Wide Temperature Operation of 40 Gbps 1550 nm Electroabsorption Modulated Lasers

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Electroabsorption modulated lasers (EMLs) exploiting the quantum confined Stark effect need thermo-electric coolers to achieve stable output power levels and dynamic extinction ratios. Temperature independent operation is reported between 20°C and 70°C for InGaAlAs/InP based monolithically integrated 1550 nm EMLs exploiting a shared active area at 40 Gbps by actively controlling the electroabsorption modulator bias voltage. Dynamic extinction ratios of at least 8 dB and fiber-coupled mean modulated optical power of at least 0.85 mW are obtained over the mentioned temperature range.

1. Introduction

Electroabsorption modulators (EAMs) integrated with distributed feedback (DFB) lasers popularly referred to as electroabsorption modulated lasers (EMLs), have been widely studied for data rates above 10 Gbps. In such EMLs, light modulation in the EAM section is achieved by controlling the optical absorption coefficient by means of an external bias. EAMs employing a quantum well active layer exploit the quantum confined Stark effect (QCSE) [1] to accomplish efficient light modulation close to the EAM band edge. Well designed QCSE based EAMs allow for device lengths in the range of 75–150 μm achieving high-speed operation without compromising extinction ratios. Other salient features include reduced chirp [2] and low drive voltage swings [3]. Wide temperature operation of such EMLs, highly desirable for integrating with low power consumption small form factor modules, has been demonstrated up to 10 Gbps by actively controlling the EAM bias. Demonstrated approaches include vertical power transfer between waveguides [4], selective growth [5] and butt-joint [6] techniques. In contrast to the above approaches, shared active area EMLs, i.e., EMLs exploiting an identical active area for both laser and modulator sections reduce the fabrication complexity considerably [7] and simultaneously boost final yield. In this letter, a 40 Gbps wide temperature operation of EMLs employing a shared active area emitting in the 1550 nm wavelength window is presented.

2. Device Layer Structure

The EMLs employed for the investigations consist of a monolithically integrated DFB laser and an EAM. The EMLs exploit a dual quantum well type active area based on the

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InGaAlAs/InP material system. The multiple quantum well (MQW) active layer consists of eight 7.5 nm thick quantum wells whose photoluminescence (PL) wavelength λ_{PL} is around 1510 nm and three 5 nm thick quantum wells with λ_{PL} around 1540 nm. The +0.95 % compressively strained quantum wells are separated by 8 nm thick −0.5 % tensile strained InGaAlAs barriers ($\lambda_g = 1.1\,\mu m$). The intrinsic active layer is embedded between 30 nm thick InGaAlAs ($\lambda_g = 1.05\,\mu m$) separate confinement heterostructures (SCHs) lattice matched to InP. The salient features of using an identical dual multiple quantum well active layer are reported elsewhere [8]. The operation wavelength of the EML is near 1560 nm at room temperature. The wavelength detuning of the EML — defined as wavelength separation between the absorption edge of the EAM and the operation wavelength — is about 55 nm at room temperature. For investigations, the fabricated EMLs were mounted p-side up on copper (Cu) heat sinks. The lengths of DFB laser and EA modulator sections are 380 µm and 115 µm, respectively.

3. Temperature Dependence

Owing to the characteristic steep absorption slope close to the band edge, QCSE based EAMs are inherently sensitive to temperature [9]. With increasing temperature, the transition energy between the electron ground state and heavy hole ground state decreases. This reduction in the transition energy with temperature can be adequately explained by the empirical Varshni relations [10, 11]. The corresponding experimental shift of the EAM absorption spectrum with temperature, in the 1550 nm wavelength window, is ≈ 0.5–0.6 nm/°C. Simultaneously, with rise in temperature, the modal effective refractive index $\langle n'_{\mathrm{eff}} \rangle$ in the laser section increases by $\approx 2.1 \cdot 10^{-4}/°C$. This results in a red shift of the operation wavelength, λ_{DFB}, by ≈ 0.1 nm/°C. The net effect is a decrease of the detuning between the absorption edge of the EAM and the laser emission wavelength by ≈ 0.4–0.5 nm/°C. This considerably degrades the EML dynamic performance in the absence of any temperature control as illustrated in Fig. 1. A nonreturn-to-zero (NRZ) pseudo-random binary sequence drive signal (Fig. 1a) of word length $2^{11} - 1$ was applied to the input port of the EAM traveling wave electrode with the output port terminated by a

