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# 200 Gb/s Uncooled EML with Single MQW Layer Stack Design

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**Abstract** *We demonstrate an EML for 200 Gb/s PAM4 modulation at uncooled conditions. The device has an identical MQW layer stack for the DFB, EAM and SOA section, which allows a simple fabrication process. The EML is designed for balanced performance from 20°C to 85°C. ©2022 The Authors*

## Introduction

The continuous increase of global data traffic generates a constant demand for development of next generation optical transmitter chips. The demand is particularly strong in data centres where enormous amounts of data need to be transmitted over short distances of up to few kilometres. The electro-absorption modulated laser (EML) has proven to be an ideal candidate as compact transmitter chip for this application scenario. It relies on simple amplitude modulation formats, can operate at extremely high speed, and has a high extinction ratio and low chirp [1-3]. With increasing data traffic, the electrical power efficiency becomes most important for data centres. Power consumption can be significantly reduced by uncooled transmitters as they do not require power for active cooling. Uncooled operation is possible for EMLs but challenging as its output power, extinction ratio and speed typically strongly depend on temperature. It has been recently shown in [4] that with careful design EMLs can operate in uncooled conditions up to 224 Gb/s. The EML shown by in [4] relies on a buried waveguide structure with separate active (multi-quantum well) MQW layer stacks, which requires complex fabrication with multiple regrowth steps.

In this paper we demonstrate a ridge waveguide based EML with a single active MQW layer stack for uncooled operation up to 200 Gb/s. Due to its simple fabrication process, the device is a promising candidate for cost and power efficient high-speed transmitter chips.

## Device Structure

Figure 1 shows the fabricated device (top) and a schematic cross section alongside the optical waveguide (bottom). The device consists of a 350 µm long distributed feedback (DFB) laser, an 80 µm long electro-absorption modulator (EAM), and a 150 µm long semiconductor optical amplifier (SOA) section, all with a ridge waveguide structure. The sections are monolithically integrated with an identical InGaAlAs MQW layer stack for all sections (c.f. Fig. 1 bottom). Since no extra regrowth steps are required, the fabrication complexity of the demonstrated EML is comparable to that of a simple directly modulated laser (DML). Additionally, the coupling losses between the sections are minimal. The use of InGaAlAs as active material allows for efficient laser operation at elevated temperatures. The compositions of the active layer were carefully adjusted to allow for all three sections (DFB, EAM and SOA) to operate well under uncooled conditions (20°C-85°C). The DFB laser has an index coupled grating with λ/4 phase shift and anti-reflection coated back facet. Hereby, a high single mode yield exceeding 98% was achieved. The grating period was chosen for lasing operation at a wavelength close to 1310 nm. The EAM section has an RF contact pad with a ground-signal-ground configuration. The size of the signal pad is minimized to reduce parasitic capacitance. Towards the front facet, the light is amplified by the integrated SOA. The output waveguide is

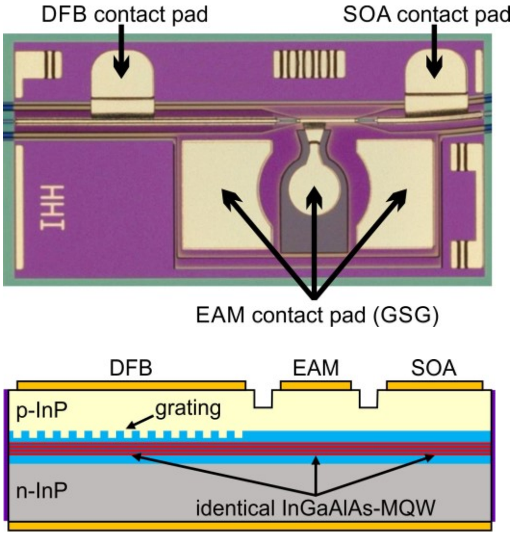

**Fig. 1:** Microscopic top view of the fabricated EML (top) and schematic cross section alongside the optical waveguide (bottom).

tilted and anti-reflection coated to mitigate optical back reflection into the laser. All sections share the same ground n-contact. The p-contacts are separated with etched isolation grooves providing isolation resistances exceeding 100 kΩ (c.f. Figure 1 bottom).

