Room-Temperature Continuous-Wave Operation of a 1.3-µm npn-AlGaInAs/InP Transistor Laser

Noriaki Sato[1], Mizuki Shirao[1], Takashi Sato[1], Masashi Yukinari[1],
Nobuhiko Nishiyama[1], Tomohiro Amemiya[2] and Shigehisa Arai[1,2]
[1] *Dept. of Electrical and Electronic Engineering, Tokyo Institute of Technology*
[2] *Quantum Nanoelectronics Research Center, Tokyo Institute of Technology*
2-12-1 O-okayama, Meguro-ku, Tokyo 152-8552, Japan
Phone: +81-3-5734-2297, Fax: +81-3-5734-2297, e-mail: n-nishi@pe.titech.ac.jp

Abstract: A room-temperature continuous-wave operation of a 1.3-µm npn-AlGaInAs/InP transistor laser was demonstrated for the first time. The threshold current and external differential efficiency were 39 mA and 13%, respectively, under common base configuration.

I. Introduction

Optical data transmission systems are widely used in backbone networks, fiber-to-the-home (FTTH) systems, rack-to-rack interconnections in supercomputers and so on. In these systems, the amounts of the data are explosively increasing and high-speed light sources are strongly demanded. For short distance communication system, direct modulation lasers are expected to be used. However, the modulation speed of conventional laser diodes (LDs) is limited around 40 Gbps due to several reasons. One of the reasons is damping effect related to carrier transport [1]. A transistor laser (TL) is based on a heterojunction bipolar transistor (HBT) with an active layer in the base region and this is a hopeful candidate for solving the problem [2]. The direct modulation bandwidth of TLs is enhanced because of the fact that the carriers can be pulled from the emitter to the collector. A room-temperature continuous-wave (RT-CW) operation and some characterizations were demonstrated for 0.98 µm TLs [3, 4]. Recently, pulsed operation of long wavelength npn-AlGaInAs TLs was demonstrated [5].

In this paper, we would like to report the first RT-CW operation of an npn TL emitting at 1.3-µm wavelength by using AlGaInAs/InP material system.

II. Device Structure

The structure of the npn TL and the SEM view of fabricated device are shown in Fig. 1 and Fig. 2 respectively. The initial wafer was grown on a (100) n-InP substrate by OMVPE technique. It consists of a 130-nm n-AlGaInAs (E_g = 1.1 eV), five fully strain compensated AlGaInAs quantum-wells (QWs; wavelength, 1.3 µm), a 100-nm p-AlGaInAs, a 10-nm p-GaInAsP (E_g = 1.0 eV) and an InP cap layer. Using a bromine-methanol solution (Br_2/CH_3OH = 1:1000) and a

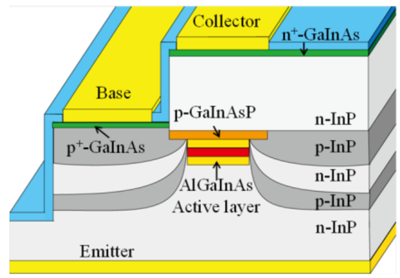

Fig. 1 The structure of fabricated npn-AlGaInAs/InP TL.

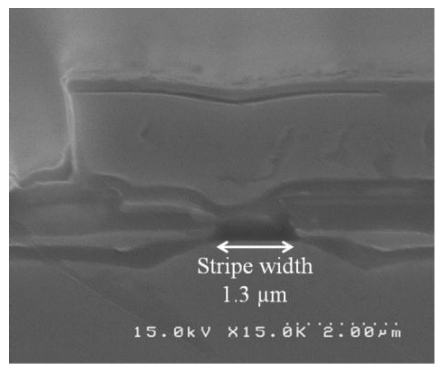

Fig. 2 SEM view of fabricated device.

