106-Gbps PAM4 Operation at an Extinction Ratio above 3.5 dB using a Conventional Buried-Heterostructure Directly Modulated Laser

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Abstract: A 106-Gbps PAM4 operation with an extinction ratio above 3.5 dB and TDECQ values of 1.85 and 3.04 dB was demonstrated using a conventional buried-heterostructure directly modulated laser at temperatures of 25 and 55 °C.

1. Introduction

In datacenters, faster data transmission is required to handle large data volumes generated by various applications such as AI and IoE. Thus, the 400GBASE-DR/FR standards for datacenters adopt a 53-GBaud PAM4 modulation and devices operating at above 100-Gbps are required. So far, electro-absorption modulator lasers are being used for such applications. However, high-speed directly modulated lasers (DMLs) reduce transceiver power consumption, footprints, and costs. To guarantee the productivity, these DMLs should be as simple as possible.

Some studies reported DMLs operating above 100-Gbps. The photon-photon resonance (PPR) and detuned-loading (DL) effects were used to operate a DFB+R laser at 112-Gbps PAM4 [1]. A membrane DR laser on a SiC substrate with the PPR and DL effects achieved a 256-Gbps PAM4 operation [2]. Examples of DMLs not using PPR and DL effects include a ridge-waveguide DML and submicron ridge localized buried-heterostructure laser, which achieved 106- and 112-Gbps PAM4 operation [3,4].

In this paper, we report a novel buried-heterostructure DML (BH-DML). Our BH-DML design is simple and thus easy to fabricate. We altered the active region design in our previously developed BH-DML [5] to increase the optical confinement factor Γ and the differential gain (dg/dn). We enhanced the relaxation oscillation frequency f_r and achieved a 106-Gbps PAM4 operation with an extinction ratio (ER) above 3.5 dB, which satisfies 400GBASE-DR/FR. To the best of our knowledge, this is the first result for a conventional BH-DML not using the PPR and DL effects.

2. Device structure

We modified the active region design of our previously developed BH-DML [5]. The cross-sectional view is shown in Fig. 1. By adopting a buried heterostructure, we can confine light not only vertically but also horizontally, constrict the current path, and improve heat dissipation. The active region is composed of AlGaInAs multiple quantum wells (MQWs) and AlGaInAs separate confinement heterostructure. It is buried by semi-insulating InP. All layers are grown by metal organic chemical vapor deposition. f_r is written as $f_r = \sqrt{(\Gamma/W_a) \times (dg/dn)}$ where W_a is the active region width. To improve the ratio of Γ to the width of the active region (Γ/W_a) and dg/dn, we increased the number of quantum wells and reduced the active region width from conventional 1.2 to 1.0 μm. The ratio Γ/W_a was increased from 0.095 to 0.171 μm^{-1} (~ 80% improvement). We also applied higher compressive strain in the quantum well layers to increase dg/dn. The thickness of the MQWs is 40% larger than the theoretical critical thickness. However, by adjusting the tensile strain in the barrier layers and the condition of epitaxial growth, we could successfully grow the MQWs. These increases in the quantum wells and compressive strain compensated the reduction in the optical gain caused by the shrinking of the active region. Additionally, we selected the thickness of the quantum wells, barriers, and separate confinement heterostructures according to the device characteristics. We applied a thinner p-cladding layer to lower the device resistance. The device length was 150 μm. We applied anti-reflection and high-reflection coatings on the front and rear facets, respectively.

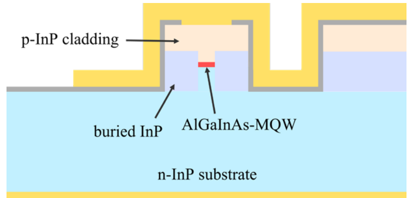


Fig. 1. Cross-sectional view of developed BH-DML.

3. Laser characteristics

We mounted the BH-DML on a ceramic carrier with a resistor for impedance matching. We used a thermoelectric cooler for temperature control. The I-L characteristics are shown in Fig. 2. The threshold current (I_{th}) values were 6.3, 10.6, and 15.4 mA at temperatures (T_c) of 25, 55, and 70 °C, respectively. The output power was above 8.7 mW at T_c of 70 °C and bias current (I_{bias}) of 75 mA. The device resistance was 6.5 Ω due to a thinner p-cladding layer. The frequency response and the f_r dependence on the square root of ($I_{bias} – I_{th}$) are shown in Fig. 3. The f_r values were 29.3, 25.6, and 21.8 GHz and the slopes of f_r were 4.96, 4.21, and 3.67 GHz/mA$^{1/2}$ at a T_c of 25, 55, and 70 °C, respectively. By improving not only Γ/W_a but also dg/dn, we could obtain good frequency performance without a high Γ/W_a value.

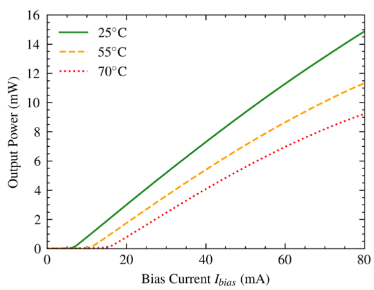


Fig. 2. L-I characteristics.

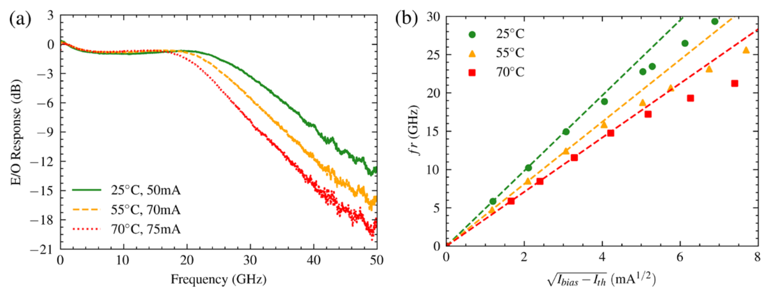


Fig. 3. (a) frequency response, (b) fr-$\sqrt{(I_{bias}-I_{th})}$ characteristics.

