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Membrane-Type Photonic Devices for Optical Circuits on SOI

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1. Introduction

In order to solve problems of future Si-LSIs such as global-wire signal delay and heat generation, an introduction of optical interconnects has been attracting much attention [1],[2] because superior power dissipation properties of optical wiring especially for high-speed signal transmission is advantageous due to high responsivity as well as low noise property of photodiodes. From the minimum receivable power of a typical photodiode used for optical fiber communications, the optical pulse energy required for the input signal can be roughly estimated to be in the order of only 10 fJ (0.1 mW peak power and 100 ps pulse width). Moreover, matured CMOS technology enables to realize not only compact and low-loss optical waveguides but also functional photonic devices to open a new field of "Silicon Photonics" [3]. Very high-speed photodetectors [4]-[6] as well as optical modulators [7],[8] were demonstrated using Si or Ge prepared on a Silicon on Insulator (SOI) substrate. For realization of small footprint device for optical wiring, Si nano-photodiodes using surface-plasmon antenna were demonstrated [9],[10].

On the other hand for light sources for optical interconnects, various approaches have been reported by using epitaxial growth or direct bonding of III-V compound laser structures on Si or SOI substrates. Raman lasers based on Si or Ge have been also realized. However, very low power consumption property is required for lasers for on-chip optical interconnects, micro-cavity lasers with high index-contrast DBR mirrors or waveguides, such as vertical cavity surface emitting lasers (VCSELs) [11], microdisk lasers [12], 2-dimensional photonic crystal lasers [13], and microdisk lasers on SOI [14],[15], seem to be very attractive candidates because they can be operated with very low threshold current and are capable for a direct modulation up to 10 Gbit/s.

We proposed "Membrane buried-heterostructure distributed-feedback (BH-DFB) laser" as shown in Fig. 1, which consists of a thin semiconductor core layer (150-200 nm) sandwiched by low-refractive index cladding layers (high index-contrast waveguide), so as to enhance an optical confinement into an active layer compared to that in conventional double-heterostructure (DH) laser [16], and demonstrated extremely low-threshold operation under an optical pumping [17].

In this paper, we would like to present recent research activities devoted to the realization of an injection-type Membrane BH-DFB laser and related optical devices for optical circuits on an SOI substrate.

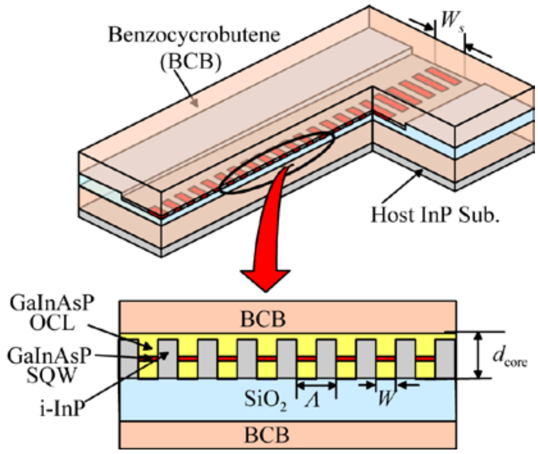

Fig. 1 Schematic structure of membrane BH-DFB laser.

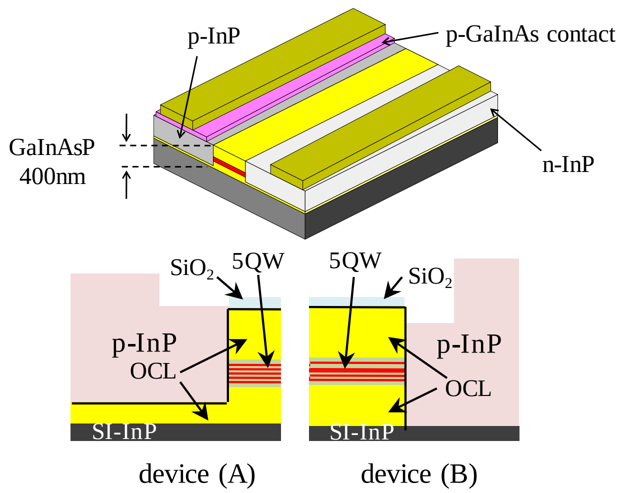

Fig. 2. Structure of LCI lasers on SI-InP .

