Lateral Current Injection Laser with Uniformly Distributed Quantum-Well Structure

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***Abstract*- Uniformly distributed quantum-well structure was introduced to a lateral-current-injection (LCI) laser to realize high internal quantum efficiency operation. As the result, superior light output characteristic was obtained with the internal quantum efficiencies of 70%.**

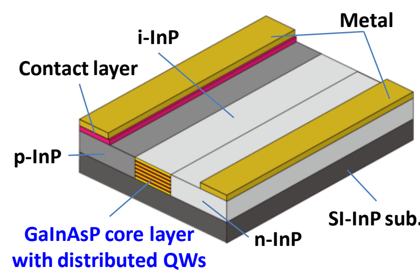
I. Introduction

The performance of the LSI will soon expected to confront the limitation due to the ohmic heating, RC delay, power consumption, and crosstalk in the global wiring. As a promising solution, a replacement of the electrical global wiring on a chip with an optical wiring is extensively studied [1]. An ultra low power consumption laser is required for such optical interconnection, and we have proposed and demonstrated distributed feedback (DFB) lasers consisting of a semiconductor membrane structure [2], where the active waveguide is sandwiched between low refractive index cladding layers such as benzocyclobutene (BCB) or SiO_2. An ultra low threshold current operation is theoretically expected due to an enhancement of the optical confinement factor in quantum-wells (QWs) by utilizing a thin (approximately 150 nm) semiconductor core layer with high index-contrast waveguide structure. Previously, we have demonstrated low threshold (0.34 mW) and stable single-mode operation under a room temperature continuous wave (RT-CW) optical pumping [3], and the device oscillated up to 85℃ under a CW condition [4].

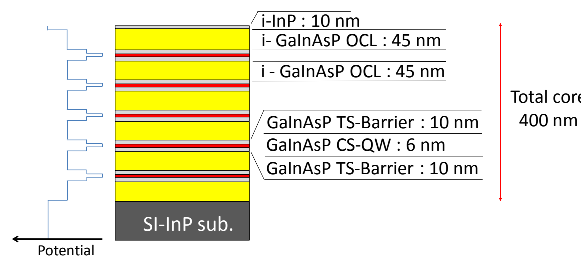
As a step to realize an injection-type membrane laser, we introduced a latera-current-injection (LCI) structure [5] and demonstrated LCI-Fabry-Perot (FP) lasers [6] and DFB lasers [7] consisting of compressively-strained (CS) 5 QWs with a 400-nm-thick GaInAsP core layer prepared on a semi-insulating (SI) InP substrate. However, relatively low internal quantum efficiency of around 40 % [8], which may be attributed to large carrier leakage from n-InP to p-InP through optical confinement layers (OCLs), was an issue to be solved. In order to improve the internal quantum efficiency of the LCI-type lasers, we introduced uniformly distributed QW structure and successfully accomplished high internal quantum efficiency operation of the LCI-FP laser.

II. Device Structure and Fabrication Process

Figure 1 shows (a) the schematic diagram of the fabricated LCI-FP laser and (b) cross sectional structure of the core layer with the uniformly distributed QWs. An initial wafer with undoped GaInAsP core layers was prepared by organometallic vapor-phase-epitaxy (OMVPE) on Fe-doped SI-InP substrate. The core layer consists of 1% CS $Ga_{0.22}In_{0.78}As_{0.81}P_{0.19}$ 5QWs, -0.15% tensile-strained (TS) $Ga_{0.26}In_{0.74}As_{0.49}P_{0.51}$ barriers and OCLs. Each QW (6-nm thick well) is uniformly distributed in the core layer and sandwiched between TS-barriers (10-nm thick) and OCLs (45-nm thick). The total thickness of GaInAsP core layers is about 400 nm. The LCI structure was fabricated by CH_4/H_2 reactive-ion-etching (RIE) and 2-step OMVPE selective area growth. First, 7-µm-wide and 400 nm-height mesa structure was formed by the RIE etching process. After removing the damage, due to the dry etching, by wet chemical etching, n-InP ($N_d = 4 \times 10^{18}/cm^3$) was selectively regrown at the side of the mesa structure as a cladding layer. Next, after etching the part of the mesa structure and the one side of the n-type cladding layer, p-InP ($N_a = 4 \times 10^{18}/cm^3$) and p-GaInAs contact layer ($N_a = 8 \times 10^{18}/cm^3$) were regrown in the same way. Then, the part of the contact layer near the stripe edge



