Uncooled Operation of 53-Gbaud PAM4 (106-Gb/s) EA/DFB Lasers with Extremely Low Drive Voltage with 0.9 Vpp

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Abstract Uncooled 53-Gbaud PAM4 operation of 1.3-μm electro-absorption modulator integrated DFB laser was demonstrated with 0.9 Vpp for the first time. We obtained extinction ratio of more than 4.9 dB and TDECQ of less than 2.3 dB from 20 to 85°C.

Introduction

Data traffic has been ever-increasing with the growth of social network services, cloud services and so on. Today, within Mega Data-centres that is leading optical transceiver market, number of 100 GbE ports is getting main stream for switch-fabric inter-connection. And in the near future, it is expected to move to even higher data rate such as 400 GbE to keep up with such trend. Recently, IEEE has standardized 400 GbE optical interface specifications for next generation transceivers based on 8 λ x 50-Gb/s (25-Gbaud) 4-level pulse amplitude modulation (PAM4) scheme for 2/10 km reach called 400 GBASE-FR8 and 400 GBASE-LR8. And 400 GbE transceivers such as CFP8, OSFP, and QSFP-DD that are compliant to those new specifications have been demonstrated or announced. However, 4 λ x 100-Gb/s (50-Gbaud) operation is strongly desired to reduce the size, power consumption, and complexity of optical transceivers.

Considering 50-Gbaud PAM4 operation for 100-Gb/s data transmission per lane, electro-absorption modulator-integrated distributed-feedback (EA/DFB) laser is the attractive light source because of its high bandwidth, low driving voltage, and compactness. Therefore, several valuable activities have been reported[1, 2]. To further enhance the advantage of the 100-Gb/s per lambda light source, wide temperature range operation, namely uncooled operation and low voltage driving are key technologies in terms of low power consumption and high port density[3, 4]. With uncooled operation, the thermoelectric cooler (TEC) can be eliminated, which leads to lower power consumption and enables simple packaging for a small form factor. In addition, if the driving voltage is lower than 1.0 V, there is a possibility that the EA modulator can be directly driven by CMOS output such as from digital signal processor (DSP) without external driver in between.

In this paper, we demonstrate uncooled 53-Gbaud PAM4 (106-Gb/s) operation of EA/DFB laser with low driving voltage for the first time. We have newly developed a high bandwidth 1.3-μm uncooled EA/DFB laser and successfully confirmed a 53-Gbaud PAM4 operation over a wide temperature range of from 20 to 85°C with 0.9 Vpp driving voltage. We obtained a high extinction ratio of more than 4.9 dB and a clear 53-Gbaud PAM4 eye diagram with a small transmission dispersion eye closure quaternary (TDECQ) of less than 2.3 dB from 20 to 85°C.

EA/DFB structure and design

The schematic structure of the newly developed EA/DFB laser chip is shown in Fig. 1. It consists of an InGaAsP-MQW EA modulator and DFB laser. The EA modulator is monolithically integrated into the DFB laser via an optical waveguide on an n-InP substrate by using the butt-joint technique. The EA modulator and the DFB laser were grown by MOCVD. This fabrication process allows us to optimize the EA modulator and the DFB laser individually. The mesa structure of the laser and the modulator was fabricated by dry etching, and the side of the mesa was buried with semi-insulated InP to reduce capacity. For low-reflection and high-optical output, an anti-reflection (AR) film with a reflectivity of lower than 0.1% and a high-reflection (HR) film were coated on front and rear facet, respectively.

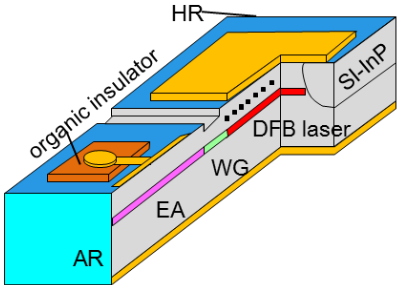

Fig. 1: Schematic view of EA/DFB laser

We applied a lumped electrode structure[3, 4], which has the advantages of a simple fabrication process and a simple electrode layout structure for assembly. To achieve uncooled 53-Gbaud PAM4 operations with low driving voltage, we designed an EA modulator by using an in-house EA modulator simulator and optimized the p-i-n structure to enhance the electric field on the EA-MQW. And we designed the modulator length from point of having enough extinction ratio at low temperature with driving voltage of less than 1.0 Vpp.

