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106GBaud (200G PAM4) CWDM EML for 800G/1.6T Optical Networks and AI Applications

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Abstract:

We report ultrahigh speed 106GBaud (200G PAM4) electro-absorption modulated laser (EML) for 800G and 1.6T optical transmission. Four CWDM EMLs of 1271, 1291, 1311 and 1331nm in 800G FR4 optical transceivers show clear eye diagram after 2km. Our 106GBaud EMLs show high bandwidth, high extinction ratio, low threshold current and high power, making it a suitable source laser for 800G/1.6T and AI applications.

Keywords: *Artificial intelligence 1, AI 2, electro-absorption modulated laser 3, EML 4, 800G optical network 5, 1.6T optical network 6, datacenter 7, cloud computing 8.*

Introduction

The advent of 800G and 1.6T optical networks marks a monumental leap in the fields of artificial intelligence (AI), data centers, and cloud computing (Kozlov, 2023; Lock, 2022; Fibermall, 2023). These cutting-edge technologies are the backbones of the modern digital infrastructure, enabling lightning-fast data transmission and processing. 800G optics empower AI applications with rapid access to vast datacenters, accelerating machine learning algorithms and real-time decision-making. On the other hand, the emergence of 1.6T networks takes this prowess another step further, providing even greater bandwidth for handling colossal workloads. Together, 800G and 1.6T optical networks are the catalysts to accelerate the future applications of AI, data centers, and cloud computing and offer unprecedented speed, scalability, and efficiency.

To empower 800G and 1.6T optical communications, an ultrahigh speed diode laser with ever-expanding bandwidth capacity becomes necessary. EML is a good candidate of such diode lasers because it possesses many performance advantages over directly modulated laser (DML), silicon photonics (SiPh) and vertical cavity surface emitting laser (VCSEL) (Takemi, 2022; Okuda et al., 2021; Honda et al., 2023; Huang et al., 2017). Figure 1 illustrates the roadmap of high-speed EML devices whereas the demand is driven by datacenter (DC) and AI waves. The progression from 28GBaud to 106GBaud EML is meeting up the computing capacity requirement of the optical communication network. For example, four lasers of 28GBaud EML can enable the data rate of 100Gb/s in the 100G LR4 optical transceiver. On the other hand. 53GBaud EML coupled with PAM4 can empower 400G DR4 and FR4 optical modules.

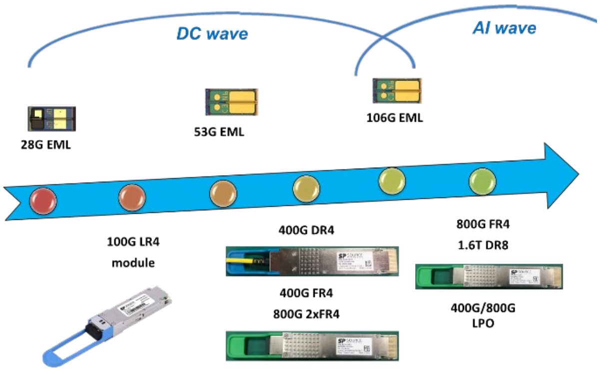

Figure 1. Roadmap of High-Speed EML Devices for Different Generations of Optical Transceivers (100G, 400G, 800G & 1.6T). The Recent AI Wave is Propelling the Demand for 800G Optical Networks Due to the Enormous Data Processing Requirements and the Expansion of AI Applications Across Industries

106GBaud EML provides the core capability of 800G and 1.6T optical transceivers (Uchiyama et al., 2023; Bhaske et al., 2023; Nishimura et al., 2023). By using 4-level pulse-amplitude modulation (PAM4), the data rate can double from the traditional 2-state non-return-to-zero (NRZ) modulation. As a result, 106GBaud PAM-4 EML can transmit 200Gb/s per lane. The 200G/lane optics can thereby realize 800G and 1.6T by incorporating only four and eight of 106GBaud EMLs in the optical modules (Huang et al., 2023).

