Modulation Bandwidth of GaInAsP/InP Lateral-Current-Injection Membrane Laser

Takahiko Shindo[1], Mitsuaki Futami[1], Kyohei Doi[1], Tomohiro Amemiya[2], Nobuhiko Nishiyama[1], and Shigehisa Arai[1,2]
[1] *Dept. of Electrical and Electronic Engineering, Tokyo Institute of Technology*
[2] *Quantum Nanoelectronics Research Center, Tokyo Institute of Technology*
2-12-1 O-okayama, Meguro-ku, Tokyo 152-8552, Japan
Phone: +81-3-5734-2512, Fax: +81-3-5734-2907, e-mail: shindou.t.aa@m.titech.ac.jp, arai@pe.titech.ac.jp

***Abstract*—** **A direct modulation bandwidth of GaInAsP/InP lateral-current-injection membrane DFB laser was theoretically investigated. It was found that 10 Gb/s modulation can be obtained at low driving current of 1 mA by adopting narrow stripe width.**

I. INTRODUCTION

As one of promising solutions for the problems of the LSI global wiring such as a RC delay time or large power consumption, an introduction of optical wiring instead of electrical global wiring is extensively studied. The power consumption of the light source for the on-chip optical interconnection is estimated to be less than 100 fJ/bit [1]. This value simply means that a driving current of semiconductor laser is limited to less than 1 mA (@ direct modulation speed of 10 Gb/s and driving voltage of 1V). For ultra-low power consumption semiconductor light source, membrane-based lasers, consisting of a thin semiconductor core layer sandwiched by low-index cladding layers such as silicon dioxide or benzocycrobutene (BCB), were proposed and have been investigated because the optical confinement factor in the active region is enhanced by a factor of 3 compared with conventional double-heterostructure lasers composed of semiconductor cladding layers [2,3]. In order to realize the electrical driving of the membrane laser, lateral-current-injection (LCI) structure [4] has been introduced. Up to now, high performance LCI type lasers on semi-insulating (SI) InP substrates with 400 nm thick core layers have been reported [5,6]. Furthermore, the LCI-membrane-distributed feedback (DFB) laser was also demonstrated with the threshold current of 11 mA. [7]. In this paper, we would like to report the direct modulation speed of the LCI membrane DFB lasers which are limited by the stripe width and the semiconductor core layer thickness.

II. STRIPE WIDTH DEPENDENCE OF DELAY TIME

Figure 1 shows a schematic structure of (a) LCI fabry-perrot (FP) laser on a SI-InP substrate and (b) LCI-membrane-distributed feedback (DFB) laser. A GaInAsP core layer in the LCI structure consisting of compressively-strained 5 quantum-wells sandwiched optical confinement layers (OCLs) was laterally sandwiched by p-InP and n-InP cladding layer as the LCI BH structure using two step OMVPE regrowth method[5]. First, we measured direct modulation response under small signal condition and evaluated a delay time of the LCI-FP lasers on a SI-InP substrate. The delay time included an RC delay time τ_{RC} and carrier transport time τ_{tr} in OCLs of the LCI structure. The delay time was estimated from fitting to the small signal response by using following modulation response formula.

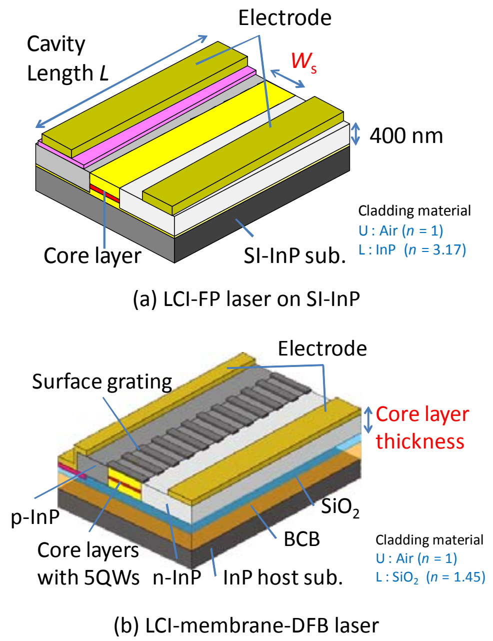

Fig. 1 Schematic diagram of LCI type lasers.

$$Response(f) = \frac{1}{1+\{2\pi f(\tau_{RC}+\tau_{tr})\}^2}\,\frac{f_r^{\,4}}{(f^2-f_r^{\,2})+f^2\Gamma^2/(2\pi)^2}$$

The LCI-FP lasers with various stripe widths were prepared on the same wafer. As can be seen Fig. 2, as the stripe width became wider, the delay time monotonically increased. For high speed operation of the membrane laser, narrower stripe width will be required. Furthermore, the delay time point to trend of an increase as the square of the stripe width (black line in Fig.2). Therefore, the total delay time of the LCI type laser is dominantly attributed to carrier diffusion time in OCLs.

