10 Gbps Operation of Membrane DFB Laser on Silicon with Record High Modulation Efficiency

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***Abstract*— We successfully demonstrated high-speed direct modulation of GaInAsP/InP membrane DFB laser on Si substrate for on-chip optical interconnection. The device showed threshold current of 0.21mA and single-mode operation with SMSR = 47dB. From small signal modulation, a record high modulation efficiency of 11GHz/mA$^{1/2}$ was obtained. A 10 Gbps direct modulation with a bit-error-rate (BER) < 10^{-9} was demonstrated at 1mA bias current.**

Keywords—membrane laser; distributed feedback laser; direct modulation;

I. INTRODUCTION

Ultra-low power consumption semiconductor laser, which can be operated with low drive current (< 1 mA) and high-speed (>10 Gbps) direct modulation, is a key device for on-chip optical interconnection. To meet this performance, we proposed and demonstrated a membrane DFB laser which has strong optical confinement into the active region and highly index-coupled grating structure [1]. Recently, a low threshold current [2] and high modulation efficiency operation [3] were realized. Here, we present large-signal modulation characteristics of the membrane DFB laser with strong index-coupling grating (κ_i = 2100 cm^{-1}). As the result, a record high modulation efficiency of 11 GHz/mA$^{1/2}$ and 10 Gbps operation with BER < 10^{-9} at a bias current of 1 mA were successfully obtained.

II. EXPERIMENTAL RESULTS

Figure 1 shows the schematic structure of the membrane DFB laser bonded on a Si substrate. The device consists of a 50-μm-long DFB section and a 20-μm-long butt-jointed built-in (BJB) passive waveguide section. The active region consists of strain-compensated GaInAsP 5 quantum-wells. A 60-nm-deep surface grating was formed to the top InP layer. The detail fabrication process is described in [2]. As can be seen in Fig. 2, a threshold current I_{th} of 0.21 mA and the differential quantum efficiency from the front facet η_d of 5 % were obtained for the stripe width W_s of 0.6 μm (threshold current density J_{th} = 700 A/cm^2). Figure 3 shows the lasing spectrum at a bias current I_b of 2 mA (I_b =9.5 I_{th}). The lasing wavelength and the sub-mode suppression ratio (SMSR) were 1545 nm and 47dB, respectively, and the stopband width of 46 nm corresponds to the index-coupling coefficient κ_i of 2100 cm^{-1}.

Next, we measured direct modulation response of this device. Figure 4 shows photograph of the measurement setup. Signals were input to the membrane DFB laser through a 40 GHz ground-signal (GS) RF probe. The light output was coupled to a spherical lensed single-mode fiber. The optical output signal was amplified by an EDFA with a tunable bandpass filter to cut ASE light, and detected by a 12 GHz band PIN-photoreceiver. Figure. 5 is measured small-signal frequency response for various bias currents. The 3dB bandwidth at I_b = 0.98 mA was 12.8 GHz. The maximum bandwidth of 13.6 GHz was obtained at I_b = 1.47 mA. The relaxation oscillation frequency f_r and 3dB bandwidth f_{-3dB} extracted from fitting of small-signal response are plotted in Fig. 6. The slope of f_r (modulation efficiency) and that of f_{-3dB} were 11 GHz/mA$^{1/2}$ and 17 GHz/mA$^{1/2}$, respectively. This modulation efficiency is more than twice of conventional AlGaInAs-based DFB laser [3], and a record high value ever reported for DFB lasers [4,5]. Next, we carried out 10 Gbps large signal modulation of this membrane DFB laser. The bias current and modulation voltage were set to 1 mA and 0.52 V_{pp} with PRBS 2^{31}-1 NRZ signal. As can be seen in Fig. 7, a BER < 10^{-9} was achieved at -5.8 dBm received power. As shown in Fig. 8, eye opening with an extinction ratio of 5dB was confirmed at a bias current of only 1 mA. If the slope efficiency of *L-I* characteristics is improved, much better BER characteristic and higher bit-rate can be obtained.

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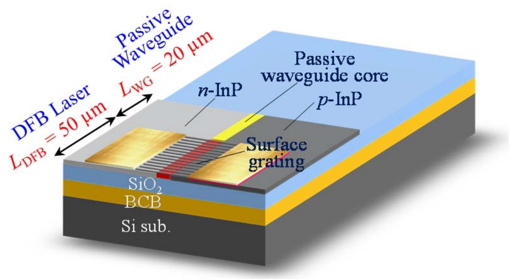

Fig. 1. Schematic structure of membrane DFB laser.