The optical output power needs to be considered as well, because there is trade-off relationship between the optical output power and the extinction ratio which has dependence on the operating temperature. Therefore, the detuning between the lasing wavelength and photoluminescence wavelength was adjusted to make it suitable for uncooled operation.

Moreover, the low TDECQ, which is an eye quality assessment in PAM4 operations[5], is also important parameter. It has been reported that higher bandwidth light source enables a lower TDECQ[6]. Therefore, we additionally fabricate an organic insulator under the p-electrode pad to reduce the parasitic capacitance by around 10%.

Static characteristics

The temperature dependencies of static characteristics of the fabricated EA/DFB laser are shown in Fig. 2. The chip was die-bonded on a carrier for temperature control by using TEC. Fig. 2(a) shows the light-current characteristics. The optical output power which includes the absorption loss of the EA modulator at non-bias is 24, 13, 7, 3 mW at 20, 50, 70, and 85°C, respectively. The measured optical spectra are shown in Fig. 2(b). The stable single-mode operations were confirmed with a high side mode suppression ratio (SMSR) of more than 40 dB over a temperature from 20 to 85°C. Fig. 2(c) shows the static extinction ratio characteristics of the EA modulator. The solid and dashed lines show the measured and simulated curve, respectively. The simulation was conducted by using the in-house simulator which considering the precise energy band structure[4]. The measured extinction ratio is in good agreement with simulated one. By carefully optimizing the MQW design and modulator length, we were able to obtain a high extinction ratio of over 13 dB even at 20°C at EA bias of -2.5 V while maintaining high linearity. Thus, possibility to achieve high extinction ratio with low voltage drive at low temperature was demonstrated.

Fig. 3 shows the E/O response (S21) at 50°C at an EA bias of -1.0 V and with an operating current of 100 mA. The measured 3-dB down frequency bandwidth was 42 GHz, which is sufficient bandwidth for 53-Gbaud modulation. This high bandwidth performance is due to the optimized design of the EA modulator and low parasitic capacitance structure.

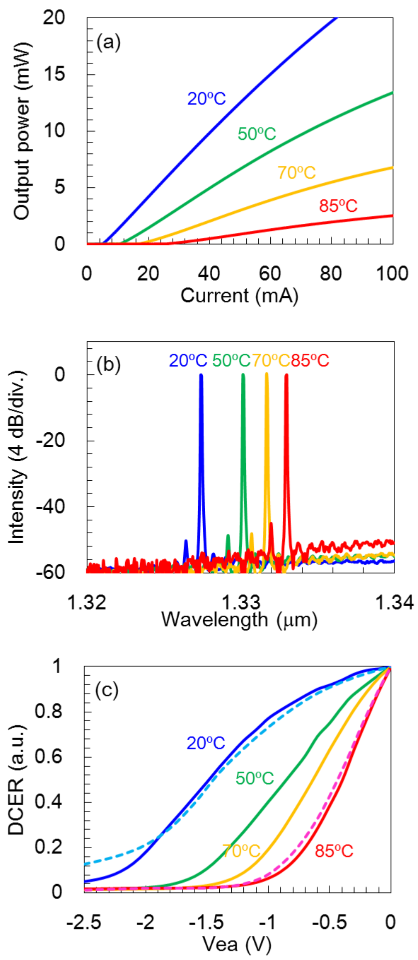

Fig. 2: Static characteristics from 20 to 85°C of fabricated EA/DFB. (a) LI curve, (b) optical spectra, (c) static extinction ratio. Solid and dashed lines are measured and simulated curves, respectively.

