95 ˚C Uncooled and High Power 25-Gbps Direct Modulation of InGaAlAs Ridge Waveguide DFB Laser

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Abstract 95˚C, 25-Gbps direct modulation of a high-power (>15mW) 1.3-μm-InGaAlAs-DFB laser is developed for the first time. The device will be a key for 4-channel CWDM uncooled light-sources used in the lower-power-consumption 100-GbE subsystems.

Introduction

Demands for the highly-efficient transmission of huge amounts of data have soared with the explosive growth of broadcast/broadgather traffic networks. Core/edge routers, switches and data servers are now essential to information communication technology (ICT) society which act as the infrastructure for our businesses and our daily life. These high-end ICT equipments strongly depend on high rate optical data transmission technologies. The technologies are the must not only in the communication networks (telecommunications), but also in the storage networks (so-called fiber channels) as well as in the local area networks (so-called LAN or Ethernet).

Recently, much attention has been paid to 100GbE technologies. The IEEE 802.3ba task force actively leads technology standards for this 100GbE [1]. In these technologies, a 10-km transmission at a data throughput of 100-Gbps is achieved by transmitting 4-λ wavelength-division multiplexing (WDM) 25-Gbps-based signals. The physical interface; 100GBASE-LR4 employs a narrow wavelength separation of 800-GHz (c.a. 4.6-nm), which is called “LAN WDM”. Due to this narrowly-spaced wavelength division, the light-sources should be cooled to stabilize the signal wavelengths on the LAN DWM grids. This causes extra power consumption at thermo-electric coolers. On the other hand, by adopting coarse wavelength-division multiplexing (CWDM), we can employ uncooled light-sources. The wavelength change caused by the temperature changes of 100 ˚C (c.a. 10nm) is half that of the typical CWDM spacing of 20-nm. Therefore, cooler-less CWDM solution is a key to achieve compact, cost-effective and low-power-consumption 100-GbE transceivers. Quite recently, uncooled 25-Gbps light-sources based on an electroabsorption modulator integrated distributed feedback (EA/DFB) laser [2] and directly-modulated DFB laser [3] have been reported. Their highest chip operation temperature was 85˚C, which roughly corresponds to the module case temperature of 75 ˚C. In this paper, we successfully demonstrated uncooled 25-Gbps directly-modulated DFB laser operated up to chip temperature of 95 ˚C that should ensure module operation from 0 ˚C to 85 ˚C.

Investigation by using the FP lasers

In addition to high bit-rate operation, to achieve low threshold current I_{th} and high slope efficiency *Se*, shortening the cavity length, L_c, is effective. Firstly, the dependences of the L_c on the device performance were investigated by using the Fabry-Perot (FP) lasers.

The results are shown in Fig. 1. The f_r-efficiency η_{fr}, which is defined as the dependence of the relaxation frequency f_r on the square root of the driving current, was increased monotonically by shortening the L_c (Fig. 1(a)). The increase in the η_{fr}, however, rapidly deviated from the proportional relation $f_r \propto 1/L_c^{0.5}$, which was below 200-μm-long. This deviation is understood to have originated from the increasing mirror loss, which was caused by shortening the L_c. The increase in the mirror loss caused the differential gain to degrade. As a result, the increase in the f_r by shortening the L_c was offset by the increase in the mirror loss. Although it was reported that the optical properties of a 150-μm-long FP laser were degraded more than those of the 200-μm-long laser at over 85 ˚C [3], this might have been due to insufficient gain originating from it having a thinner active layer in the short cavity region than our laser. According to Fig. 1(b), in addition to increasing the f_r, shortening the L_c is effective for lowering the I_{th} and raising the *Se*. Therefore, from the above investigations, the L_c was designed at 160 μm.

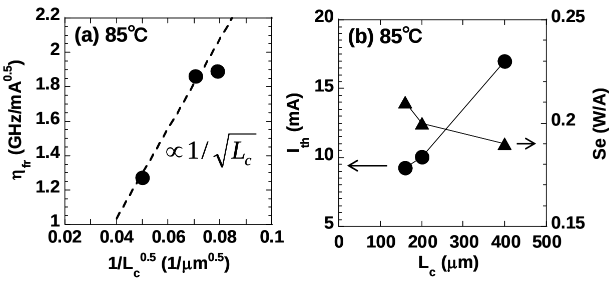


Fig. 1: Dependences of the cavity length on f_r-efficiency, threshold current, and slope efficiency

25-Gbps operation of the DFB laser

The fabricated InGaAlAs DFB laser was a 160-μm-long ridge waveguide (RWG) laser. The optical coupling κ was designed to be about 80 cm^{-1}. The front and rear facets were coated with AR/HR films.

