GaInAsP/InP Lateral-Current-Injection Membrane DFB Laser Integrated with GaInAsP Waveguides on Si Substrate

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***Abstract*— A lateral-current-injection membrane DFB laser integrated with GaInAsP waveguides and a detector was fabricated by butt-joint regrowth technique. As a result, a threshold current of 700 µA under room-temperature CW condition was obtained.**

I. Introduction

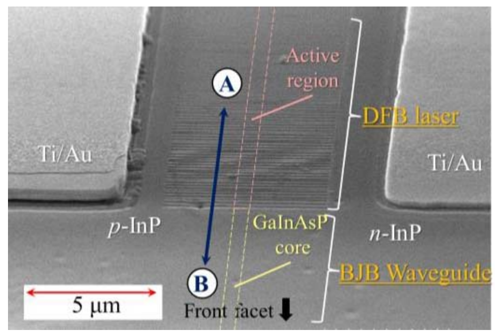
The performance of large scale integrated circuits (LSIs) have been improved by the scaling law. However, recently, global electrical wiring in LSIs is limiting the performance of the LSIs due to its RC delay and power dissipation. Therefore, the introduction of on-chip optical interconnection to the global wiring is expected as one of promising solutions to overcome such performance limit [1]. For the on-chip optical interconnection, the light source requires to achieve ultra-low power consumption operation. For this purpose, we have proposed and demonstrated a GaInAsP/InP membrane distributed feedback (DFB) laser [2] which consists of a thin semiconductor core layer sandwiched by low refractive-index cladding such as air, benzocyclobutene (BCB), and SiO_2. Because of high index contrast between the core and cladding layers, the semiconductor membrane structure produces strong optical confinement into the active layer and an ultra-low threshold lasing operation can be possible.

We reported low threshold lateral-current-injection (LCI) membrane DFB lasers [3], GaInAsP wire waveguides [4], and 10 Gbps lateral junction membrane photodetectors [5]. As an integration technique of these membrane photonic devices, butt-joint built-in (BJB) structure [6] can be expected to provide high efficiency coupling. We have demonstrated smooth surface after butt-joint regrowth technique for thin GaInAsP/InP waveguide layer / active layer integration by organo-metallic vapor phase epitaxy (OMVPE) [7].

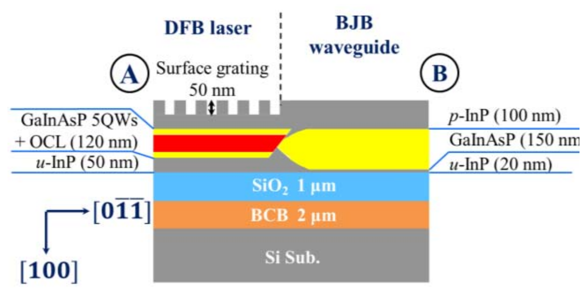
In this paper, we present LCI membrane DFB lasers integrated with GaInAsP waveguides on a Si substrate prepared by OMVPE. As a result, we obtained lasing operation with sub-mA threshold current under RT-CW condition.

II. Device Structure and Fabrication Process

Figures 1 (a) and (b) show the scanning electron microscope (SEM) image of the fabricated device and the schematic cross sectional diagram observed from the $[01\bar{1}]$ direction, respectively. The initial wafer consisted of etch stop layers (300-nm-thick GaInAs and 100-nm-thick InP), p^+-GaInAs contact layer (Be-doped,



(a) SEM image of top view.



(b) Schematic cross sectional diagram observed from the $[01\bar{1}]$ direction.

Fig. 1 Structure of the fabricated device.

$N_A = 8 \times 10^{18}$ cm^{-3}, 50 nm), p-InP layer (Be-doped, $N_A = 1 \times 10^{18}$ cm^{-3}, 100 nm), five 1% compressively-strained $Ga_{0.22}In_{0.78}As_{0.81}P_{0.19}$ quantum wells (undoped, 6 nm) with 0.15% tensile-strained $Ga_{0.26}In_{0.74}As_{0.49}P_{.51}$ barriers (undoped, 10 nm), which corresponds the bandgap wavelength of 1.52 µm, sandwiched by $Ga_{0.21}In_{0.79}As_{0.46}P_{0.56}$ optical confinement layers (OCLs, undoped, 15 nm), InP layer (undoped, 50 nm), i.e., the total thickness of the membrane core layer was 270 nm, were grown on an n-InP (100) substrate by gas source MBE. The fabrication process of BJB-LCI membrane DFB lasers on a Si substrate was as follows. First, 10-µm-wide and 20 to 300-µm-long island patterns along with [011] direction covered with 50-nm-thick SiO_2 masks was formed by CH_4/H_2 reactive-ion etching (RIE) and selective wet etching (H_2SO_4:H_2O_2: H_2O = 1:1:40 at 20°C for 8 min.). Then an InP buffer layer (10-nm-thick), $Ga_{0.21}In_{0.79}As_{0.46}P_{0.54}$ core layer (155-nm-thick, λ_g = 1.22 µm), an InP cap layer (20 nm-thick) were grown by OMVPE selective-area growth. Subsequently, a lateral

