4 x 200 Gb/s EML-Array with a Single MQW Layer Stack

M. Theurer[(1)], C. Kottke[(1)], R. Freund[(1, 2)], F. Ganzer[(1)], P. Runge[(1)], M. Moehrle[(1)], U. Troppenz[(1)], A. Sigmund[(1)], and M. Schell[(1, 2)]

[(1)] *Fraunhofer Heinrich-Hertz-Institute, Einsteinufer 37, D-10587 Berlin, Germany*
michael.theurer@hhi.fraunhofer.de
[(2)] *Technical University Berlin, D-10587 Berlin, Germany*

Abstract: We demonstrate an EML-array for up to 4x200 Gb/s PAM4 modulation at 45°C. Its single MQW layer stack design allows for low-cost fabrication. The device is optimized for equal performance over four LAN-WDM wavelength channels.

1. Introduction

With digitalization in almost all areas of life, global data traffic is constantly increasing. The biggest share of this data traffic is transmitted within datacenters over relatively small distances up to only a few kilometers. Here, the electro-absorption modulated laser (EML) has proven to be an ideal candidate as compact high-speed transmitter. EMLs have a small footprint, high extinction ratio and can be modulated at high-speed with low chirp [1, 2]. They can be fabricated as arrays, allowing for small footprint transmitter modules with reduced packaging costs [3]. A further cost reduction can be achieved by using a single MQW layer stack design, thus keeping manufacturing simple. This has already been demonstrated for EML-arrays with multiple wavelength channels, ranging over a span of up to 7.5 nm with up to 56 Gb/s per channel [4, 5]. In this paper, we demonstrate a single MQW layer stack based EML-array that addresses four wavelength channels in the LAN-WDM grid (13.6 nm span) with up to 200 Gb/s per channel for fiber transmission up to 10 km.

2. Device Structure

The device comprises four EMLs in an array (c.f. left in Figure 1) with each EML operating at a different wavelength in the LAN-WDM grid (c.f. right in Figure 1). Light is generated by 350 µm long distributed feedback (DFB) lasers with index coupled grating with λ/4 phase shift, resulting in a high side mode suppression ratio >45 dB (c.f. right in Figure 1). The DFB back facets are anti-reflection (AR) coated for a high single mode yield, which is essential for arrays. The forward output light of the DFB lasers is modulated by electroabsorption modulator (EAM) sections with ground-signal-ground (GSG) contacts. The GSG contacts are routed via transmission lines to the backside of the array to allow easy access for packaging. The length of each EAM section is gradually increased from 80 µm to 110 µm for the shortest to the longest wavelength channel, respectively. This achieves equal extinction ratio and optical modulation bandwidth over the full wavelength range. Semiconductor optical amplifiers (SOA) with lengths of 170 µm down to 140 µm are integrated at each EML to boost the output power. The waveguide at the front facets is tilted and anti-reflection coated to mitigate back reflection into the laser. The device is fabricated with a simple ridge waveguide structure. A single InGaAlAs based multi quantum well (MQW) layer stack is used, further simplifying the fabrication.

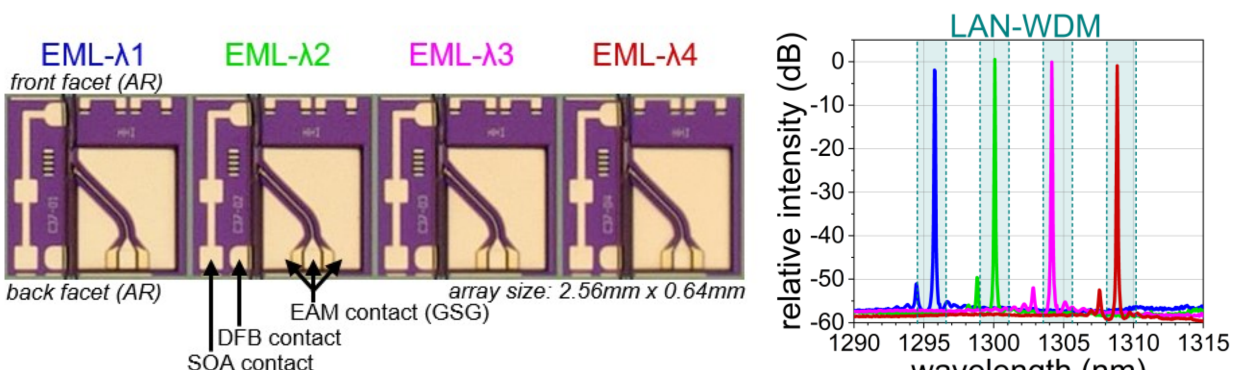

Fig. 1. Top view photograph of the fabricated EML-array (left) and corresponding optical spectra of each EML in the array (right). I_{DFB} = 100 mA, I_{SOA} = 40 mA, T = 45°C.