2. Lateral Current Injection Lasers and Photodiodes on SI-InP Substrate

Since the membrane BH-DFB laser has very thin semiconductor core layer and the cladding layers (BCB or SiO_2) are insulating materials as shown in Fig. 1, current injection type lasers can't be realized by conventional DH structures where current is injected along the vertical direction. Hence we investigated lateral current injection type lasers [18] prepared on a semi-insulating (SI) InP substrate, which can be provided by 3-step OMVPE growths for an initial quan-

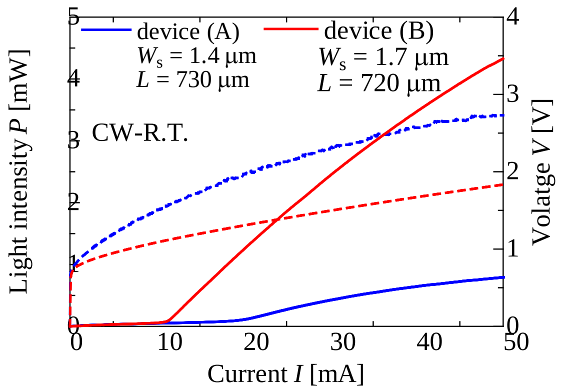

Fig. 3. I-L and I-V curves of fabricated LCI laser.

tum-well structure, n-InP and p-InP cladding/current injecting layers as shown in Fig. 2, and obtained RT-CW operation. Figure 3 shows the light output properties and voltage–current (V–I) curves of devices having similar cavity lengths. While device A showed slightly poor light output property, which may be attributed to non-radiative recombinations at p-InP current injecting layer left on the SI-InP substrate, device B showed a threshold current of 11 mA and an external differential quantum efficiency of 33%. The differential series resistance was 20 Ω which is 2–3 times higher than that of conventional DH lasers because of thin and long current injection layer of the LCI structure [19].

Then the same structure (device A) was tested as a photodiode with a network performance tester with a LN modulator and 1550 nm DFB laser. Figure 4 shows the frequency response of the device with the length of 220 µm. The 3-dB bandwidth was observed to be 6 and 7.5 GHz under the bias conditions of 0 and -2 V, respectively. The speed is limited by the carrier transit time in the absorption layer, because the RC time constant is lower than that of a vertical pn junction structure due to much lower capacitance (C = 20 fF) of the lateral junction structure. Figure 5 shows the bit error rate (BER) measurement results. An error-free detection up to 6 Gbps at a bias of 0 V was achieved, and clear eye opening was obtained up to 10 Gbps when biased with -2 V [20].

3. Conclusions

In conclusion, we successfully demonstrated lateral current injection type lasers prepared on SI-InP substrates with moderately low threshold current and high differential quantum efficiency. We can expect much lower threshold current of high index-contrast membrane DFB laser structure by eliminating the substrate side since the optical confinement factor of the active region will be enhanced by a factor of around 2 to 3, and the optimal cavity length can be shortened for low power consumption operation.

Acknowledgements

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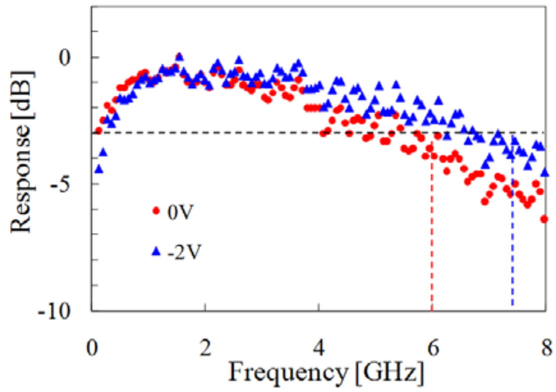

Fig. 4 Frequency response of lateral junction photodiode at bias voltages of 0 and -2 V.

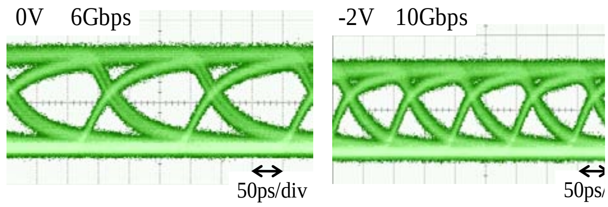

Fig. 5 BER measurements at 0Vcondition and eye patterns.

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