10 Gbit/s Data Transmission through Optical Link by Using Membrane DFB Laser and PIN-PD

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***Abstract*- 10 Gbit/s data transmission through an optical link formed on a Si substrate was carried out by using GaInAsP/InP membrane-based DFB laser and PIN photodiode. The 3dB bandwidth of 11.3 GHz and the BER of 6×10^{-7} at 10 Gbit/s operation were obtained.**

I. Introduction

On-chip optical interconnection is widely investigated for future interconnection of Si CMOS. The problems of electrical interconnection, such as Joule heating and signal delay, can be solved by introducing optical interconnection. Silicon photonics-based on-chip optical link using an external light source was demonstrated with 3 Gbit/s data transmission [1]. Since an optical link consisting of extremely low-threshold lasers capable of high-speed direct modulation is attractive for low-power consumption and easy assembling, integrated optical links using photonic crystal laser [2] and microdisk laser [3] were demonstrated. However, actual error rate measurements were not done yet. To obtain good data transmission, an efficient integrated structure with low threshold laser is needed. We demonstrated a sub-mA threshold operation of a membrane DFB laser as a light source for on-chip optical interconnection [4,5]. A DFB laser has edge-emitting structure which is easy to integration with in-plane output waveguide. By combining with semiconductor membrane structure, strong optical confinement to the active layers and large index-coupling coefficient of grating can be achieved. So we can expect highly efficient and low-power consumption optical link. In a previous experiment, monolithic integration of a membrane DFB laser, a passive waveguide and PIN-photodiode (PD) using butt-jointed built-in structure was demonstrated [6]. However, the results were limited to only static characteristics.

In this paper, we present data transmission experiment using membrane photonic integrated circuit optical link formed on a Si substrate. The membrane DFB laser operated at a threshold current of 0.48 mA. A 3dB bandwidth of full optical link was 11.3 GHz at a laser bias current of 2.73 mA. Data transmission of the membrane optical link by directly modulating the DFB laser was carried out and a bit-error-rate (BER) of 6×10^{-7} was achieved at 10 Gbit/s operation.

II. Device Structure

Figure 1 shows a photograph of the fabricated device and schematics of cross sections at active and passive regions. The detail fabrication process is described in ref. [6]. The active layers of laser were strain-compensated GaInAsP 5QWs. The device lengths of membrane DFB laser and PIN-PD were 80 µm and 200 µm, respectively. These devices were connected by 500 µm-long GaInAsP waveguide. The thickness of semiconductor core layer on SiO_2 cladding layer was 270 nm. These devices had common core stripe width of 0.9 µm. The DFB laser had cleaved facet at opposite side to the PIN-PD for light output measurement.

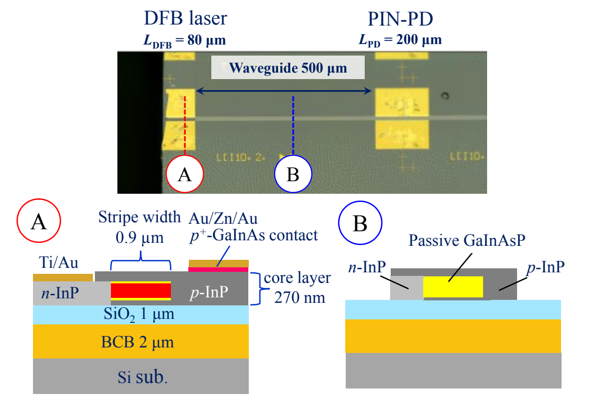

Fig. 1 Photograph of fabricated membrane optical link and shematics of cross section.

III. Static and Modulation Characteristics

Figure 2 shows light output characteristics of the laser and photocurrent characteristics of a PIN-PD as a function of injection current to the laser. These measurements were conducted separately. Firstly, the light output of laser from the facet side was measured. The threshold current was 0.48 mA and the maximum output power from facet was 46 µW at an injection current of 3.1 mA. During the photocurrent measurement, a bias voltage of the PIN-PD was set to -1 V. A clear threshold characteristic was confirmed in the photocurrent versus injection current characteristic, and the threshold well agrees with the threshold obtained from the light output characteristic . The maximum photocurrent was 158 µA at laser injection current of 3.5 mA. The output of DFB laser was fluctuating between the front and the rear side, and caused the fluctuation in photocutrrent. The light output of the DFB laser to the PIN-PD side was estimated to be a few times larger than that from the facet. Asymmetric output may be caused by the facet phase of the grating.