3. Experimental Results

For experimental characterization, the EML-array is mounted on a temperature-controlled heatsink fixed at 45°C. Figure 2 (a) shows the optical output power ex-facet versus the DFB current for each EML. The threshold current increases from 30 mA to 56 mA for EML-λ1 to EML-λ4, respectively. This is expected as the EMLs with longer wavelengths have DFBs with a larger detuning to the MQW layer stacks gain maximum. An equal output power of 12.3 dBm is achieved by choosing DFB/SOA currents of 80mA/40mA, 80mA/40mA, 100mA/40mA and 100mA/60mA for EML-λ1, EML-λ2, EML-λ3 and EML-λ4, respectively (indicated by dotted line in Figure 2 (a)). This current setting will be used for all further experiments.

The different wavelength detuning to the MQW layer stacks absorption peak for each EML in the array usually leads to different performance regarding extinction ratio and modulation speed. Typically, a longer wavelength (i.e. larger detuning) leads to lower extinction ratio but higher speed. In this design, we carefully adapted the EAM length to counter this behavior. By choosing a longer EAM section for the larger wavelengths, an equal extinction ratio of up to 15 dB is achieved for all four channels (c.f. Figure 2 (b)). The bias voltage at operation point ranges from -1.1 V to -1.7 V for EML-λ1 to EML-λ4, respectively. The frequency response measured with an RF-probe with integrated 50 Ω matching resistor is shown in Figure 2 (c). An identical response with a 3dB bandwidth >42 GHz is achieved for all four EML in the array.

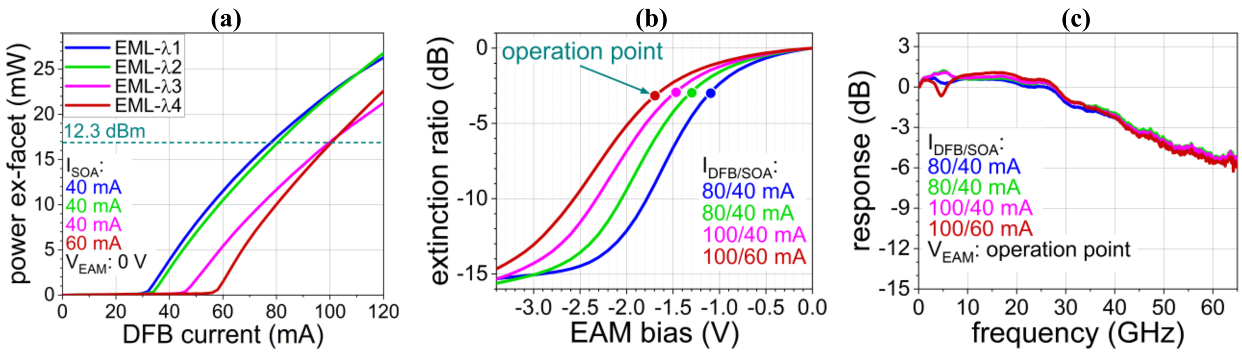

Fig. 2. Measured ex-facet output power versus DFB current (a), static extinction ratio versus EAM bias (b) and small signal frequency response (c) for all EMLs in the array. T = 45°C.

Next, we tested the EML-array performance for high baud rate PAM4 data transmission. The electrical PAM4 signal was generated by an interleaved operated AWG at 256 GS/s (Keysight M8199A) and amplified by two electrical amplifiers (Keysight M8158A, SHF M827B). The second amplifier also functioned as bias-T to add the DC-bias voltage to the amplifier output. The output was connected to the individual EMLs with an RF-probe with integrated 50 Ω matching resistor. The EML output light was coupled to a lensed fiber, which was connected to an optical amplifier (EDFA), a variable attenuator and a photodiode (in-house 50 GHz design). The EDFA and variable attenuator were used to control the optical power at the photodiode. The electrical output of the photodiode was amplified (SHF M804) and measured with a 256 GS/s oscilloscope (Keysight UXR0704AP). Digital signal processing was applied consisting of a root-raised cosine pulse shaping at the Tx and Rx side (roll-off factor 0.1) and a linear equalization at symbol rate at the Rx side.

The bit error rate (BER) versus the received optical power, measured for all four EMLs individually, is shown at the top of Figure 3. For reference, the 7% FEC threshold (BER = $3.8\text{x}10^{-3}$) is marked with a dashed line. All four EMLs show nearly identical performance, which can be attributed to the well balanced extinction ratio and modulation speed (c.f. Figure 2 (b) & (c)). At 100 GBd PAM4, a BER below the 7% FEC limit is achieved for a received optical power of around 1 dBm for all four LAN-WDM channels, thus demonstrating each EMLs capability to operate at 200 GB/s. The measured average optical output power ex-facet at 100 GBd PAM4 was 9.5 dBm, 9.5 dBm, 9.5 dBm and 9.1 dBm for EML-λ1, EML-λ2, EML-λ3 and EML-λ4, respectively. The measured optical eyes at 100 GBd PAM4 with 6 dBm received optical power are shown at the bottom in Figure 3 for reference.