## Experimental Results

The experimental characterisation was carried out with the bare chip mounted onto a submount on a temperature controlled heatsink.

Figure 2 shows the optical output power for 20°C to 85°C measured with an integrating sphere. The threshold current varies from 55 mA to 25 mA with the lowest threshold current at the highest temperature. This behaviour is typical for EML with a single MQW layer stack, as the DFB operates on the longer wavelength side of the gain spectrum. Due to the change of threshold current, a similar output power is achieved over a wide temperature range. By adjusting the SOA current for each temperature, an identical output power can be realized for 20°C to 85°C as it is exemplarily demonstrated for 8.5 mW at 90 mA DFB current in Figure 2.

For 20°C to 85°C the optical wavelength varies from 1304.1 nm to 1311.6 nm. The high side mode suppression ratio (SMSR) >40 dB is maintained over the entire temperature range (c.f. Figure 3).

Figure 4 and Figure 5 illustrate the dependence of extinction ratio (ER) and frequency response with temperature. At low temperatures the extinction ratio is low (c.f. Figure 4) and the 3 dB bandwidth is high (c.f. Figure 5). At high temperatures it is vice versa. In our design, an optimum balance between ER and frequency response was targeted, which will allow for high speed modulation over the full temperature range. From 20°C to 85°C the typical EAM operation point biases (c.f. circles in Figure 4) vary from -2.2 V to -0.7 V. The corresponding slope of the ER curve varies from 3.2 dB/V to 6.6 dB/V, respectively. Figure 5 shows the measured frequency response with the EAM bias set to the corresponding operation point. The 3 dB bandwidth varies from >67 GHz at 20°C to 34 GHz at 85°C.

Next, we tested the device performance for high-speed PAM4 modulation over the full temperature range by measuring the back-to-back bit error rate (BER) at different baud rates. The electrical transmitter setup consisted of an interleaved operated AWG at 256 GS/s (Keysight M8199A), two amplifiers to boost the signal to the required EML driving level (Keysight M8158A, SHF M827B) with the latter also functioning as a bias-T, and a RF-probe with integrated 50 Ω matching resistor to contact the EML chip (DUT) (c.f. Figure 6). The optical signal