In this paper, we report high-performance 106GBaud (200G PAM4) EMLs that provide cost-effective solutions to 800G and 1.6T optical transceivers. Our 106GBaud EMLs can achieve high bandwidth, high ER, low threshold current, and high power that can make 800G and 1.6T optics economically feasible. For the same functionality, the 106GBaud EML also helps reduce the power consumption and budget of the optical transceiver since the number of lasers becomes half when compared with 53GBaud EML.

Materials and Methods

Figure 2 shows the 3-D schematic of a 106GBaud EML device structure where the front section of the EML device is the electro-absorption modulator (EAM) for RF modulation, and the rear section is the distributed feedback laser diode (DFB-LD) for DC bias. The LD and EAM were joined by using metal organic chemical vapor deposition (MOCVD) butt-joint (BJ) technology (Huang et al., 2016). The active region was comprised of quaternary InGaAsP multi-quantum well (MQW) and separate confinement (SCH) layers. Under the EAM bondpad, a low-k polyimide was deposited to reduce the capacitance. The top oxide layer was deposited for surface passivation. Ti/Pt/Au metallization was used as the p-contact to achieve low contact resistance and robust reliability (Huang & Vartuli, 2003).

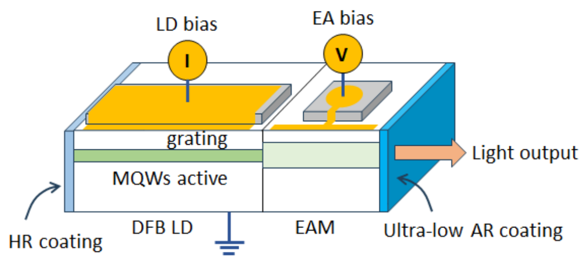

Figure 2. 3-D Schematic Device Structure of 106GBaud EML. The Front EAM Pad is for RF Modulation, and the Rear DFB Laser is for DC Bias

To minimize optical reflection, the front facet of EML is coated with antireflective coating (AR) by ion beam sputtering (IBS) to achieve both ultra-low reflectivity and self-hermetic film quality. The EML chip was attached to Si submount before direct current (DC) and RF test characterization. The LD section was biased with DC current from 0 to 150mA. Upon constant LD bias, the EAM section was tested with a reverse voltage ranging from 0 to -3V. Based on the plot of fiber power versus EAM voltage, extinction ratio (ER) can be extracted based on the ON and OFF states. The peak-to-peak voltage swing between the ON and OFF states was 1V.

Results

Figure 3 shows the light versus current (LI) curve of a 106GBaud EML device where the modulator was not biased at 53°C. The threshold current (I_{th}) taken from the LI was about 17mA, and the optical power was about 16mW at 60mA. The LI showed good linearity with small rollover, and the power reached 33mW at 120mA. When the modulator was set at 0V, there was very little light absorption from the modulator section. So, the output power of the laser section was fully collected by the LI measured from the front facet of the EAM.

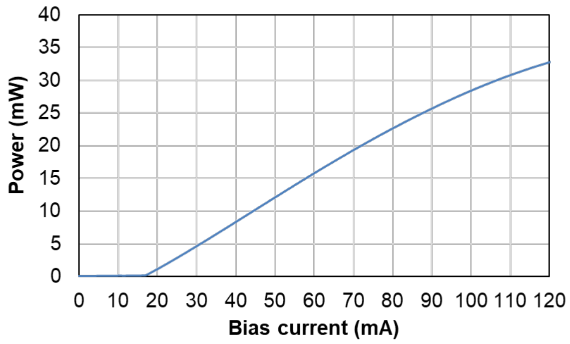

Figure 3. LI Curve of the 106GBaud EML Device at 53°C. The Output Power was Measured with no Bias to the EAM Section (V_{EA}=0V).

Figure 4 shows the output power curve of a 106GBaud EML device as a function of EAM voltage where the LD bias was tested at 53°C, 50mA. As the EAM section was subjected to reverse bias, light absorption by the EA modulator started to occur. The light absorption from the modulator increased with increasing reverse voltage. As the magnitude of reverse voltage became larger, the power decreased due to larger light absorption. The ER was proportional to the slope shown in the box during the voltage swing. For example, the voltage swing at 1.0V where the V_{ON} and V_{OFF} are 0.5V and 1.5V, respectively. Using the same method, we can extract ER value at different EAM voltages to compile a full ER curve.