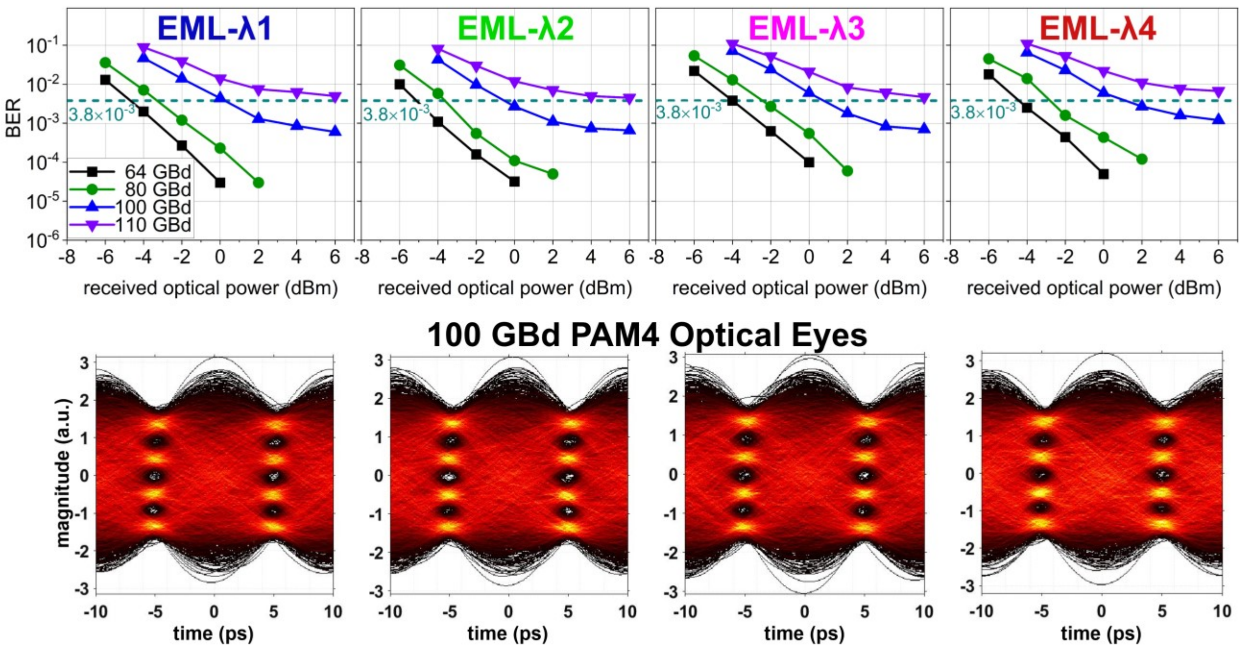

Fig. 3. Measured back-to-back BER for PAM4 modulation at different baud rates (top) and received optical eyes for 100 GBd PAM4 modulation at 6 dBm received optical power (bottom). $I_{DFB\text{-}\lambda1} = I_{DFB\text{-}\lambda2} = 80$ mA, $I_{DFB\text{-}\lambda3} = I_{DFB\text{-}\lambda4} = 100$ mA, $I_{SOA\text{-}\lambda1} = I_{SOA\text{-}\lambda2} = I_{SOA\text{-}\lambda3} = 40$ mA, $I_{SOA\text{-}\lambda4} = 60$ mA, $V_{EAM\text{-}\lambda1} = -1.1$ V, $V_{EAM\text{-}\lambda2} = -1.3$ V, $V_{EAM\text{-}\lambda3} = -1.4$ V, $V_{EAM\text{-}\lambda4} = -1.7$ V, $V_{pp\_EAM\text{-}\lambda1\_100GBd} = V_{pp\_EAM\text{-}\lambda2\_100GBd} = V_{pp\_EAM\text{-}\lambda3\_100GBd} = V_{pp\_EAM\text{-}\lambda4\_100GBd} = 0.6$ V, T = 45°C.

In a further experiment, we measured the BER after fiber transmission for 100 GBd PAM4 modulation. A standard single mode fiber with a length up to 20 km was inserted between the EDFA and the variable attenuator in the setup. A BER below the 7% FEC limit was achieved with all four EMLs for fiber lengths up to 10 km. After 20 km fiber transmission the BER is above the 7% FEC limit, increasing with short emitting wavelength of the DFB. This is in accordance to the expected lower dispersion tolerance for EMLs with wavelengths further away from the zero dispersion wavelength of 1310 nm for SMF fibers.

