Electrode Position Dependence of Energy Cost in Lateral-Current-Injection Membrane Distributed Reflector Laser

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***Abstract*—The energy cost of a lateral current injection (LCI) type membrane distributed reflector (DR) laser for electrode position was theoretically investigated. As a result, the optimal structure to minimize the energy cost was revealed.**

I. Introduction

On-chip optical interconnect is one of the prospective solution for high-speed and low power consumption operation of LSI circuits [1]. In order to introduce the on-chip optical interconnect, realization of optical devices with ultra-low power consumption are crucial. For the light sources, the operation energy cost of ~100fJ/bit [2] or less will be required. For such purpose, light sources with high-speed modulation and low power consumption such as VCSELs [3] and photonic crystal lasers [4] have been reported in recent years. However, there are some problems such as difficulty of in-plane integration and insufficient output power to transmit signal.

To overcome these problems, we have proposed a semiconductor membrane laser [5] and demonstrated room-temperature continuous-wave (RT-CW) operation under current injection with less than 1-mA threshold current [6]. The membrane structure consists of a thin semiconductor core layer sandwiched by much lower refractive-index materials such as SiO_2, BCB, and air. This high index-contrast structure enables to realize strong optical confinement into the active region, and results in low threshold current operation. We also adopt a lateral current injection (LCI) structure due to the top and bottom insulating claddings [7]. However, such LCI structure may cause high resistance due to thin thickness and long current pass compared with conventional vertical injection type lasers, and this high resistance may affect energy cost for data transport. In this paper, we show the design concept to minimize the energy cost of the membrane laser in terms of electrode position.

II. Structure of Membrane DR Laser

The structure of a LCI type membrane-DR (LCIM-DR) laser is shown in Fig. 1. The DR structure consists of an active DFB section and a passive distributed-Bragg-reflector (DBR) section [8]. In the calculation, we assumed the DBR with the reflectivity of 99% at the one side of the laser cavity, and introduced $\lambda/4$ phase-shift in the DFB section to reduce the threshold current. At the front side, the reflectivity of 0% was assumed.

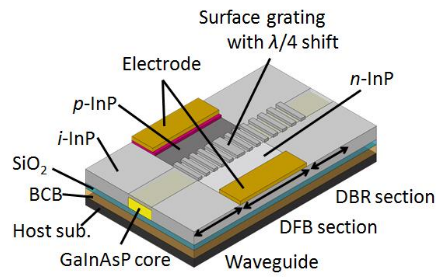

Fig. 1 Schematic view of a LCI membrane DR laser

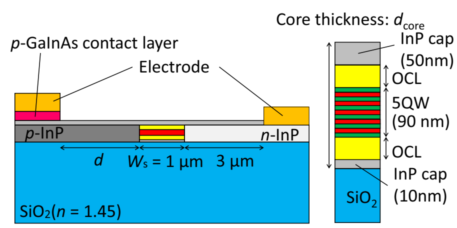

Fig. 2 Cross sectional view of the membrane DR laser and structure of the core layer.

Figure 2 shows the cross sectional view of the LCIM-DR laser and the structure of core layer. The total core layer thickness of 250 nm, which should minimize the operation energy at 10 Gb/s operation [9], and a surface grating depth of 50 nm, which corresponds the index coupling coefficient of κ_i = 1800 cm^{-1}, was used for calculation. For estimation of power consumption, we assumed *p*-InP cladding is dominant in whole resistance as the device resistance. Here, the ideal contact resistance of ~10^{-6} $\Omega \cdot cm^2$ was assumed. The *p*-InP cladding resistance is critical issue for shorter cavity structures including membrane lasers. Some of the solutions for reduction of the resistance are to reduce the resistivity of *p*-InP cladding by high doping and to reduce *p*-electrode distance. However, *p*-InP has absorption coefficient of 20 cm^{-1} for 1×10^{18} cm^{-3}[10], and there is a trade-off relation between resistivity and absorption loss. The electrodes and the p^+-GaInAs contact layer also have absorption coefficient of approximately 800000 cm^{-1} and 5000 cm^{-1}, respectively. Therefore, too close distance between the active region and the electrodes causes high absorption of the waveguide. Figure 3 shows the cross sectional field profile of the membrane laser. In the case of the *p*-electrode distance of d = 0.2 µm, the

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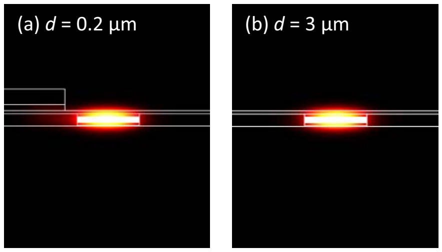

Fig. 3 Cross sectional mode profile of membrane laser.

mode profile changes and overlaps to lager area of the electrode, resulting the total absorption loss increases.

III. Electrode Position Dependence

In order to estimate actual effects of absorption loss and device resistance, the threshold current and device resistance of LCIM-DR laser was investigated as shown in Fig. 4. The reason for increase of threshold current at $d < 1$ µm is large absorption coefficient of the electrode. However, it is found that the effect of the absorption at *p*-InP cladding is small.

Figure 5 shows energy cost under the conditions of light output power of 0.16 mW at 10 Gb/s operation, as a function of *p*-electrode distance. The light output power of 0.16 mW was defined by using the assumptions of minimum receivable power of -13 dBm (0.05 mW) for typical PIN photodiodes with a low cost trans-impedance amplifier at 10 Gb/s operation and the link loss of 5 dB. From this result, we confirmed that the optimal electrode position to minimize the energy cost exists, and the minimum energy cost of 45 fJ/bit was obtained at *p*-electrode distance $d = 0.8$ µm, cavity length $L = 15$ µm and resistivity of $\rho_{p\text{-InP}} = 0.035$ Ω·cm (the doping concentration of $N_A = 4 \times 10^{18}/\text{cm}^3$) [11]. This also shows that if the *p*-electrode distance set to optimal length, it is not need to increase the doping concentration.

IV. Conclusion

The energy cost of LCIM-DR laser was investigated in terms of electrode position. As a result, it was shown that electrode position to reduce both of resistance and absorption loss exists and large increase of doping concentration is not need.

Acknowledgment

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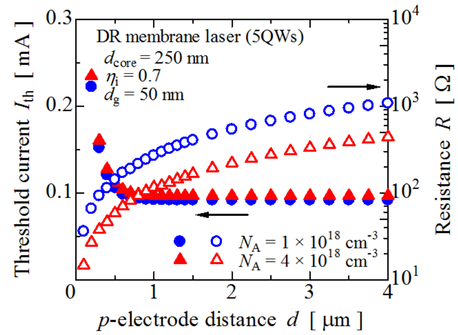

Fig. 4 Threshold current and resistance of LCIM-DR laser dependence on *p*-electrode distance.

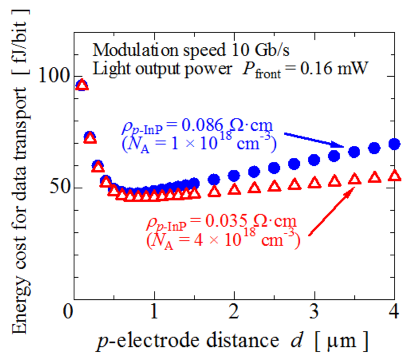

Fig. 5 *p*-electrode distance dependence of energy cost.

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