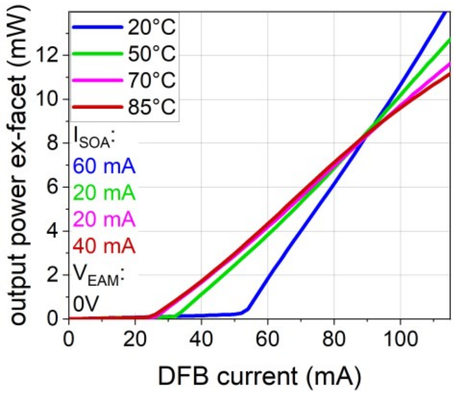

**Fig. 2:** Optical output power ex-facet vs. DFB current.

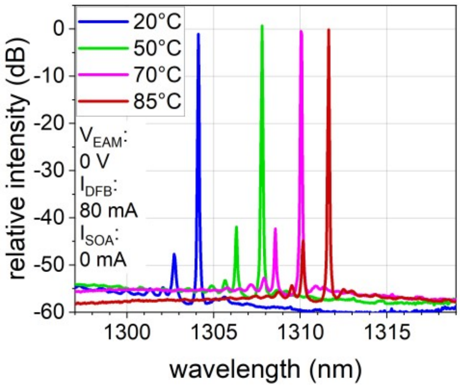

**Fig. 3:** Optical spectra.

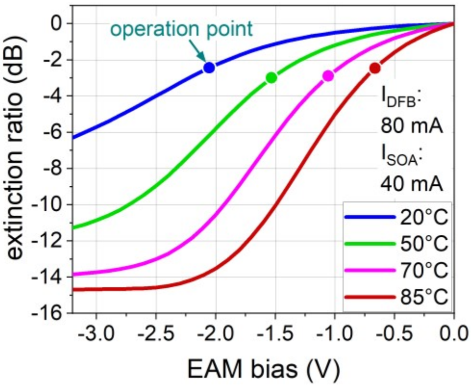

**Fig. 4:** Static extinction ratio vs. EAM bias.

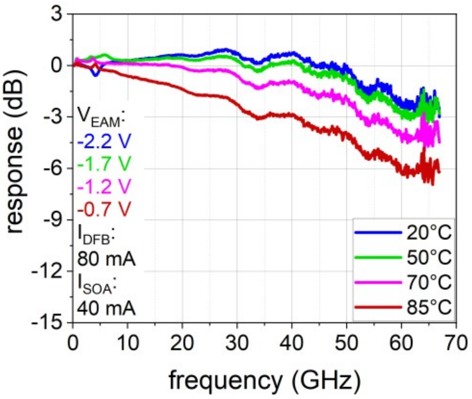

**Fig. 5:** E/O frequency response.

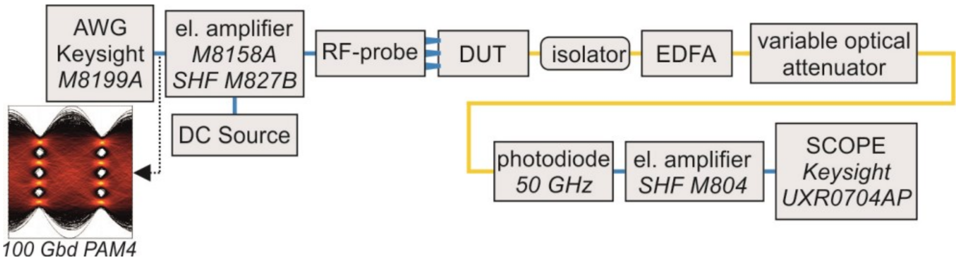

**Fig. 6:** Experimental Setup for PAM4 modulation.

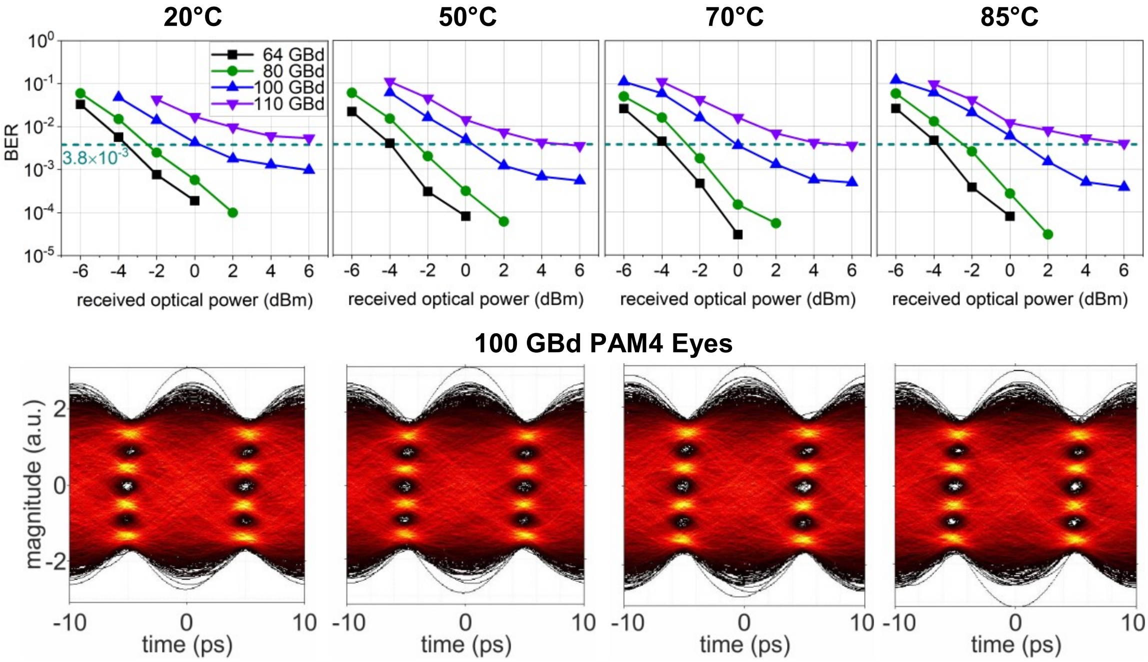

**Fig. 7:** Back-to-back bit error rate for PAM4 modulation at different baud rates and temperatures (top) and corresponding received optical eyes at 100 GBd PAM4 modulation (bottom). $I_{DFB\text{-}20°C}$ = 100 mA, $I_{DFB\text{-}50°C}$ = $I_{DFB\text{-}70°C}$ = $I_{DFB\text{-}85°C}$ = 80 mA, $I_{SOA\text{-}20°C}$= $I_{SOA\text{-}50°C}$= $I_{SOA\text{-}50°C}$ = 20 mA, $I_{SOA\text{-}85°C}$ = 40 mA, $V_{EAM\text{-}20°C}$ = -2 V, $V_{EAM\text{-}50°C}$ = -1.5 V, $V_{EAM\text{-}70°C}$ = -1 V, $V_{EAM\text{-}85°C}$ = -0.5 V, $V_{pp\text{-}20°C\text{-}100Gbd}$ = 0.9 V, $V_{pp\text{-}50°C\text{-}100Gbd}$ = 0.6 V, $V_{pp\text{-}70°C\text{-}100Gbd}$ = 0.7 V, $V_{pp\text{-}85°C\text{-}100Gbd}$ = 0.7 V.

level in front of the photodiode (in-house 50 GHz design) was controlled by an optical amplifier (EDFA) and variable optical attenuator. After electrical amplification (SHF M804), the signal was acquired with a 256 GS/s oscilloscope (Keysight UXR0704AP). The digital signal processing consisted 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 Rx side.