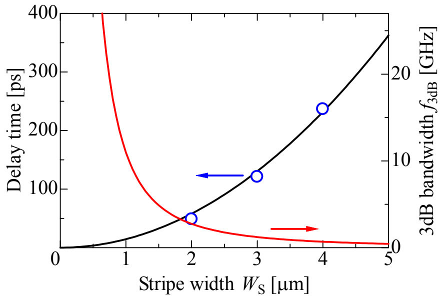

Fig. 2 Delay time dependence on the stripe width of the fabricated LCI-FP lasers with various stripe widths.

As can be seen Fig. 2, The delay time with the stripe width of 1 μm is estimated to be about 15 ps. This value is adequate level for direct modulation over 10 Gb/s.

III. Modulation Bandwidth

Figure 3 shows the calculated threshold current and relaxation oscillation frequency at a bias current of 1 mA as a function of the core layer thickness of the LCI-membrane-DFB laser as shown in Fig. 1(b) [7]. In this calculation, the core layer structure with 5 quantum-wells was assumed to be the same as the fabricated LCI-FP laser on SI-InP substrate. The top and bottom cladding layer of the membrane laser were air and SiO_2, respectively. The internal quantum efficiency of the LCI structure was assumed to be 70% which was experimentally obtained by LCI-FP lasers on SI-InP substrate [6]. As the core layer thickness becomes thinner, the threshold current can be dramatically reduced due to an enhancement of optical confinement factor. When core layer thickness of 150 nm is used, the index-coupling coefficient of the grating becomes 2900 cm^{-1} and the threshold current of 0.16 mA and the differential quantum efficiency of 20% can be attained with the cavity length of 40 μm. In the same way, the relaxation oscillation frequency could be enhanced to be 8.9 GHz (@ I_b = 1 mA) by reduction of the core layer thickness to be 150 nm. These values are adequate as the light source for on-chip optical interconnection.

The 3dB bandwidth f_{3dB} dependence on the square root of the bias current of the membrane laser with various delay times (τ_s) is shown in Fig. 4. f_{3dB} could be increased to higher than 10 GHz when the delay time is reduced to 15 ps by adopting a narrow stripe width of 1 μm (as expected from Fig. 2).

IV. Conclusion

In conclusion, toward the light source of the on-chip optical interconnection, optimal structure of the membrane laser was investigated. From the experimental and numerical results, thin core layer thickness of 150

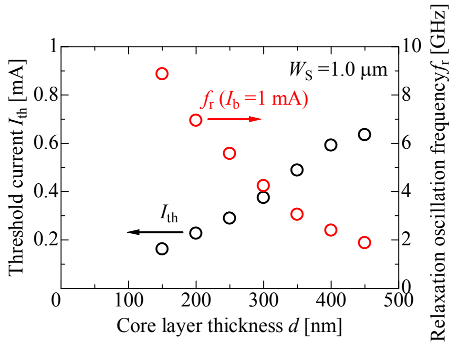

Fig.3 Calculated threshold current and the relaxation oscillation frequency of the LCI-membrane-DFB laser.

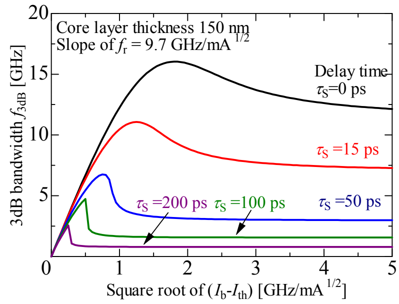

Fig. 4 Calculated 3-dB bandwidth of the LCI-membrane-DFB laser with various delay time.

nm for strong optical confinement effect and narrow stripe width less than 1 μm for smaller delay time are required.

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