(a)



(b)

Fig. 1 (a) Schematic device structure and (b) cross sectional structure of distributed QWs

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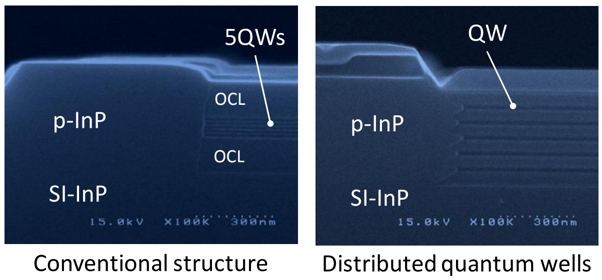

Fig. 2 Cross sectional SEM view of the conventional core layers structure and distributed quantum wells.

was removed by wet chemical etching to reduce optical absorption of the waveguide. Finally, Ti/Au electrodes were deposited on both the p-contact and the n-InP sections. Figure 2 shows cross sectional SEM views of the conventional core layers structure and the uniformly distributed QW structure.

III. Lasing Characteristics

Figure 3 shows current-light output (*I*-*L*) (solid line) and voltage-current (*V*-*I*) characteristics (dashed line) of the LCI-FP laser with the distributed QW structure under RT-CW condition. The cavity length and the stripe width were 600-μm and 1.2-μm, respectively. As can be seen in Fig. 3, relatively low threshold current (I_{th}) of 12 mA and a high differential quantum efficiency (η_d) of 63% (both facet) were obtained. The differential series resistance and the voltage at the threshold were 1.1 V and 21 Ω, respectively. These values were almost the same level as those of conventional LCI-FP laser. The lasing wavelength of this device was 1580 nm.

Figure 4 shows the reciprocal of the differential quantum efficiency of the LCI lasers as a function of the cavity length. The solid line and the dashed line in this graph represent the LCI lasers with the uniformly distributed QW structure and LCI lasers with the conventional QW structure, respectively. From this result, the internal quantum efficiency (η_i) of 70 % and the waveguide loss of 3.5 cm^{-1} of the LCI lasers with the uniformly distributed QW were obtained, while those of the conventional QW structure were 41 % and 3.2 cm^{-1}, respectively. Since this improved internal quantum efficiency was almost the same as that of our vertical-current-injection 5QWs lasers, this result indicates that carrier leakage out of QWs was suppressed by narrowing the GaInAsP OCL in the conventional LCI structure.

IV. Conclusion

In order to improve internal quantum efficiency of the LCI lasers, we introduced an uniformly distributed quantum-well structure and acieved an internal quantum efficiency of 70% which is almost the same as conventional GaInAsP/InP vertical-current-injection lasers. Therefore, this structure can be applied to realize low power consumption lasers based on membrane structure.

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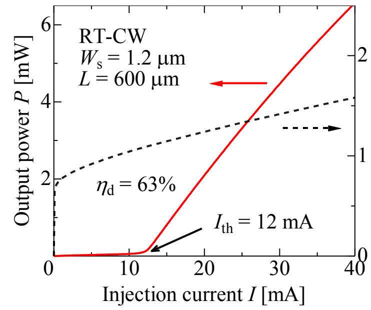

Fig. 3 Lasing characteristics.

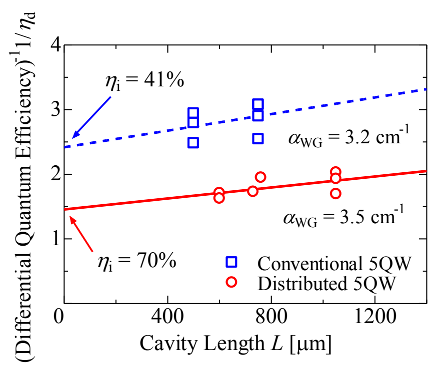

Fig. 4 Reciprocal of differential quantum efficiency dependence on cavity length.

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