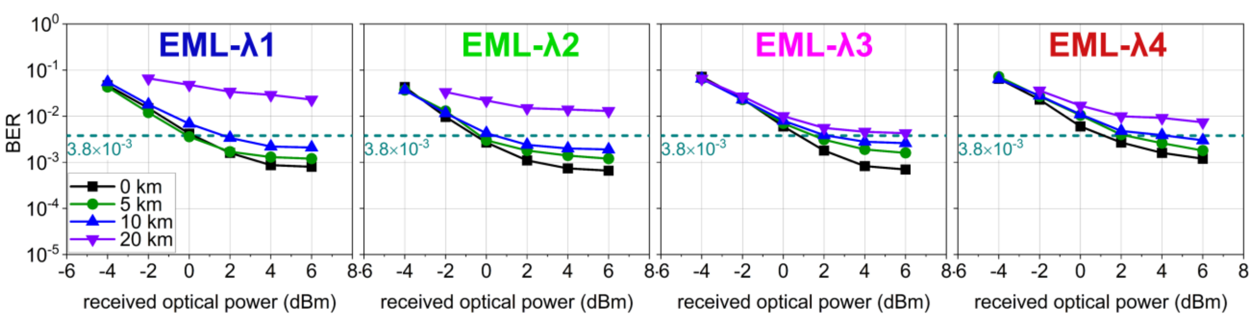

Fig. 4. Measured BER for 100 GBd PAM4 modulation transmitted over different fiber length. $I_{DFB\text{-}\lambda1} = I_{DFB\text{-}\lambda2} = 80$ mA, $I_{DFB\text{-}\lambda3} = I_{DFB\text{-}\lambda4} = 100$ mA, $I_{SOA\text{-}\lambda1} = I_{SOA\text{-}\lambda2} = I_{SOA\text{-}\lambda3} = 40$ mA, $I_{SOA\text{-}\lambda4} = 60$ mA, $V_{EAM\text{-}\lambda1} = -1.1$ V, $V_{EAM\text{-}\lambda2} = -1.3$ V, $V_{EAM\text{-}\lambda3} = -1.4$ V, $V_{EAM\text{-}\lambda4} = -1.7$ V, $V_{pp\_EAM\text{-}\lambda1\_100GBd} = V_{pp\_EAM\text{-}\lambda2\_100GBd} = V_{pp\_EAM\text{-}\lambda3\_100GBd} = V_{pp\_EAM\text{-}\lambda4\_100GBd} = 0.6$ V, T = 45°C.

4. Conclusion

We demonstrated for the first time 4 x 200 Gb/s PAM4 fiber transmission up to 10 km for an O-band EML-array with single MQW layer stack. The array operates in the LAN-WDM grid and is optimized for equal performance over all four wavelength channels. A high extinction ratio, a modulation bandwidth >42 GHz and an averaged modulated output power ex-facet >9 dBm is achieved for all wavelength channels. The device is promising candidate as a compact and cost efficient 800 Gb/s transmitter for terabit data links.

5. Acknowledgement

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 871769 (POETICS) & 825502 (TERIPHIC)

Funded by the European Union

6. References

[1] H. Asakura et al., “384-Gb/s/lane PAM8 Operation Using 76-GHz Bandwidth EA-DFB Laser at 50°C with 1.0-Vpp Swing over 2-km Transmission,” in 2022 Optical Fiber Communications Conference (OFC), Mar. 2022, Th4C.4.

[2] S. Kanazawa et al., “Transmission of 214-Gbit/s 4-PAM signal using an ultra-broadband lumped-electrode EADFB laser module,” in 2016 Optical Fiber Communications Conference and Exhibition (OFC), Mar. 2016, Th5B.3.

[3] S. Kanazawa et al., “High-Speed (400 Gb/s) Eight-Channel EADFB Laser Array Module Using Flip-Chip Interconnection Technique,” IEEE Journal of Selected Topics in Quantum Electronics, vol. 21, no. 6, pp. 183–188, Nov. 2015.

[4] S. Yang et al., “Gain-Coupled 4 × 25 Gb/s EML Array Based on an Identical Epitaxial Layer Integration Scheme,” IEEE J. Select. Topics Quantum Electron., vol. 25, no. 6, pp. 1–6, Nov. 2019.

[5] M. Theurer et al., “4 x 56 Gb/s High Output Power Electroabsorption Modulated Laser Array With up to 7 km Fiber Transmission in L-Band,” Journal of Lightwave Technology, vol. 36, no. 2, pp. 181–186, Jan. 2018.