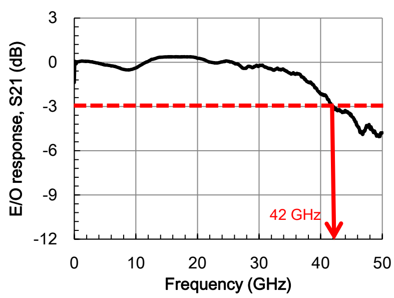

Fig. 3: E/O response (S21) at 50°C, EA bias of -1.0 V and operating current of 100 mA

Experimental setup for PAM4 operation

Fig. 4 shows a schematic of the experimental setup for uncooled 53-Gbaud PAM4 operation. To generate the 53Gbaud PAM4 driving signal, we used an arbitrary waveform generator (AWG) and set it to 53-Gb/s 2^{15}-1 pseudo-random bit sequences (PRBSs) with de-emphasis (4 tap). The electrical signal from the

AWG was amplified by using a linear driver with a bandwidth of >67 GHz to obtain enough driving voltage. The maximum output signal amplitude from linear driver was around 1.2 Vpp after being de-embedded. Then, the DC bias voltage to the EA modulator was applied through a bias tee. The driving voltage of the EA modulator was set to be 0.9 Vpp in all temperatures to explore the possibilities for direct operation of CMOS without the driver. The driving voltage of each level of PAM4 was set to be the same voltage in spite of the nonlinear extinction performance of the EA modulator. In the experiment, the temperature of the EA/DFB bonded to the carrier was changed from 20 to 85°C using TEC. The operating current of the DFB laser was fixed to 100 mA. The optical output of the EA/DFB was detected by a digital communication analyser (DCA). The conditions obtaining the TDECQ are compliant with what is defined in the IEEE standarization[7] except for the test pattern.

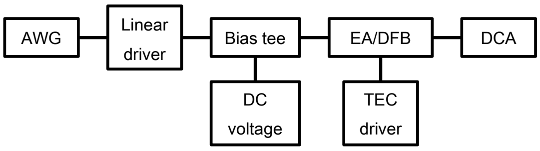

Fig. 4: Experimental set up for uncooled 53-Gbaud (106-Gb/s) PAM4 operation.

Experimental results of PAM4 modulation

Fig. 5 shows the PAM4 optical eye diagrams of the uncooled 53-Gbaud operation with and without equlizer of 5 tap. The extinction ratio at each temperature was set to around 5 dB by adjusting the bias voltage. As shown in the figure, excellent eye openings with TDECQ of less than 1.9 dB were obtained from 20 to 70°C. Even at a temperature of 85°C, TDECQ was 2.3 dB, which can meet the requirement in IEEE specification[7] of 3.4 dB. No significant difference was observed between the PAM4 eye with equalizer and that without equalizer from 20 to 85°C, as shown in Fig. 5. This indicates that the signal processing of Rx DSP might be reduced in the receiver side, which leads to the low power consumption operation.

The average power of the chip facet was over +5 dBm from 20 to 70°C. These results shows that our uncooled EA/DFB can be applicable for the 400 GbE transvers in practical use.

Conclusion

We newly developed a high bandwidth 1.3-μm uncooled EA/DFB laser and demonstrated uncooled 53-Gbaud PAM4 operation from 20 to 85°C with a low driving voltage of 0.9 Vpp for the fist time. A high extinction ratio of more than 4.9 dB and a TDECQ lower than 2.3 dB were obtained from 20 to 85°C. These results are promising to realize low power consumption 400 GbE transceivers for high port density switch application in data centres.

References

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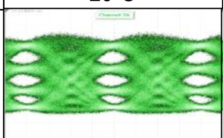
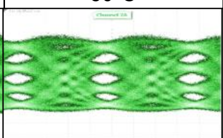
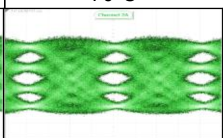
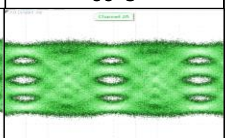
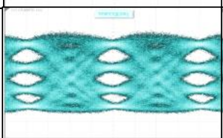
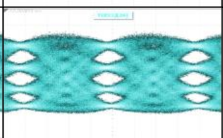
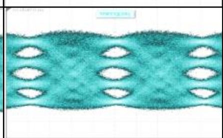
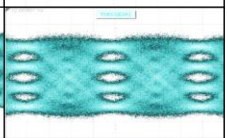
53-Gbaud PAM4	20°C	50°C	70°C	85°C
Without equalizer				
With equalizer (5 tap)				
Extinction ratio (dB)	4.9	5.7	5.6	6.7
TDECQ (dB)	1.9	1.6	1.7	2.3

Fig. 5: Optical eye diagrams of 53-Gbaud (106-Gb/s) operation with and without equalizer (5 tap). Measurement temperatures are 20, 50, 70, and 85°C.