Figure 2 shows the temperature dependences of the *I-L* curve and the *I-Se* curve. The I_{th} at 85 ˚C and 95 ˚C are 13.1 mA and 14.9 mA, respectively. In addition, the *Se* at the I_{th} is 0.36 W/A at 85 ˚C and 0.34 W/A at 95 ˚C. As you can see from Fig. 2(a), maximum output power higher than 15 mW was successfully obtained at 95 ˚C. In general, because of the lateral current spreading, the RWG laser seems to be inferior to the buried-hetero (BH) laser at reducing the I_{th}. The spreading part is, favorably, reduced by shortening the L_c. On the other hand, the current leakage is one of the problems that needs to be overcome for the BH laser, the L_c of which is shorter than 200 μm, especially at over 70 ˚C [4]. Therefore, the RWG laser is considered to be optimal for cavity lasers shorter than 200 μm when compared with the BH structure.

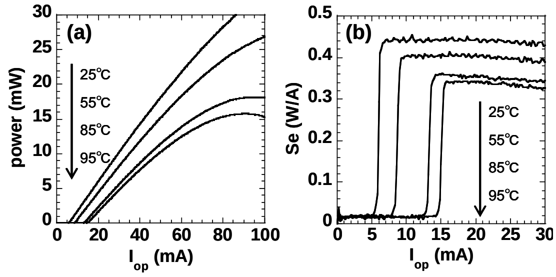


Fig. 2: *I-L* curves and *I-Se* curves of the DFB laser

The eye patterns were also measured by using a homemade 25-Gbps pulse-pattern generator (PPG). The laser was directly modulated using a 25-Gbps-non-return-to-zero (NRZ) signal that had a 2^{31}-1 pseudo-random-bit sequence (PRBS). Figure 3 shows the back-to-back and the 10-km-transmitted 25-Gbps-eye diagrams at 25 ˚C, 85 ˚C, and 95 ˚C. The applied modulation voltage was 2.0 V_{pp} for all temperatures, and the bias currents I_b at 25 ˚C, 85 ˚C, and 95 ˚C are 36 mA, 66 mA, and 65 mA, respectively. The dynamic extinction ratios of more than 6-dB were obtained in all the back-to-back eye diagrams. In addition, clear 10-km-transmitted 25-Gbps eye diagrams were also obtained, as shown in the figure. High power operation by achieving very low I_{th} and very high Se is the key for obtaining clear 10-km-transmitted 25-Gbps eye diagrams at high temperatures, e.g. at 95 ˚C. As stated earlier, to our knowledge, this is the first report that details clear eye diagrams obtained at 95 ˚C in the 1.3-μm direct modulation lasers (DMLs). Furthermore, these results indicate that achieving an uncooled operation for 100GbE is possible by CWDM. Note that the I_b at 85 ˚C was a little larger than that at 95 ˚C. This is only a problem with the setting of the I_b.

A long-term-reliability test was also carried out by using 200-μm-long DFB lasers at 85 ˚C (Fig. 4). In this test, the operation current was controlled to be a certain output power. It was confirmed that stable behavior up to 4000 hours was demonstrated. This result also indicates that cost effective and low power consumption transmitters for 100GbE can be achieved by using the DMLs.

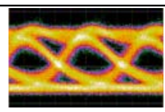
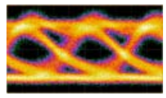
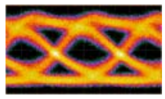
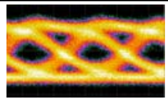
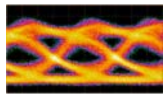
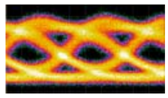
condition	Back-to-Back	10 km
(a) 25℃ I_b=36mA V_{pp}=2.0V ER=9dB		
(b) 85℃ I_b=66mA V_{pp}=2.0V ER=6dB		
(c) 95℃ I_b=65mA V_{pp}=2.0V ER=7dB		

Fig. 3: 25-Gbps-eye diagrams

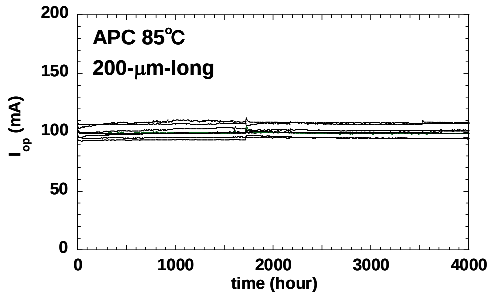


Fig. 4: Long-term-reliability test

Conclusions

We developed an uncooled 25-Gbps and 1.3-μm direct modulation InGaAlAs RWG-DFB laser. The low threshold current of I_{th} = 14.9 mA and the high slope efficiency of *Se* = 0.34 W/A were obtained at 95 ˚C. By achieving such very low I_{th} and very high *Se*, output power of more than 15 mW was also obtained at 95 ˚C. In addition, the clear 25-Gbps-eye pattern with the large dynamic extinction ratio of more than 6 dB was also successfully obtained at 95 ˚C, and stable behavior up to 4000 hours was also demonstrated. To our knowledge, this is the first report on a clear eye diagram at 95 ˚C. These characteristics show that the directly modulated 1.3-μm InGaAlAs RWG-DFB lasers are attractive as uncooled high-speed light sources for 100GbE.

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