CH_4/H_2 reactive-ion-etching (RIE) process with SiO_2 stripe mask, high mesa stripe (about 1.0 µm height) was formed. Then first cleaning processes were undergone using a mixture of $Br_2:CH_3OH$ = 1:40000, a mixture of $H_2SO_4:H_2O_2:H_2O$ = 1:1:40, and 1% BHF. The second cleaning process was the thermal cleaning process in the OMVPE reactor under an atmosphere of PH_3 for 45 min at 650 °C, which was optimized for high quality buried heterostructure (BH) AlGaInAs/InP LDs [6]. After that, mesa stripes were buried alternately with n-InP and p-InP. After removing the SiO_2 mask, a 200-nm p-GaInAsP base layer (E_g =1.0 eV), a 50-nm n-InP collector layer were regrown across the entire surface. Next, 6-µm SiO_2 mask was formed on the stripe and a 250-nm-high mesa stripe was formed by RIE (p-InP exposed) followed by OMVPE regrowth of a 250-nm-thick p-InP, a 30-nm-thick p^+-GaInAs base contact layer, and a 50-nm-thick n-InP layer. After removing the SiO_2 mask, a 2000-nm n-InP sub-collector layer, a 50-nm n^+-GaInAs

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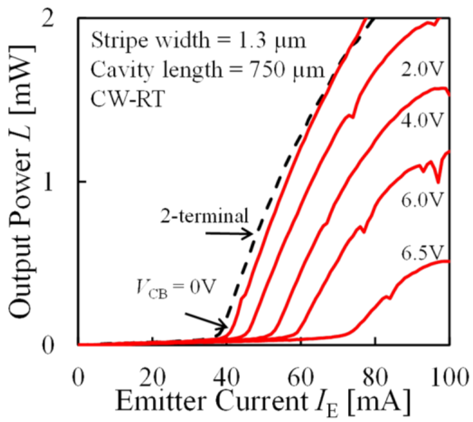

Fig. 3 Lasing characteristics of the TL under common base configuration.

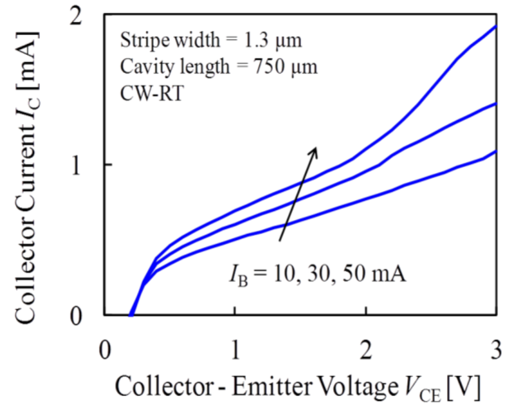

Fig. 4 .$V_{CE} – I_C$ characteristics.

collector contact layer, and an InP cap layer were regrown. Then, the collector and base mesas were formed by RIE and wet etching. Finally, the collector, base and emitter (backside) electrodes were formed by evaporating Ti/Au (25 nm/ 200 nm) on the device and laser cavities were formed by cleavage without high reflective coating.

III. Lasing Characteristics

Figure 3 shows current-output power (*I-L*) and current-voltage (*I-V*) characteristics with common base configuration under RT-CW condition. The cavity length and the stripe width were 750 μm and 1.3 μm, respectively. A threshold emitter current was 39 mA and a differential quantum efficiency from the both facets was 13%. The threshold current density was 3.5 kA/cm^2. Lasing operation was achieved for the first time with an npn-TL emitting at 1.3-μm wavelength using AlGaInAs/InP material system. Applying the collector base voltage V_{CB}, the reduction of output power due to an increase in the threshold current was observed. This is because Franz-Keldysh effect. The effective bandgap of p-GaInAsP base layer was changed by applying the voltage. As a result, the absorption at p-GaInAsP base layer was increased.

Figure 4 shows the collector current I_C dependence on the collector emitter voltage V_{CE}. The base current was 10mA, 30mA, and 50mA under CW operation. Typical transistor behavior was observed; however, very low current gain $\beta \approx 0.02$ was obtained. This value is smaller than that of previous result [7]. Thicker base layer made the effect of carrier pulling to the collector small. To realize high-speed operation, higher current gain should be expected in the future.

IV. Conclusion

In conclusion, we demonstrated, for the first time, RT-CW operation of an npn-AlGaInAs/InP TL emitting at 1.3 μm wavelength region. Under common-base configuration, controlling output power was demonstrated by applying collector-base voltage.

This research was financially supported by a Grant-in-Aid for Scientific Research (#19002009, #21226010, #22360138, 24246061) from the Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT).

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