Development of Semiconductor Lasers Capable of 10-Gbit/s Direct Modulation at Wide Temperature Ranges

Noriaki KAIDA*, Tatsuya TAKEUCHI, Taro HASEGAWA, Nobumasa OKADA, Kan AKIYAMA, Gaishi CHIFUNE, Yutaka ONISHI, Yasuo YAMASAKI, Katsumi UESAKA, Nobuyuki IKOMA and Takuya FUJII

With the current increase in information traffic, even higher speed and density transmission is required for access network equipment. To meet this demand, optical transceivers capable of operating in high-temperature environments and saving energy are indispensable. Thus far, development has been focused on 10-Gbit/s semiconductor lasers that cover a wide temperature range. Since the standardization of 100 Gigabit Ethernet in June 2010, directly modulated 25-Gbit/s lasers have been under development to reduce the production cost of this system. This paper reports on the development of a 1.3-μm wavelength distributed feedback (DFB) laser, which is designed to have a wide temperature operating range and a high processing speed. The authors also describe test results of 10-Gbit/s modulation conducted in a temperature range of -40˚C to 85˚C and 25-Gbit/s modulation below 75˚C.

Keywords: 10Gbit/s, 100Gbit/s, AlGaInAs, buried hetero structure, DFB laser

1. Introduction

Recent rapid growth in information traffic requires high density transmission for access network systems, where optical transceivers capable of high temperature operation with low power dissipation are indispensable. The 10-Gbit/s uncooled directly modulated laser diode (DML) is a key device in the transceivers, and much development has been focused on its high bitrate operation at high temperature. Furthermore, development of 25-Gbit/s DML has been also advanced aggressively these days [(1)-(3)], as 25-Gbit/s DML is expected to be a low-cost light source for the 100-Gbit/s network by 4 wavelength division multiplexing (WDM), like the 100 Gigabit Ethernet (100GbE) [(4)]. For 25-Gbit/s DML, high speed and high temperature operation is more important than before.

In this paper, we report on our 1.3-μm wavelength DFB laser diode, and show its high performance of 10-Gbit/s operation over a wide temperature range. 25-Gbit/s operation is also demonstrated.

2. Device Design

For a high speed DML capable of wide temperature range operation, high output power at high temperature, high relaxation oscillation frequency (fr) and wide bandwidth are needed. To achieve both of high output power and wide bandwidth, we chose a short length cavity and buried hetero (BH) current blocking structure. The active region was designed to optimize the trade-off between output power and fr. Details of our new DML is explained with the schematic view shown in **Fig. 1**.

The laser was fabricated on the n-InP substrate and its cavity length was 200 μm. The front facet was covered with an anti-reflection (AR) film and the rear was covered with a high reflection (HR) film. The diffractive grating was

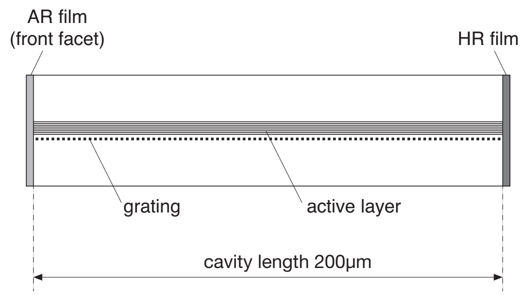


Fig. 1. Schematic view of the laser

formed below the active region and κL value, which shows strength of distributed feedback, was 1.2. For the active region, AlGaInAs multi quantum well (MQW) structure was used. This material system is more suitable for high-speed lasers than the conventional GaInAsP material system, because its strong confinement for electron brings high fr. To realize strong optical confinement, the active region consisted of 10 quantum wells of 5 nm thickness. Quantum wells were designed to have as large as 1.3% of compressive strain for high fr. Barrier layers were designed to have tensile strain to realize high reliability by compensated strain MQW structure.