Figure 5 shows the typical optical spectra of 106GBaud EMLs of coarse wavelength division multiplexing (CWDM). Each EML lane exhibits excellent single-mode DFB performance with the side-mode-suppression-ratio (SMSR) over 50dB. The SMSR measures the main peak to sub-peak ratio. To meet IEEE802.3 specifications, 800G FR4 uses center wavelengths of 1271, 1291, 1311 and 1331nm for CWDM channels (L0, L1, L2 and L3, respectively) (Welch, 2023; Wang, 2023). 800G DR4 uses eight EMLs with a center wavelength of 1311nm.

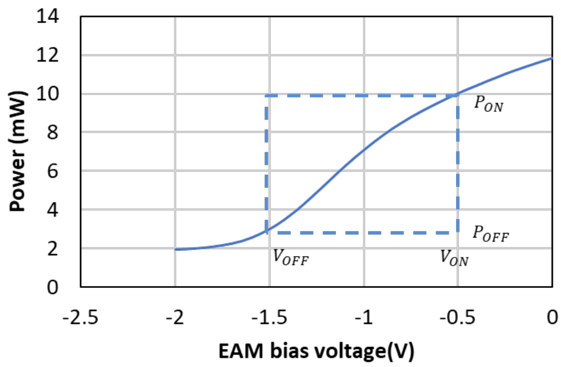

Figure 4. Fiber-Coupled Power Curve of the 106GBaud EML Device as a Function of the EAM Reverse Voltage where the LD Section was Biased at 53°C, 50mA. The ER Can be Extracted from the EA Absorption Curve. The Voltage Swing between ON and OFF States are Indicated

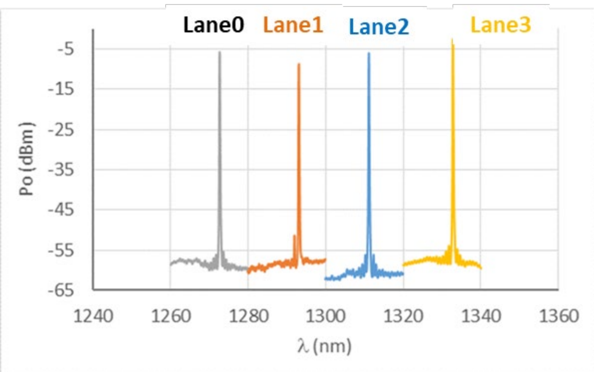

Figure 5. The Optical Spectra of 106GBaud CWDM EML Devices for 800G FR4 Transmission. Each Lane Shows Excellent Single-Mode DFB Performance with SMSR (Main Peak to Sub-Peak Ratio) over 50dB

Figure 6 shows the electrical-optical frequency response plot of 106GBaud EML. The 3dB bandwidth reached about 65-67 GHz, well above the specification of 60 GHz. The ultra-low AR (with residual reflectivity<10^{-4}) also helped achieve good S21 flatness.

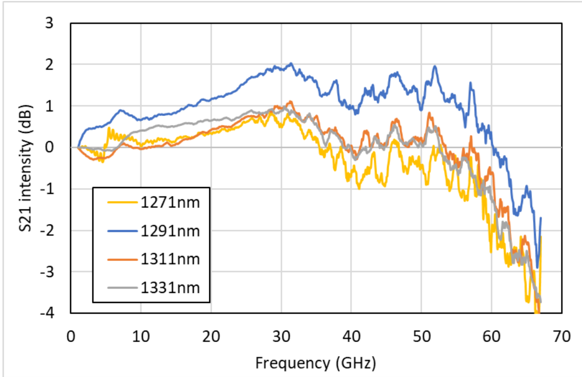

Figure 6. Frequency Response Curve of the 106GBaud EML Device Showing High 3dB Bandwidth and Good S21 Flatness

