TuB3 (Contributed Oral)
11:00 – 19:00

Improved Quantum Efficiency of GaInAsP/InP Top Air-Clad Lateral Current Injection Lasers

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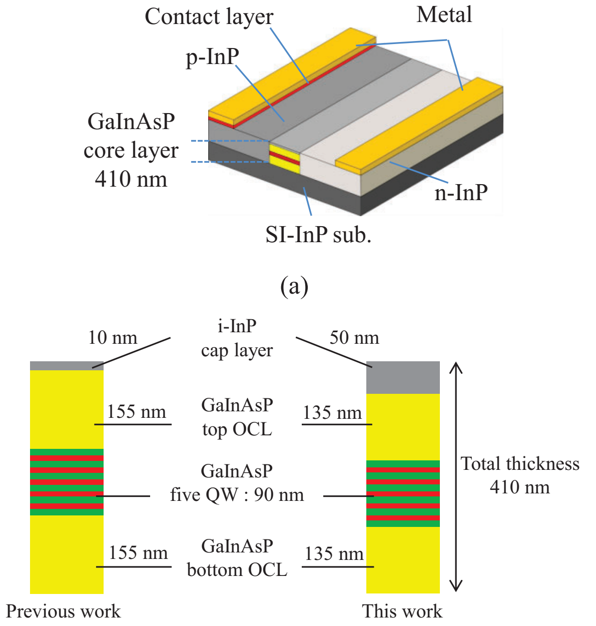
Abstract- **An internal quantum efficiency (η_i) of GaInAsP/InP top air-clad lateral current injection (LCI) lasers was considerably improved by covering the top surface with 50-nm thick InP cap layer. As the result, threshold current of 6.7 mA and the differential quantum efficiency of 56% were attained for five- quantum-wells (QWs) LCI laser with the cavity length of 500 μm and the stripe width of 1.5 μm.**

I. INTRODUCTION

With technology scaling, global wiring in LSI technologies has become a dominant bottleneck owing to signal delay, power consumption, and crosstalk [1]. Instead, introduction of optical interconnect is a very intriguing approach to address the problems confronted in electrical global wiring. However, the realization of photonic integrated circuits imposes strict limits particularly on the energy of the optical output devices [2]. As an ultralow power consumption light source, we have proposed and demonstrated a GaInAsP/InP membrane distributed feedback (DFB) laser consisting of a thin semiconductor core layer sandwiched by low-index claddings such as air, benzocyclobutene (BCB), or SiO_2. The membrane structure produces a large refractive-index difference between the core layer and the cladding layers and supports strong optical confinement to the active region, leading to ultralow power consumption. In our previous report, low threshold (irradiated power: 0.34 mW) under room temperature continuous wave (RT-CW) optical pumping was successfully demonstrated [3],[4]. Toward an injection-type membrane laser, a lateral current injection (LCI) structure [5] was introduced and demonstrated. To date, stable single-mode operation with relatively low threshold current around 10 mA under RT-CW conditions has been achieved for devices fabricated on a semi-insulating (SI) InP substrate [6]. We incorporated the LCI structure into membrane lasers and demonstrated an injection-type GaInAsP/InP membrane DFB laser for the first time by using BCB adhesive bonding [7]. However, they exhibited a relatively low internal quantum efficiency (η_i) of around 40%, which was attributed to a large amount of carrier leakage in the optical confinement layers (OCLs) and surface recombination at the air-semiconductor interface. To suppress the carrier leakage in the OCLs, uniformly distributed five-QWs structure was introduced, and successfully obtained high η_i up to 70% [8].

In this research, we proposed a different approach to improve η_i of LCI lasers, focusing on the thickness of a InP cap layer. The 10-nm-thick i-InP cap layer had been used to prevent surface recombination by the top GaInAsP OCL, whose surface recombination velocity is about one order of magnitude larger than that of InP. For further passivation, a 50-nm-thick InP cap layer was introduced to LCI-FP lasers and high η_i operation of them was successfully accomplished.



(a)

(b)

Fig. 1 (a) Schematic device structure and (b) cross-sectional structure of newly introduced core layer (previous core layer as reference).

