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Room-temperature Continuous-wave Operation of Lateral Current Injection Membrane Laser

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***Abstract*—Toward realization of an ultralow-power-consumption semiconductor light source for optical interconnection, we have been investigating the lateral current injection (LCI) membrane distributed feedback (DFB) laser. This time, we realized membrane Fabry-Perot (FP) laser with 220 nm core thickness and demonstrated room-temperature continuous-wave (CW) operation with a threshold current of 3.5 mA for the cavity length of 700 µm and the stripe width of 1.0 µm, which is almost the same as the theoretical value.**

***Keywords*— membrane laser; lateral current injection; strong optical confinement; optical interconnects**

I. INTRODUCTION

It is predicted that the progress of the processing speed and integration of large scale integrated circuits (LSIs) will soon confront limitation associated with RC delay and large power dissipation in the electrical interconnection in the global wiring. As one of the promising approaches for solving this problem, an introduction of optical interconnection instead of the electrical interconnection has been extensively studied [1]. An ultralow-power-consumption semiconductor laser is strongly required for such optical interconnections, and we demonstrated a GaInAsP/InP membrane distributed feedback (DFB) laser consisting of a thin semiconductor core layer sandwiched by low refractive-index claddings such as air, benzocyclobutene (BCB), and SiO_2. Since the membrane structure produces a large refractive-index difference between the core layer and the cladding layers and supports strong optical confinement into the active region, it leads to ultralow power consumption operation [2]. Previously, an optically pumped membrane laser with low threshold pump power 0.34 mW under room temperature continuous wave (RT-CW) was demonstrated [3]. Toward an injection-type membrane laser, a lateral current injection (LCI) structure [4] was introduced and an injection-type GaInAsP/InP membrane DFB laser was demonstrated [5]. Recently, RT-pulsed operation with a threshold current of 3.8 mA was realized for LCI membrane DFB lasers with the core thickness of 450 nm where the active region consists of 5 quantum-wells (5QWs) and the optical confinement factor in each quantum-well was ξ = 2.1%/well [6].

This time, we would like to report a RT-CW operation of a LCI GaInAsP membrane laser with the core thickness of 220 nm by introducing highly Be-doped p-GaInAs contact layer for the first time. A threshold current of 3.5 mA and a differential quantum efficiency of 11% from the front facet were obtained.

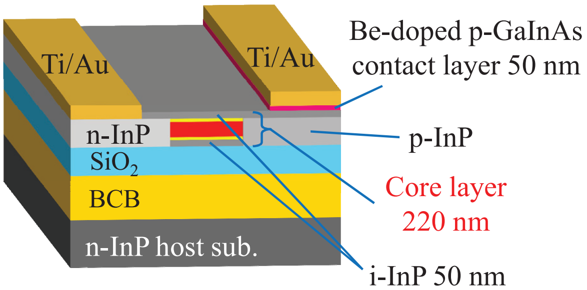

Fig. 1 Schematic structure of the membrane laser with Be-doped contact layer.

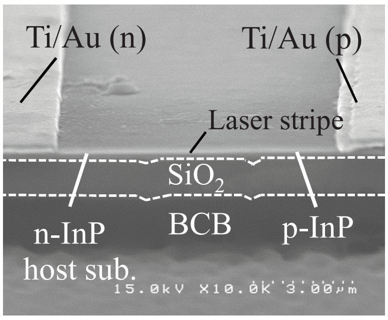

Fig. 2 Cross sectional SEM view of the fabricated device.

II. DESIGN AND FABRICATION

Figure 1 shows the schematic structure of LCI membrane laser with a Be-doped contact layer. Top and bottom cladding layers were composed of air (n = 1) and SiO_2 (n = 1.45), respectively. The device was fabricated as follows. Firstly, an initial wafer with a Be-doped p-GaInAs ($N_A = 8 \times 10^{18}$ /cm^3) contact layer was prepared on an n-InP substrate by gas-source molecular-beam-epitaxy (GSMBE) method; the core layer consists of five 1% compressively-strained (CS) $Ga_{0.22}In_{0.78}As_{0.81}P_{0.19}$ 5QWs (6 nm thick each) with -0.15% tensile-strained (TS) $Ga_{0.26}In_{0.74}As_{0.49}P_{0.51}$ barriers (10 nm thick each), and an undoped-GaInAsP optical confinement layers (OCLs, λ_g = 1.2 µm, 15 nm thick each). The total thickness of the core layer including 50-nm-thick undoped-InP cap layers is 220 nm. The introduction of the Be-doped contact underneath the QWs had an advantage of low dopant diffusion. The optical confinement factor ξ is 3.2%/well which is 1.5 times larger than that of the previously reported device with 450 nm core thickness [5],[6]. Secondly, the LCI structure was fabricated by two-step organo-metallic-vapour-

