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Lateral Current Injection Type Membrane DFB lasers

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Abstract

Lateral current injection (LCI) type membrane distributed feedback (DFB) lasers, proposed as light sources for on-chip optical wiring in LSIs, were theoretically investigated from aspects of low power consumption operation and high-speed direct modulation capability. It was confirmed that the LCI-membrane-DFB laser can be a good candidate for a low-pulse-energy (100 fJ/b) light source at high-speed operation (10 Gb/s), but the series resistance was found to be an important issue for low power consumption operation as well as a small footprint.

I. Introduction

Since the operating speed of LSIs will be limited by RC delay time and ohmic heating in the electrical wiring, an introduction of an on-chip optical wiring has become one of the promising solutions to overcome this problem [1], and the available power consumption for the signal source such as a semiconductor laser was estimated to be 100 fJ/b or less [2]. It simply means that the driving current of the light source is limited to less than 1 mA (with assumption of 10 Gb/s direct modulation and driving current of 1 V). Micro-cavity lasers such as vertical cavity surface-emitting lasers (VCSELs) [3] and photonic-crystal (PC) lasers [4],[5] have been reported to be promising devices for such low-power-consumption and high-speed operation.

We have proposed a semiconductor membrane laser, consisting of a thin (several hundred nm) semiconductor core layer sandwiched between low-refractive-index cladding layers, such as SiO_2 or BCB, so as to strongly confine optical mode field into the gain medium [6] and demonstrated very low threshold operation under optical pumping [7]. Then we realized injection type membrane lasers [8] by adopting the lateral current injection (LCI) structure [9] and a surface grating structure [10].

In this paper, we would like to present theoretical investigation of fundamental operation properties of the LCI membrane DFB lasers, i.e. threshold and low power consumption at high-speed (10 Gb/s) modulation.

II. Low threshold operation

Figure 1 shows the schematic structure of a LCI membrane DFB laser with a surface grating structure, where the active region consists of GaInAs/InP strain-compensated 5 quantum-wells (5QW; 6-nm-thick wells and 9-nm-thick barriers) and the stripe width was assumed to be 1 μm, used for the calculation of a threshold current and a differential quantum efficiency. 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, the output power P_0 of 0.16 mW (-8 dBm) is required for the light source. Figure 2 shows the cavity length L dependences of threshold current I_{th} and the operation current I_{op} for this requirement, where each point was calculated by varying the index-coupling coefficient κ_i of the surface grating and the optimum cavity length for the minimum I_{th} was selected. As can be seen, both I_{th} and I_{op} decrease with decreasing L (increasing κ_i).

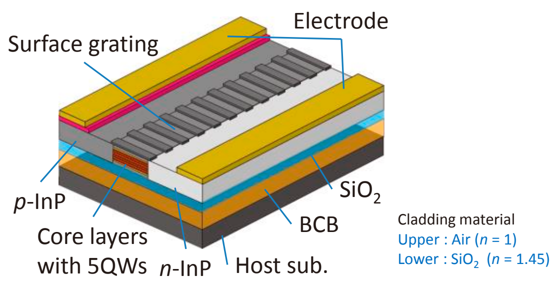

Fig. 1 Schematic diagram of LCI-membrane-DFB laser with a surface grating structure.

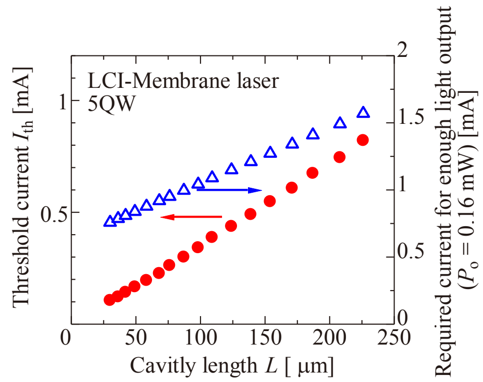

Fig. 2 Cavity length dependences of threshold current and operation current for required output power of 0.16 mW.

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

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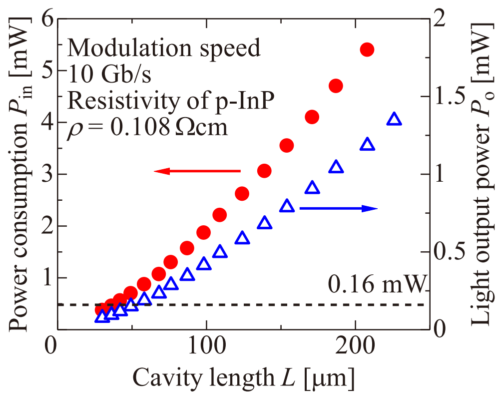

Fig. 3 Cavity length dependences of power consumption and the peak output power at a bias required for 10 Gb/s modulation.

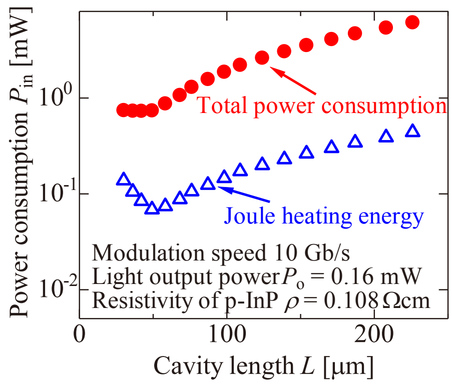

Fig. 4 Cavity length dependences of Joule heating energy and total power consumption at the bias current which satisfies P_0= 0.16 mW and the modulation speed of 10 Gb/s.

LCI membrane DFB lasers as well as PC lasers consisting of a thin (150-200 nm) semiconductor core will increase Joule heating hence the total energy cost for transmission signal, it was taken into account by assuming the resistivity of the p-cladding region ($\rho_{p\text{-InP}}$ = 0.108 Ω•cm at the doping level of N_A=4×10^{18} cm^{-3}) and the distance between the active region and the metal contact of 1 μm. Other resistances were assumed to be negligible and the device had ideal diode characteristics.

Figure 3 shows the cavity length dependences of the peak power P_0 at the bias current I_b required for 10 Gb/s modulation and the power consumption P_{in}. As can be seen, P_0= 0.16 mW, which corresponds to the energy cost of 100 fJ/b, can be attained at L= 50μm (the series resistance is around 100 Ω), whereas the Joule heating increases with decreasing the cavity length and P_0 becomes less than 0.16 mW at I_b required for 10 Gb/s modulation. Figure 4 shows the cavity length dependences of Joule heating energy and total power consumption at I_b satisfying P_0= 0.16 mW and 10 Gb/s modulation. As can be seen, the Joule heating energy and the total power consumption increase with decreasing the cavity length due to the increase of the series resistance.

IV. Conclusions

Low power consumption capability under high-speed direct modulation of lateral-current-injection membrane DFB laser was theoretically investigated by taking into account the Joule heating energy in the series resistance. Even though 10 Gb/s modulation with the energy cost of 100 fJ/b can be attainable with the cavity length of 50 μm, the series resistance will be crucial factor in light sources for on-chip optical interconnects.

Acknowledgment

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