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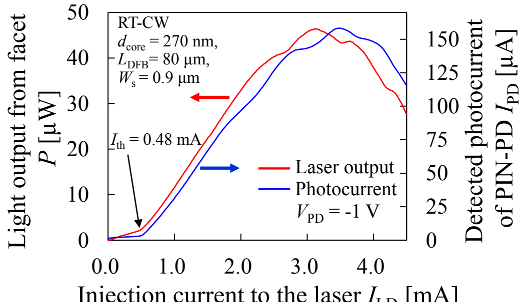


Fig. 2 Light output characteristics of the laser and photocurrent characteristics.

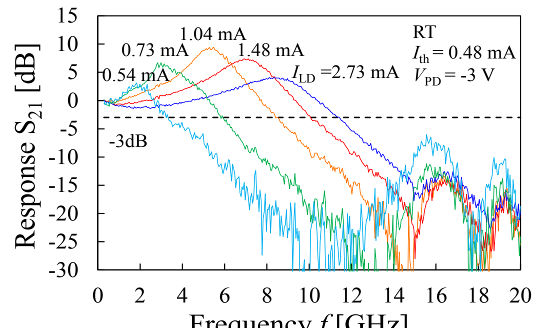


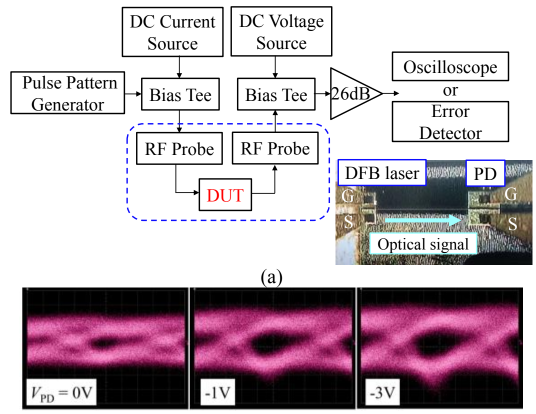
Fig. 3 Small signal responses of full optical link with various laser injection currents.

Next, modulation characteristics measurements of the membrane optical link were carried out. Small signal response S_{21} of the full optical link was measured by using a vector network analyzer. We defined port 1 as an input to the laser, port 2 as an output of the PIN-PD. Figure 3 shows a small signal response of full optical link with various laser injection currents. A clear relaxation oscillation characteristic of laser was observed. The maximum 3dB bandwidth was 11.3 GHz at a laser bias current of 2.73 mA. The modulation efficiency of the DFB laser was 7.2 GHz/mA$^{1/2}$ obtained from the relaxation oscillation frequency.

Finally, data transmission experiment of the optical link was performed. Figure 4(a) shows the measurement setup for the data transmission. The modulation signal generated by a pulse pattern generator was combined with DC bias current via bias tee. A combined signal was directly applied to the DFB laser using a ground-signal (GS) probe without impedance matching. The optical signal was transmitted to the integrated waveguide, then detected by the PIN-PD biased by DC voltage source. The electrical output signal of the PIN-PD was received by the GS probe. The RF part of signal was separated by bias tee, and amplified by a 38 GHz amplifier with 26 dB gain (SHF 806E). The eye diagrams were recorded by an oscilloscope and the BER characteristics were measured by an error detector. The signal form was non-return-to-zero (NRZ) signal and PRBS pattern of 2^{31}-1 with a modulation voltage of 0.75 V. Figure 4(b) shows 10 Gbit/s eye diagrams measured for various PIN-PD bias voltages at I_{LD} = 2.5 mA. The eye opening was obtained by applying sufficient bias voltage to the PIN-PD. The BER curves showed an error floor and the minumim BER was 6×10^{-7} at 10 Gbit/s. The reason of this poor BER results was most likely insufficient output power of the laser. We can expect more clear eye opening and BER below 10^{-9} by improving the laser output.

IV. Conclusion

We demonstrated 10 Gbit/s data transmission by using membrane-based optical link on a Si substrate. The fabricated optical link showed a 3dB bandwidth of 11.3 GHz at laser bias current of 2.73 mA. We confirmed the eye opening at 10 Gbit/s NRZ signal with PRRS of 2^{31}-1 and the BER of 6×10^{-7} was obtained.



(b)

Fig. 4 (a) Measurement setup for data transmission of optical link. (b) 10 Gbit/s eye diagrams for various PIN-PD bias voltages at I_{LD} = 2.5 mA.

Acknowledgment

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