106-Gb/s PAM4 Uncooled Operation (25–85 °C) of Directly Modulated DFB Lasers in the CWDM Range

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Abstract – 106-Gb/s PAM4 operation was demonstrated from 25 to 85 °C using four directly modulated DFB laser over a 1.3-μm CWDM range. Eye openings were achieved in BTB and after 500-m and 2-km SMF transmissions up to 85 °C.

I. Introduction

With the continued explosion of network traffic, the capacity needs to be expanded without increasing either the cost or power consumption of optical components. Data traffic in data centers and 5G wireless networks occupy a particularly significant proportion of the total capacity. In response to the demand, the bandwidths of optical transceivers for data centers are being increased from 100GbE to 400GbE. Four-level pulse amplitude modulation (PAM4) at 53 Gbaud (106 Gb/s) has been widely adopted and is expected to be utilized for optical transceivers in data centers and 5G applications. Moreover, 53-Gbaud PAM4 technology is also under discussion for 800GbE short-reach applications such as a 53-Gbaud × 8-lanes parallel optical interface [1].

A directly modulated DFB laser (DML) is a promising candidate as a 106-Gb/s light source for data centers and 5G applications thanks to its simple structure, low driving current, compactness, and cost effectiveness. Several activities on DMLs have been reported, such as 50-Gbaud-class PAM4 [2–5] and beyond-100-Gbaud PAM4 operation [6]. DMLs can operate without thermoelectric cooler (TEC) control in a wide temperature range, leading to a promising solution for uncooled operation with low power consumption. Some applications also require DMLs with different lasing wavelengths across the coarse wavelength division multiplexing (CWDM) range (i.e., from 1271 to 1331 nm). Therefore, a comprehensive study of uncooled 106-Gb/s PAM4 operation by using DMLs over the CWDM range is indispensable for an affordable 106-Gb/s light source.

In this work, we developed ridge-waveguide (RWG) DMLs with four different wavelengths in the CWDM range, namely, 1271 (lane 0), 1291 (lane 1), 1311 (lane 2), and 1331 nm (lane 3). The four DMLs possess high relaxation oscillation frequencies $f_r$ even at high temperature because of their high differential gain $dg/dn$ and high optical confinement factor $\Gamma$. Thus, they all exhibit clear 106-Gb/s (53-Gbaud) PAM4 eye openings from 25 to 85 °C. Transmission performance after 500 m and 2 km are also reported from 25 to 85 °C.

II. Device structure

We designed the RWG-DMLs with four different wavelength lanes considering both high $\Gamma$ and high $dg/dn$ for high bandwidth on the basis of our previously developed 1310-nm DMLs [2]. The semiconductor layers of the DMLs were epitaxially grown on a n-type InP substrate by metal-organic chemical-vapor deposition. In order to achieve high temperature operation, the photoluminescence wavelengths for each lane were designed to get optimal wavelength detuning. The band structure of the InGaAlAs multi-quantum-well (MQW) layers resulted in high $dg/dn$ even at high temperature. The MQW layers and SCH layers also contributed to increasing $\Gamma$ [2]. Cavity lengths and κLs were designed to be 150 μm and around 2.0 for all four lanes. We incorporated an asymmetric corrugation pitch modulated grating structure to suppress longitudinal spatial hole-burning [7] and set the grating pitches of the four DMLs to 195, 198, 202, and 205 nm, respectively.

III. Experimental results

All characteristics of the laser chips, including E/O response and waveforms, were evaluated in a chip-on-carrier (COC) configuration with both a resistor for 50-Ω impedance matching and a TEC to control DML temperature ($T_{\text{LD}}$). Figure 1 shows light-current characteristics of the four DML chips at $T_{\text{LD}}$ of 25 and 80 °C. The threshold currents at 80 °C were from 13.7 to 16.3 mA, and the optical output powers at the bias current ($I_b$) of 70 mA was more than 6.7 mW. The lasing spectra with 50 mA at 25 °C in Fig. 2 indicate high side-mode suppression ratios over 45 dB. E/O responses of the four DMLs were measured at 25 and 85 °C, and $f_r$-slope characteristics were found to be from 3.8 to 4.4 and from 2.8 to 3.0, respectively (Fig. 3). The 3-dB bandwidths ($f_{3\text{dB}}$) of the four DMLs at 85 °C with 70 mA were over 20.1 GHz, meaning that all four DMLs held superior bandwidths up to 85 °C.

Evaluation of 106-Gb/s PAM4 eye diagrams was performed in the following setup similar to our previous study [2]. An electrical signal with a short stress pattern random quaternary (SSPQR) test pattern was generated by a Keysight M8045A pattern generator (PG). A single-ended signal was input through an RF amplifier to
modulate each of the DMLs up to 35 mApp. DC bias ($I_b$) was also applied via a bias tee just before an RF probe. Optical waveforms were detected by a Keysight N1092C sampling oscilloscope. The eye diagrams were measured with a 5-tap feed-forward equalizer (FFE) under a back-to-back (BTB) configuration. The outer extinction ratio (ER) was adjusted to 3.0 dB, which was limited by a signal-voltage of the PG output and the RF amplifier gain. Figure 4 shows 106-Gb/s PAM4 eye diagrams after equalization for all four lanes. Eye openings over four levels were confirmed at $T_{LD}$ from 25 to 85 °C in the BTB configuration. We also evaluated transmission performance through 500-m and 2-km SMFs with zero dispersion at 1310 nm. Eye openings were observed in a typical lane-2 DML even after 500-m and 2-km transmissions at 85 °C, as shown in Fig. 5.

![Fig. 1. Light-current characteristics.](image1)

![Fig. 2. Spectra of four DMLs at 25 °C.](image2)

![Fig. 3. f-slope characteristics.](image3)

![Fig. 4. 106-Gb/s PAM4 optical eye-diagrams of the four DMLs at 25 and 85 °C with $I_b$ of 50 mA and 70 mA, respectively.](image4)

![Fig. 5. 106-Gb/s PAM4 eye-diagrams in BTB and after 500-m and 2-km transmission at $T_{LD}$ of 85 °C.](image5)

### IV. Conclusion

We achieved 106-Gb/s PAM4 operation of DMLs from 25 to 85 °C with the 1.3-μm CWDM range, which demonstrates the excellent potential of the newly developed RWG-DMLs with four different wavelengths. All DMLs showed eye openings at 85 °C as well as superior performance after 500-m and 2-km transmission. These results reveal the feasibility of an uncooled-DML solution for 400GbE and beyond, paving the way to cost-effective transceivers with low power consumption for hyper-scale data centers.

### V. References