3. DC Characteristics

Figure 2 shows the light-current characteristics of the newly developed laser. The threshold current and the slope efficiency were: 2.4 mA and 0.76 W/A at -40˚C; 4.7 mA and 0.65 W/A at 25˚C; 15.7 mA and 0.44 W/A at 85˚C; 20.0 mA and 0.38 W/A at 95˚C, respectively. The thermal degradation of linearity was very small and an output power as high as 20 mW was obtained up to 95˚C.

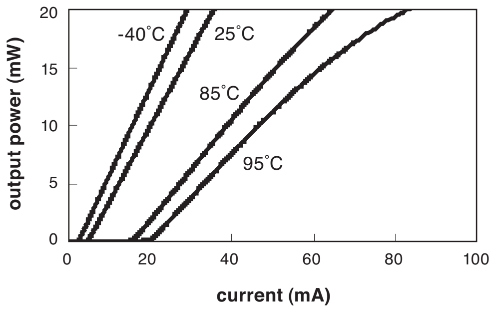


Fig. 2. Light-current characteristics

4. AC Characteristics

Figure 3 shows the electro-optic (EO) response of the new laser at 25˚C and its current dependence. The 3-dB down bandwidth became wider as the injection current increased, and exceeded 20 GHz at the injection current larger than 30 mA. Because of use of the BH structure, this wide bandwidth was accompanied with the excellent DC characteristics formerly mentioned.

Figure 4 shows fr - current characteristics at -40, 25 and 85˚C. The values of fr were measured by fitting the frequency response spectrum shown in **Fig. 3**. The D-factor, defined as the slope of fr on square root of the difference between injection current and threshold current, was 2.8 GHz/mA$^{0.5}$ at -40˚C; 3.6 GHz/mA$^{0.5}$ at 25 ˚C; and 2.6 GHz/mA$^{0.5}$ at 85˚C, respectively. These high values were realized over the wide temperature range by short cavity length and the optimization of active region design.

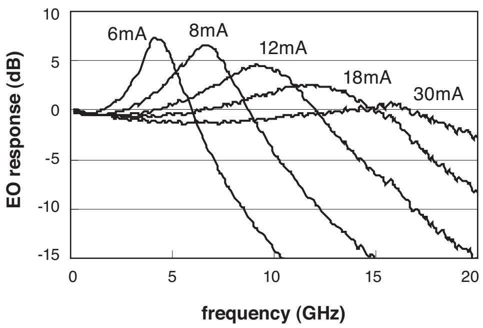


Fig. 3. EO responses

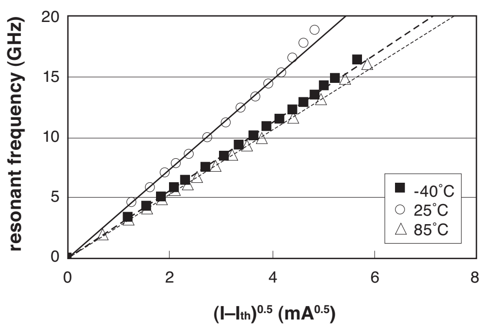


Fig. 4. Current dependence of fr

5. 10-Gbit/s Optical Waveforms

Figure 5 shows 10-Gbit/s optical waveforms of the new laser at -40, 25 and 85˚C. Clear eye opening was shown at each temperature.