Figure 7. The Eye Pattern of 200G PAM4 EML in 800G Optical Transceiver. Clear Eye Opening and Good TDECQ are Demonstrated

Figure 7 shows the PAM4 eye pattern of 800G optical transceiver. The 106GBaud EML chips show excellent eye opening in the 800G transceiver where the transmitter dispersion eye closure quaternary (TDECQ) values are around 1.7 and 2.4dB at modulation rates of 106GBaud and 113GBaud. TDECQ is an important index to evaluate the optical transmission quality of PAM4 (King, 2016; Fibermall, 2023). The typical target of TDECQ is ≤3.9dB. Table I shows the ER and TDECQ of the 106GBaud EMLs in the 800G optical transceivers. The 106GBaud EML can meet both TDECQ and ER targets for 800G optical transceivers.

Table 1. ER and TDECQ of the 106GBaud EMLs in 800G Optical Transceivers

Modulation speed	ER (target≥3.5dB)	TDECQ (target≤3.9dB)
106GBaud (212 Gb/s PAM4)	4.6 dB	1.7dB
113GBaud (226 Gb/s PAM4)	4.6 dB	2.4 dB

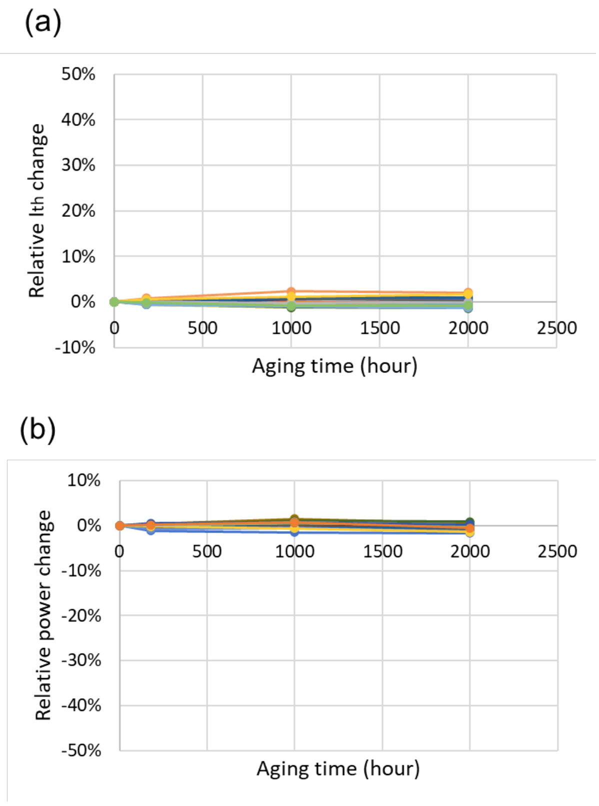

Figure 8. Aging Plots of 106GBaud EMLs Based on the Stress Condition of 85°C, 85mA. The Relative Changes of (a) Threshold Current and (b) Optical Power are Small After 2000hr Aging

Figure 8 shows the long-term aging plot of 106GBaud EML chips where the aging condition was 85°C, 85mA. Both threshold current and optical power showed very little change after 2000hr aging. Since no failure occurred, we estimated the device lifetimes by sublinear fit on the aging curves. Using the end-of-life criterion of 20% change in power, the mean-time-to-failure (MTTF) of the 106GBaud EML in the 53°C operating condition is about 1845 years, representing great reliability margin for the 20-year guarantee life per Telcordia. The wear-out failure rate is projected to be around 8 FITs, substantially less than the requirement of 200 FITs.

Conclusion

We have manufactured ultra-high speed 106GBaud (200G PAM4) EML for 800G optical transmission. An extinction ratio of >4.6dB and TDECQ of <2.4dB have been achieved. The high-speed, high power 106GBaud EML can meet the stringent performance and reliability requirements of 800G AI supercomputing. The 106GBaud EML lasers of CWDM (1271, 1291, 1311 and 1331nm) can support 800G FR4 with clear eye diagrams after 2km, making it extendable to 1.6T applications.

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Conflict of interests

No conflict of interest.

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