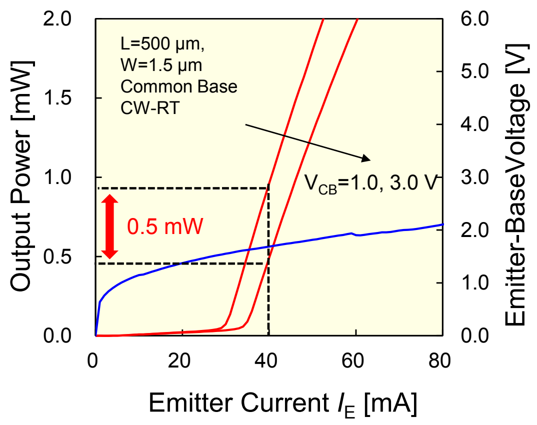

Fig. 3. Lasing characteristic of the TL.

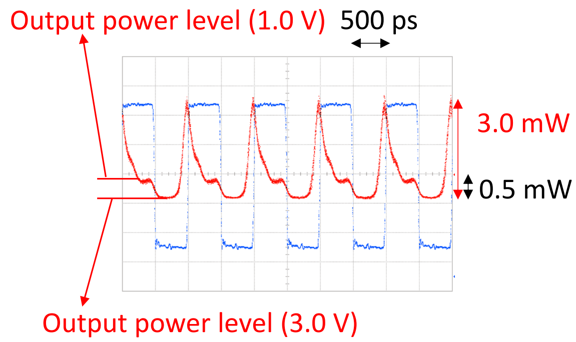

Fig. 4. Output signal at 1 GHz.

voltage V_{CB} was carried out between 1.0 and 3.0 V, where the difference between the output power levels was about 0.5 mW.

IV. Measurement

The device was mounted and wire-bonded on AlN sub-mount with co-planer pad for high speed modulation. The electrical signal generated by pulse-pattern generator was injected through 40 GHz high-speed probe. The light was detected by 8 GHz-band PIN receiver. The emitter current I_E was set at the fixed current of 40 mA and the collector-base voltage V_{CB} was modulated from 1.0 V to 3.0 V with square-shaped 1 GHz "1010" pulse (rise-up and fall-down times were 35 ps) as shown in Fig. 4. The pink and green lines show electrical and optical signals, respectively. Please note the electrical signal is inverted in Fig.4. When V_{CB} changes from 3.0 to 1.0 V, an enhanced intensity of the light pulse was observed with its half width of about 150 ps and the peak intensity of about six times higher than that of the steady state operation level at V_{CB} = 3.0 V. This behavior can be explained by loss mechanism. When the V_{CB} is reduced, the cavity loss suddenly becomes lower, that causes many photons. On the other hand, those photons are absorbed in the cavity when V_{CB} is high. From this light pulse width, an approximately 6 GHz modulation can be expected at the bias current of only 1.3-1.4 times the threshold. By adjusting voltage shape and device structure, we expect an enhancement of the modulation bandwidth [5, 6].

V. Conclusion

The collector-base voltage loss-modulation of a 1.3-µm *npn*-AlGaInAs/InP transistor laser was demonstrated. When the emitter current I_E was set at 40 mA and the collector-base voltage V_{CB} was modulated from 1.0 V to 3.0 V at 1 GHz, pulse width of 150 ps with the peak intensity of 6 times the DC bias level was observed.

Acknowledgment

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