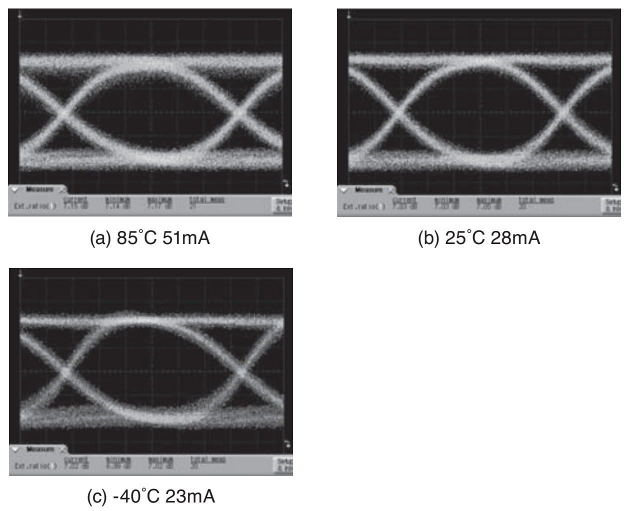


Fig. 5. 10-Gbit/s eye diagrams

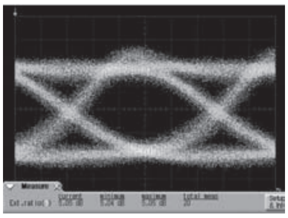
The measurement was carried out with 9.95-Gbit/s non-return-to-zero (NRZ) signals with 2^{31}-1 pseudo-random-bit-sequence (PRBS). Each waveform was measured with a Bessel-Thomson filter. An extinction ratio was set to 7 dB. Values of bias current and operating temperature are described below the each waveform. Current values were set to keep constant output power at each temperature.

6. 25-Gbit/s Optical Waveforms

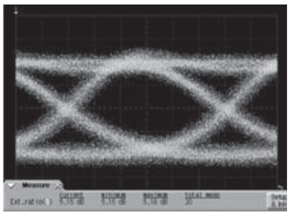
Figure 6 shows 25-Gbit/s optical waveforms of the new lasers at 25˚C and 75˚C. For this measurement, we have fabricated 4 lasers of different wavelength (1271 nm, 1291 nm, 1311 nm and 1331 nm) in the same design.

The measurement was carried out with 25.78-Gbit/s NRZ signals with 2^{31}-1 PRBS. Each waveform was measured without a Bessel-Thomson filter. An extinction ratio was set to 5 dB. Wavelength, bias current and operating temperature are described below the each waveform. Bias current was set to 60 mA at 75˚C, and to keep constant output power at 25˚C.

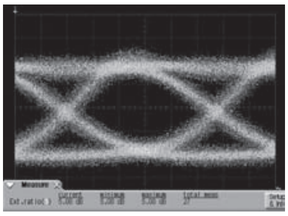
Clear eye opening was obtained at each temperature and each wavelength. This result shows our new DFB lasers are suitable for the 100GbE LAN-WDM system, in which



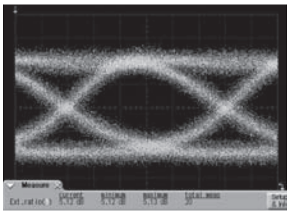
(a) 1271nm 25˚C 37mA



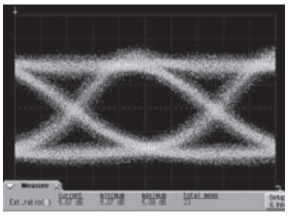
(b) 1271nm 75˚C 60mA



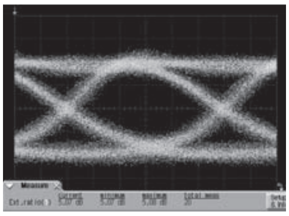
(c) 1291nm 25˚C 38mA



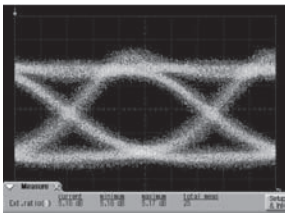
(d) 1291nm 75˚C 60mA



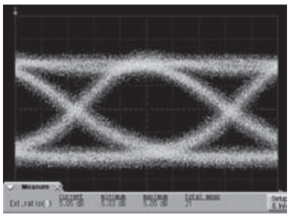
(e) 1311nm 25˚C 38mA



(f) 1311nm 75˚C 60mA



(g) 1331nm 25˚C 34mA



(h) 1331nm 75˚C 60mA

Fig. 6. 25-Gbit/s eye diagrams

lasers are operated with thermo-electric coolers. It also shows the new lasers are promising for the 100-Gbit/s coarse WDM (CWDM) system, in which lasers of 1271 nm, 1291 nm, 1311 nm and 1331 nm are used without thermo-electric coolers.