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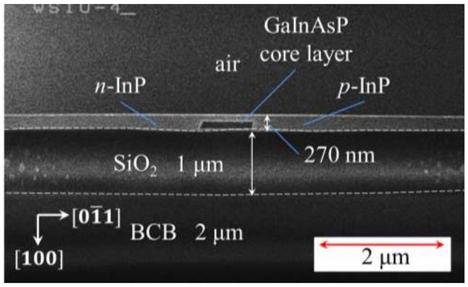

Fig. 2 A SEM image of cross sectional of GaInAsP waveguide facet observed from $[0\bar{1}\bar{1}]$ direction.

pn junction was formed to prepare the LCI structure by two-step OMVPE selective-area growth [3]. Next, a 1-µm-thick SiO2 film was deposited on the wafer and was bonded upside down onto the Si host substrate, on which 2-µm-thick BCB was spin coated and precured at a temperature of 210 °C in N_2 atmosphere. These wafers were pressed under a pressure of approximately 25 kPa at 130 °C. The bonded wafer was, then, hard-cured at 250 °C for 1 hour in N_2 atmosphere. After the wafer-bonding process, the InP substrate and the etch stop layers were removed by polishing and wet chemical etching. The exposed Be-doped contact layer was also removed by selective etchant for GaInAs, except the region for the *p*-electrode. After removing the *p*-InP cap layer on the *n*-electrode region, Ti/Au electrodes were deposited. Finally, 50-nm deep surface grating, which corresponds to index-coupling coefficient κ of 1300 cm^{-1}, was formed by electron beam lithography. Figure 2 shows a cross sectional SEM image of GaInAsP waveguide region. The embedded waveguide structure and flat regrowth surface are clearly observed.

III. Lasing Characteristics

The light output power was measured from the cleaved facet of integrated waveguide, which was 260 µm away from the laser section. Figure 3 shows light-current (*L*-*I*) and voltage-current (*V*-*I*) curves of a device with the cavity length *L* of 150 µm and the stripe width W_s of 0.8 µm. Under the RT-CW condition, a threshold current I_{th} of 700 µA and an external differential quantum efficiency η_d of 2% (front facet) were obtained. The low threshold current lasing is result of strong index-coupling structure, but the small η_d of 2% is due to the too long cavity of 150 µm for large index-coupling coefficient κ (1300 cm^{-1} by calculation and 970 cm^{-1} by measurement). The photocurrent was also detected by an integrated detector section which is 500 µm away from the laser section connected by the waveguide. Figure 4 shows a lasing spectrum of the fabricated device at a bias current of 1.4 mA ($2I_{th}$). Two double-peaks near the wavelength of 1538 nm and 1560 nm were observed. These spectral peaks may be attributed to lasing of higher order transverse mode. The stopband width is estimated to be approximately 20 nm which corresponds to an index-coupling coefficient κ of 970 cm^{-1}.

IV. Conclusion

For the on-chip optical interconnection, we demonstrated BJB-LCI membrane DFB laser integrated with a detector and waveguides on a Si substrate. A threshold current of 700 µA and an external differential quantum efficiency of 2% through the waveguides were realized for the device with a stripe width of 0.8 µm and a cavity length of 150 µm. This work shows the possibility of low power consumption operation of membrane photonic integrated circuit.

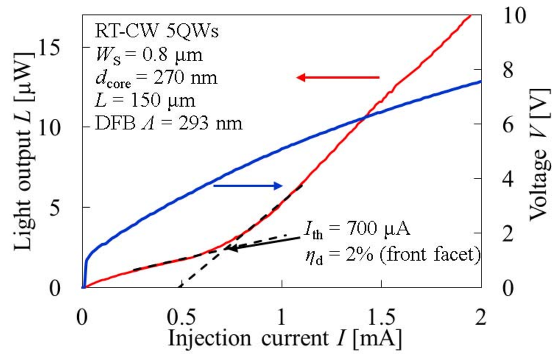

Fig.3 Light output and voltage-current characteristics of the BJB-LCI membrane DFB laser.

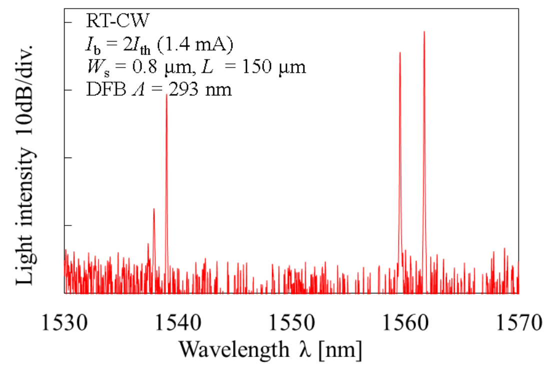

Fig.4 A lasing spectrum of the BJB-LCI membrane DFB laser.

Acknowledgment

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