II. DEVICE STRUCTURE AND FABRICATION PROCESS

Figure 1(a) schematically illustrates the structure of an LCI-FP laser. The cross-sectional structure of its core layer, which has a total thickness of 410 nm, is shown in Fig. 1(b):right; that of a conventional core layer having the same total thickness is also shown as a reference (Fig. 1(b):left). The core layer consists of five 1% compressively-strained $Ga_{0.22}In_{0.78}As_{0.81}P_{0.19}$ QWs (6-nm-thick well), 0.15% tensile-strained $Ga_{0.26}In_{0.74}As_{0.49}P_{0.51}$ barriers (10 nm), top and bottom OCLs (λ_g = 1.2 μm), and an undoped InP cap layer. As shown in Fig. 1(b), newly introduced core layer has 50-nm-thick InP cap layer, while conventional counterpart is

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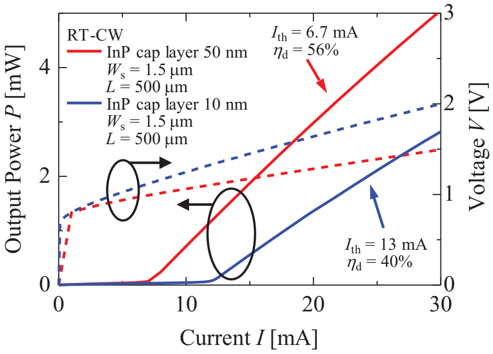

Fig. 2 Lasing characteristics.

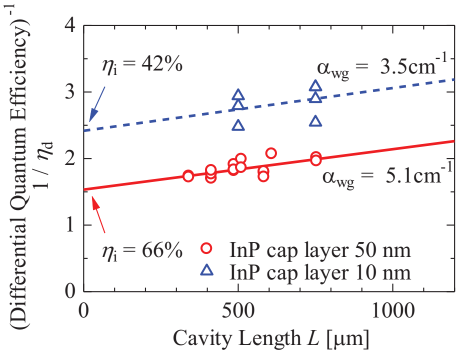

Fig. 3 Reciprocal of differential quantum efficiency dependence on cavity length.

10-nm-thick.

The device was fabricated as follows. An initial wafer with undoped core layers containing five QWs and OCLs was grown by organometallic vapor-phase epitaxy (OMVPE) on an Fe-doped SI InP substrate. The LCI structure was fabricated by CH_4/H_2 reactive-ion etching (RIE) and two-step OMVPE selective area growth. First, a mesa stripe with 7 µm wide and 400 nm high was formed by RIE etching with a SiO_2 mask, and n-InP ($N_d = 4 \times 10^{18}$ /cm^3) was selectively regrown on both sides of the mesa as a cladding layer. Next, one side of the cladding layer was etched, and p-InP ($N_a = 4 \times 10^{18}$ /cm^3) and the p-GaInAs contact layer ($N_a = 8 \times 10^{18}$ /cm^3) were regrown in the same way. Finally, Ti/Au electrodes were deposited on both the p-contact and the n-InP sections.

III. LASING CHARACTERISTICS

Figure 2 shows the light output properties (*I-L*) (solid line) and voltage–current (*V–I*) characteristics (dashed line) of an LCI laser with 50-nm-thick InP cap layer and a conventional 10-nm-thick InP cap layer counterpart having the same cavity lengths and stripe widths. RT-CW operation was achieved and a relatively low threshold current (I_{th}) of 6.7 mA, which corresponds to the threshold current density of 890 A/cm^2, and differential quantum efficiency (η_d) of 56% (both facets) were obtained for the former device, while those of the latter one were 13 mA and 40%, respectively. As for the differential series resistance, 22 Ω for the former and 37 Ω for the latter were observed. The voltage at the threshold was 1.0 V, which is quite low compared with previously reported LCI lasers.

Figure 3 shows the reciprocal of the differential quantum efficiency of LCI lasers as a function of the cavity length. The solid and the dashed lines represent LCI lasers with 50-nm-thick InP cap layer and those with 10-nm-thick InP cap layer (previously reported LCI lasers), respectively. These results revealed that the internal quantum efficiency of the devices with 50-nm-thick InP cap layer was much improved to 66% compared with 42% of devices with 10-nm-thick InP cap layer. This internal efficiency improvement can be attributed to suppression of carrier recombination at the air-semiconductor interface. Thicker InP cap layer may provide passivation effects which relax not only surface recombination velocity but also surface band bending. If this thick InP cap layer structure is applied to injection-type membrane laser, lower threshold operation can be expected.

IV. CONCLUSION

An introduction of thick (50-nm) InP cap layer was found to be very effective to improve internal quantum efficiency of GaInAsP/InP top air-clad LCI lasers. As the result, relatively low threshold current of 6.7 mA, differential quantum efficiency of 56%, and the internal quantum efficiency of 66% were obtained.

ACKNOWLEDGMENT

This research was financially supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan and the Japan Society for the Promotion of Science (JSPS) under Grants-in-Aid for Scientific Research (#19002009, #22360138, #21226010, #23760305, #10J08973) by JSPS and the council for Science and Technology Policy (CSTP) under FIRST program and also by the Ministry of Internal Affairs and communications under SCOPE program.

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