7. Reliability

Figure 7 shows the result of a high temperature operating test carried out at 95˚C. Operating current of each laser was controlled to keep constant output power in this test.

During the 5,000-hour test, no failure had occurred and the median lifetime value was 0.75 x 10^6 hours. This value gives the lifetime of as long as 7.61 x 10^6 hours under the actual usage condition (55˚C, 13 mW).

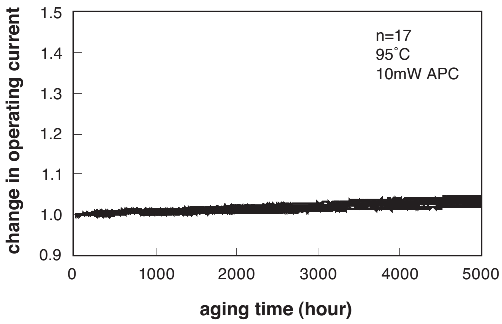


Fig. 7. Results of aging test

8. Conclusion

We developed a 1.3-μm wavelength DFB laser capable of 10-Gbit/s direct modulation in a temperature range of -40˚C to 85˚C.

Owing to the BH current blocking structure, this laser showed both excellent DC characteristics as high power as 20 mW even at 95˚C and wide bandwidth larger than 20 GHz. Excellent 10-Gbit/s optical waveforms were shown in a wide temperature range of -40˚C to 85˚C because of the D-factor larger than 2.6 GHz/mA$^{0.5}$.

We fabricated 4 DFB lasers of different wavelength and demonstrated 25-Gbit/s operation. Clear eye opening was achieved up to 75˚C at each wavelength. Our new lasers are promising for the 100-Gbit/s communication system.

References

(1) T.Tadokoro, T.Yamanaka, F.Kano, H.Ohashi, Y.Kondo, and K.Kishi, "Operation of a 25-Gbps Direct Modulation Ridge Waveguide MQW-DFB Laser up to 85˚C," Proc. OFC'09, OThT3, San Diego, USA, March 2009.

(2) K.Otsubo, M.Matsuda, S.Okumura, A.Uetake, M.Ekawa, and T.Yamamoto, "Low-Driving-Current High-Speed Direct Modulation up to 40Gb/s Using 1.3-μm Semi-Insulating Buried-Heterostructure AlGaInAs-MQW Distributed Reflector(DR)Lasers," Proc. OFC'09, OThT6, San Diego, USA, March 2009.

(3) T.Fukamachi, T.Shiota, K.Kitatani, T.Ban, Y.Matsuoka, R.Mita, T.Sugawara, S.Tanaka, K.Shinoda, K.Adachi and M.Aoki, "95˚C Uncooled and High Power 25-Gbps Direct Modulation of InGaAlAs Ridge Waveguide DFB Laser," Proc. ECOC'09, 8.1.5, Vienna, Austria, September 2009.

(4) IEEE P802.3ba 40Gb/s and 100Gb/s Ethernet Task Force, http://www.ieee802.org/3/ba

Contributors (The lead author is indicated by an asterisk (*).)

N. KAIDA*

- Sumitomo Electric Device Innovations, Inc.
He is engaged in the development of semiconductor lasers for high speed communications.

T. TAKEUCHI
- Sumitomo Electric Device Innovations, Inc.

T. HASEGAWA
- Sumitomo Electric Device Innovations, Inc.

N. OKADA
- Manager, Sumitomo Electric Device Innovations, Inc.

K. AKIYAMA
- Group Manager, Sumitomo Electric Device Innovations, Inc.

G. CHIFUNE
- Transmission Devices R&D Laboratories

Y. ONISHI
- Dr. Eng.
Assistant Manager, Transmission Devices R&D Laboratories

Y. YAMASAKI
- Assistant Manager, Transmission Devices R&D Laboratories

K. UESAKA
- Group Manager, Transmission Devices R&D Laboratories

N. IKOMA
- Group Manager, Transmission Devices R&D Laboratories

T. FUJII
- Department Head, Sumitomo Electric Device Innovations, Inc.