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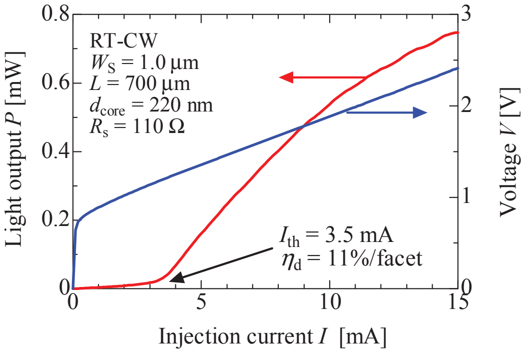

Fig. 3 Light output and V-I characteristics.

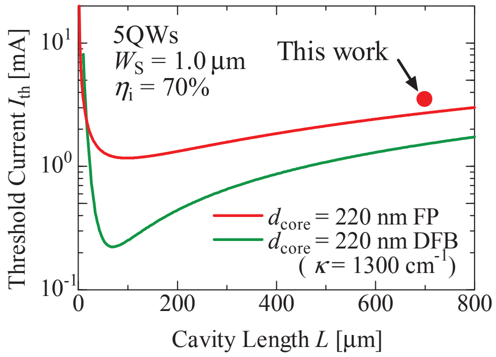

Fig. 4 Calculated threshold current as a function of cavity length.

phase-epitaxy (OMVPE) selective area regrowth. A 7-µm wide mesa was formed by CH_4/H_2 reactive ion etching (RIE) and an n-InP ($N_D = 4 \times 10^{18}$ /cm^3) was selectively regrown at both sides of the mesa as a cladding layer with a SiO_2 mask. After etching the part of the mesa and the one side of the n-type cladding layer, a p-InP ($N_A = 4 \times 10^{18}$ /cm^3) was regrown in the same way. Then, 1-µm-thick SiO_2 bottom cladding layer was deposited on the wafer. Meanwhile, 2-µm-thick BCB was spin-coated onto the InP host substrate and it was thermally pre-cured for its polymerization in N_2 environment at 210°C. We used the InP substrate just because of easiness of cleavage, but it can be any substrate such as Si or SOI. The wafer and host substrate were bonded with a bonding pressure of about 25 kPa at 130°C, and completely solidified by hard-curing at 250°C under N_2 atmosphere. Subsequently, the InP host substrate and etch-stop layers were removed by polishing and wet etching. A part of the top Be-doped p-GaInAs contact layer near the stripe edge was removed by wet chemical etching. Finally, Ti/Au electrodes were evaporated on the n-InP and p-InP regions. Figure 2 shows a cross-sectional SEM view of the fabricated device around the core layer.

III. EXPERIMENTAL RESULTS

The light output and voltage–current (V–I) characteristics of the LCI-membrane laser with the core thickness of 220 nm were shown in Fig. 3. The cavity length and the stripe width were 700 µm and 1.0 µm, respectively. As can be seen, the threshold current of 3.5 mA (a threshold current density of 100 A/cm^2/well) and the differential quantum efficiency of 11%/facet were obtained under a RT-CW condition. The rise-up voltage, differential series resistance, and the voltage at the threshold were 0.8 V, around 110 Ω, and 1.2 V, respectively. Further reduction of the series resistance will be required for ultralow threshold operation of a LCI membrane DFB laser with very short cavity structure.

Figure 4 shows the calculated threshold current as a function of the cavity length for a LCI membrane FP laser and a LCI membrane DFB laser with surface grating, where the depth of surface grating on the top of the laser stripe was assumed to be 30 nm and the index-coupling coefficient κ was estimated to be 1300 cm^{-1}. As can be seen, the threshold current of the fabricated device is almost the same as the calculated value (I_{th} = 2.7 mA @ L = 700 µm, W_S = 1.0 µm) by assuming an internal quantum efficiency of η_i = 70% and the reflectivity of R = 20% for both facets (It is much smaller than that in conventional lasers in the thin core membrane structure). As the next step, we try to realize a LCI membrane DFB laser with very short cavity for ultralow threshold operation.

IV. CONCLUSION

The LCI membrane laser with 220 nm core thickness was realized and a RT-CW operation with threshold current of 3.5 mA and external quantum efficiency of 11%/facet was achieved for the cavity length of 700 µm and the stripe width of 1.0 µm. These results indicate ultralow threshold operation of the LCI membrane DFB laser with very short cavity.

ACKNOWLEDGMENT

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