WA1.1 (Invited)
09:00 – 09:30

Semiconductor Membrane Photonic Devices for Ultra-low Power Consumption Operation

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Abstract

Our research activities of GaInAsP/InP lateral current injection semiconductor membrane lasers and related devices intended for on-chip optical interconnects are reviewed and remaining issues to be solved for ultra-low power consumption operation are discussed.

I. INTRODUCTION

After the challenging proposal of optical interconnects to electronic chips by Miller [1] and the estimation of the available power consumption for the signal source to be 100 fJ/b or less [2], various light sources or optical modulators for ultra-low power consumption operation with high-speed capability, such as vertical cavity surface-emitting lasers (VCSELs) [3] and photonic-crystal (PC) lasers [4],[5], have been reported.

We have proposed and demonstrated a semiconductor membrane DFB laser in 2001, consisting of a thin (150-200 nm) semiconductor core layer sandwiched between low-refractive-index cladding layers so as to enhance the modal gain by a factor of around 3 compared with conventional semiconductor lasers [6] and demonstrated very low threshold operation under an optical pumping [7]-[9]. Then current injection type lasers were realized [10]-[12] by adopting the lateral current injection (LCI) structure [13] and BCB adhesive bonding [14].

In this paper, we would like to present recently obtained experimental results on the LCI membrane lasers. An issue of the series resistance of them will be also discussed for ultra-low power operation under a high-speed modulation.

II. LCI MEMBRANE LASERS –EXPERIMENTAL-

Figure 1 shows a schematic diagram of a photonic-integrated circuit (PIC) base on the LCI membrane DFB laser, a passive waveguide, and a p-n photodiode, which can be bonded with BCB on a chip by a back end process. The LCI membrane DFB laser with a surface grating structure [10] (Fig. 2) consisting of GaInAs/InP strain-compensated 5 quantum-wells (5QW; 6-nm-thick wells and 9-nm-thick barriers) was fabricated by 3-step OMVPE growth. A threshold current I_{th} of 11 mA (threshold current density J_{th}=3.7 kA/cm^2) and the differential quantum efficiency η_d of 2.5%/front facet was obtained for the core thickness d_{core} of 450 nm, stripe width W_s= 1 µm, and the cavity length L=300 µm. These poor characteristics were considered to be due to a low internal quantum efficiency due to non-radiative recombination centers and poor p-side contact.

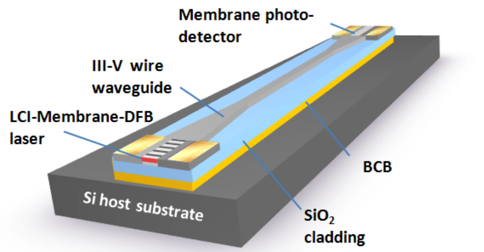

Fig. 1 Schematic diagram of a membrane-based photonic integrated circuit.

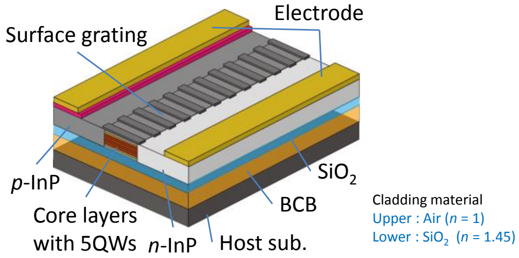

Fig. 2 Schematic diagram of LCI-membrane-DFB laser with a surface grating structure.

Figure 3 indicates improved lasing property of membrane Fabry-Perot laser by introducing Be-doped GaInAs contact layer [11]. I_{th} =3.5 mA (J_{th}=500 A/cm^2) and η_d =11%/ facet were obtained for d_{core} =220 nm, W_s= 1 µm, and L=700 µm. The internal quantum efficiency was estimated to be close to 70%, which is comparable to that of our 1-step grown conventional lasers [12].

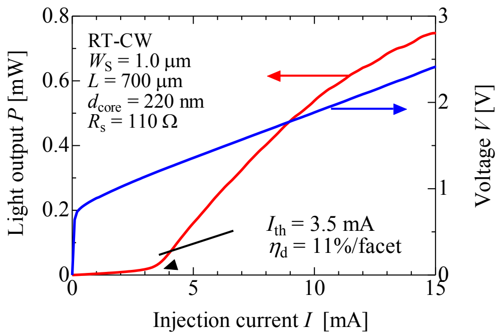

Fig. 3 Light output and V-I characteristics.

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III. JOULE HEATING AND POWER CONSUMPTION AT HIGH-SPEED MODULATION

Since the relaxation oscillation frequency f_r can be increased by the reduction of the volume of the active region and increasing the bias current I_b, shorter cavity length seems to be advantageous for high-speed modulation. However, the series resistance of short cavity LCI membrane DFB lasers will increase Joule heating hence the total energy cost. By assuming the resistivity of the p-cladding region to be $\rho_{p\text{-InP}} = 0.108\ \Omega{\bullet}\text{cm}$ at the doping level of $N_A = 4\times10^{18}\ \text{cm}^{-3}$ (4 times higher than that of the present device in Fig. 3) and the distance between the active region and the metal contact to be 1 µm, total power consumption was calculated.

Figure 4 shows the cavity length dependences of Joule heating energy and total power consumption at I_b satisfying P_0= 0.16 mW (which corresponds to the energy cost of 100 fJ/b by assuming the minimum receivable power of PIN-PD to be 50 µW (-13 dBm) at 10 Gb/s and a loss margin of 5dB) and 10 Gb/s modulation. As can be seen, the fraction of the Joule heating energy to the total power consumption increases with decreasing the cavity length due to the increase of the series resistance.

IV. CONCLUSIONS

Lateral current injection (LCI) membrane laser with improved internal quantum efficiency of around 70% was obtained by 3-step OMVPE growth. For ultra-low power consumption operation with high-speed modulation of the LCI-DFB laser, not only the short cavity with high coupling coefficient but also the reduction of the series resistance will be crucial factor in light sources for on-chip optical interconnects.

ACKNOWLEDGMENT

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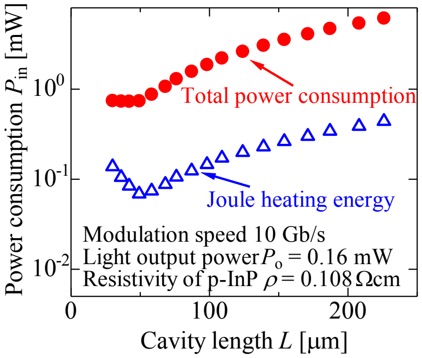

Fig. 4 Cavity length dependences of Joule heating energy and total power consumption at the bias current which satisfies P_0= 0.16 mW and the modulation speed of 10 Gb/s.

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