4. 106-Gbps PAM4 experimental result

The PAM4 experimental setup is shown in Fig. 4. A short stress pattern random quaternary (SSPRQ) pattern was output from a waveform generator (Keysight M8196A) and amplified by an RF amplifier (SHF M807C). A 5-tap de-emphasis was used to compensate the electrical signal. The signal was applied to the BH-DML, and the emitted light was collected by a sampling oscilloscope (Keysight N1092C) in back-to-back (BTB) configuration or after a 10 km transmission over a single mode fiber (SMF). A 5-tap feed-forward equalization was applied to the received signal and the transmitter dispersion eye closure quaternary (TDECQ) was computed using Keysight FlexDCA. The extinction ratio (ER) was 3.5 dB and the I_{bias} values were 50, 70, and 75 mA at T_c of 25, 55, and 70 °C, respectively. The optical eye diagrams and TDECQ values are shown in Fig. 5. We achieved TDECQ values of 1.85 and 3.04 dB in BTB at T_c of 25 and 55 °C, respectively. These results satisfy the 400GBASE-DR/FR specification (TDECQ < 3.4 dB for ER > 3.5dB). To the best of our knowledge, these are the first results for a conventional BH-DML not using PPR and DL effects. Eye opening was confirmed at T_c of 70 °C. Eye diagrams after 10 km transmission were good. Furthermore, the ER improved from 3.5 to 5.0 dB. The TDECQ dependence on the extinction ratio is shown in Fig. 6. The TDECQ reached a maximum value of 3.29 dB. Both ER and TDECQ satisfied the 400GBASE-DR/FR specification.

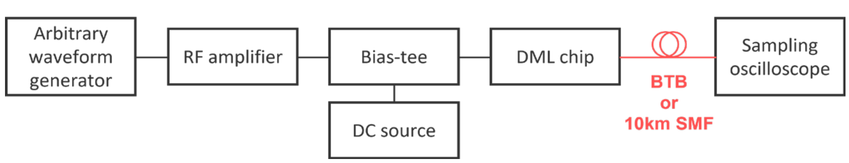


Fig. 4. PAM4 experimental settings.

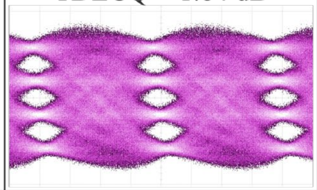
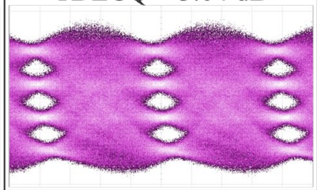
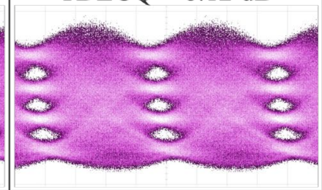
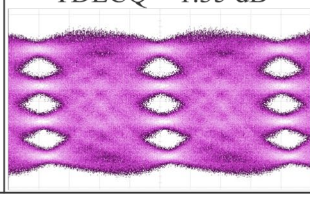
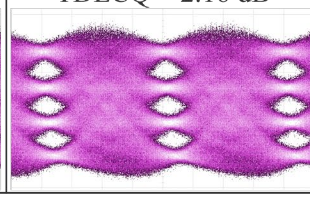
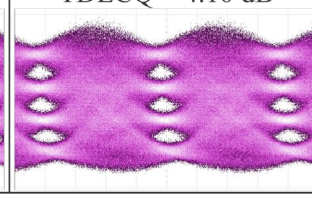
Tc, Ib	25 °C, 50 mA	55 °C, 70 mA	70 °C, 75 mA
BTB ER = 3.5 dB	TDECQ = 1.84 dB 	TDECQ = 3.04 dB 	TDECQ = 8.12 dB 
10km ER = 3.5 dB	TDECQ = 1.35 dB 	TDECQ = 2.16 dB 	TDECQ = 4.10 dB 

Fig. 5. 106-Gbps PAM4 optical eye-diagrams.

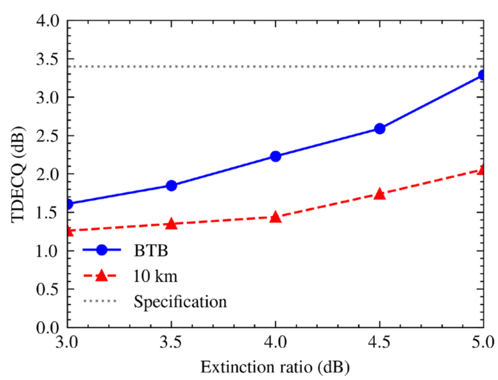


Fig. 6. TDECQ dependence on extinction ratio.

5. Conclusion

We modified the active region design of a previously developed BH-DML. Our BH-DML design is simple and thus easy to fabricate. We increased the number of quantum wells above the critical thickness and narrowed the active region to improve Γ/W_a. We also applied higher compressive strain in the quantum well layers to increase dg/dn. By enhancing f_r, we achieved a 106-Gbps PAM4 operation at an ER above 3.5 dB in conformity with 400GBASE-DR/FR. The TDECQ reached the values of 1.85 and 3.04 dB at temperature of 25 and 55 °C, respectively. To the best of our knowledge, these are the first results for a conventional BH-DML not using PPR and DL effects.

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