The measured BER versus received optical power is shown at the top of Figure 7. The 7% FEC threshold ($3.8 \times 10^{-3}$) is marked with a dashed line for reference. From 20°C to 85°C the device exhibits a very similar performance for each temperature. This can be explained by the aforementioned balancing between ER and frequency response (c.f. Figure 4 and Figure 5). For 100 GBd PAM4 modulation, a BER below the 7% FEC threshold is achieved at around 1 dBm received optical power for all temperatures, thus demonstrating the devices capability for 200 Gb/s uncooled operation. At the bottom of Figure 7 the corresponding received optical eyes at 100 GBd PAM4 are shown. At all temperatures open eyes with similar quality are visible. The measured average optical output power ex-facet for 20°C, 50°C, 70°C, 85°C was 5.5 dBm, 5.6 dBm, 5.9 dBm, 5.9 dBm, respectively.

## Conclusions

We demonstrate for the first time PAM4 modulation up to 200 Gb/s for an uncooled EML with a single MQW layer stack. Careful balancing of the devices ER and frequency response characteristic allows for equal performance over the full temperature range of 20°C to 85°C. The averaged modulated output power ex-facet exceeds 5.5 dBm for all temperatures. The single MQW layer design allows for a simple fabrication process. The device is a promising candidate for cost and power efficient 200 Gb/s transmitters in 1.6 Tb/s links.

## Acknowledgement

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