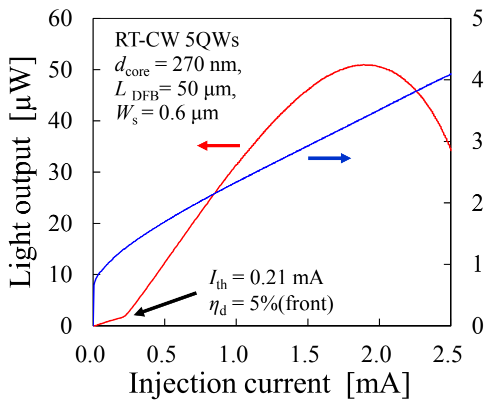

Fig. 2. Light output and voltage characteristics.

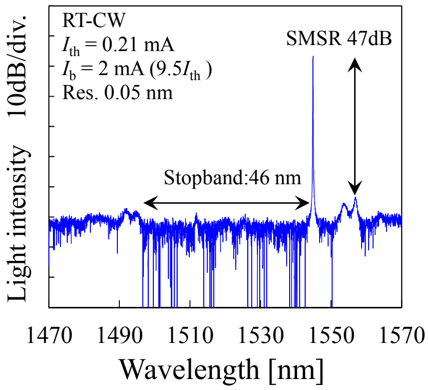

Fig. 3. Lasing spectrum.

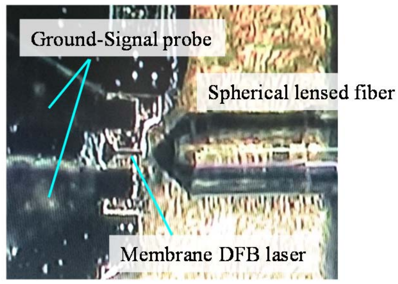

Fig. 4. Photograph of the measurement setup.

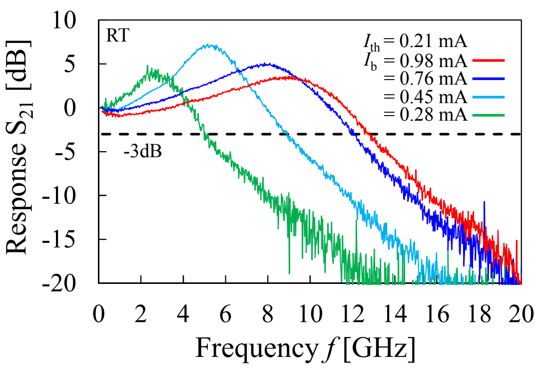

Fig. 5. Small-signal frequency response.

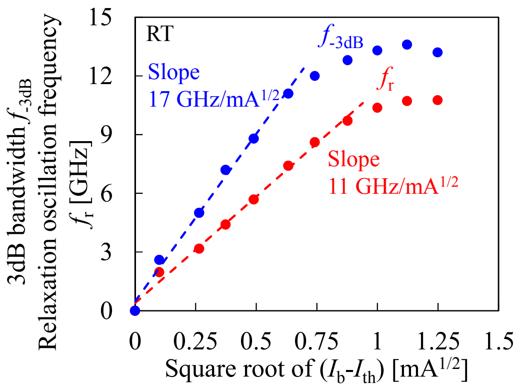

Fig. 6. Relaxation oscillation frequency and 3dB bandwidth as a function of square root of bias current.

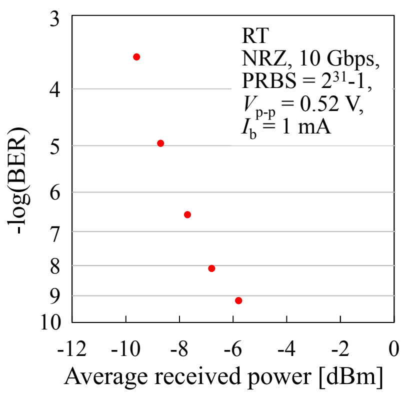

Fig. 7. BER measurement at 10 Gbps biased at 1 mA.

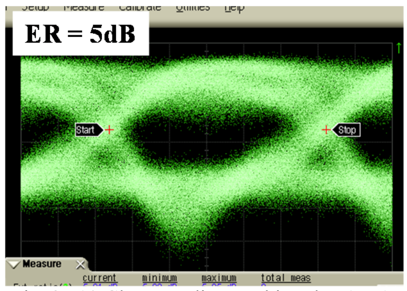

Fig. 8. 10 Gbps eye diagram biased at 1 mA.

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