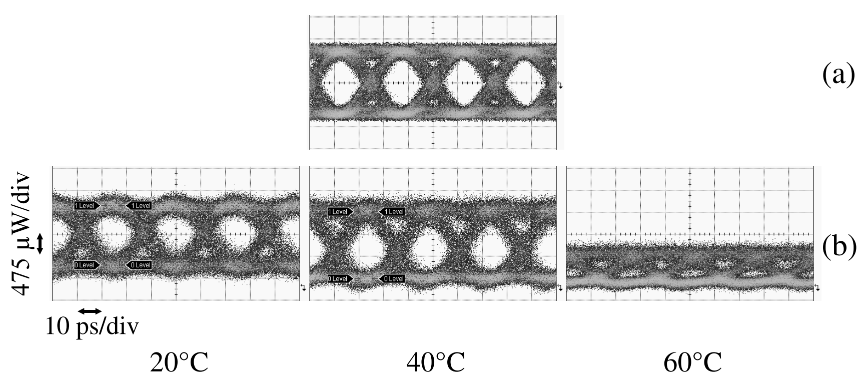

Fig. 1: Electrical drive signal with a peak-to-peak modulation voltage $V_{pp} = 2.5$ V (a). Experimental 40 Gbps optical eye diagrams with $V_{\mathrm{EAM}} = -2.5$ V and $I_{\mathrm{LD}} = 80$ mA (b). The operating temperature of the EML is indicated below the corresponding eye diagrams.

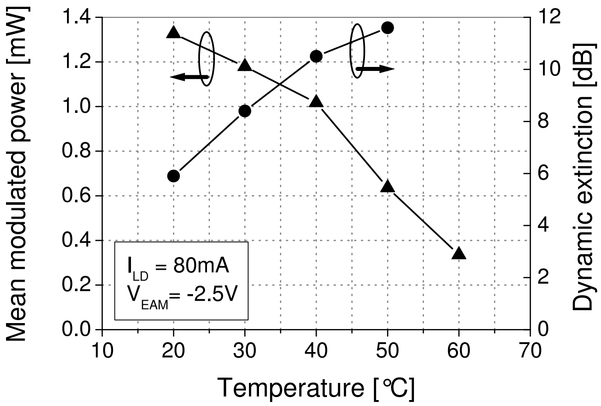

Fig. 2: Mean modulated fiber-coupled optical power and corresponding dynamic extinction ratios as a function of temperature at a constant EAM bias of −2.5 V.

50 Ω resistor. The peak-to-peak modulation swing was $V_{pp} = 2.5$ V. Fig. 1b shows the recorded optical eye diagrams at 40 Gbps with the EAM biased at −2.5 V for a laser current of 80 mA. Temperature-dependent average power and dynamic extinction of the large-signal results are summarized in Fig. 2. The temperature values correspond to the active layer temperature (or junction temperature) measured with an accuracy of ±0.1 °C. The mean modulated (average) optical power in fiber dropped from 1.3 mW at 20 °C to about 0.36 mW at 60 °C. This drop in optical power is predominantly attributed to the increase of "ON" state insertion loss at the operating wavelength. On the contrary, the dynamic extinction ratio increases from about 6 dB at 20 °C to nearly 12 dB at 50 °C. This is simply the result of increasing absorption swing with decreasing wavelength detuning, which is however obtained at the expense of optical power. The chosen EAM bias voltage delivers an optimum performance at 40 °C with more than 10 dB dynamic extinction and a mean modulated optical power of 1.0 mW in fiber. For temperatures above 50 °C, no reliable estimate of the dynamic extinction was possible due to low available power.

4. Wide Temperature Operation

From the large-signal modulation results presented in the previous section, it is evident that a constant EAM bias voltage does not offer satisfactory performance over a wide temperature range of interest. In order to investigate the possibility of temperature-independent operation, static extinction measurements were performed, by varying the heat sink temperature. The corresponding experimental results are presented in Fig. 3. Static light extinction of at least 20 dB per 3 V was obtained. Most notably, the maximum extinction slope shifts toward low reverse bias voltages with increasing temperature. For instance, the maximum extinction slope occurs near −2.85 V at 20 °C while for the case of 65 °C it occurs near −1.55 V. This shift of the optimum bias point with temperature is empirically fit to yield the relation

$$V_{\mathrm{EAM}} \approx -3.5\,\mathrm{V} + 0.03\,T\,\frac{\mathrm{V}}{^\circ\mathrm{C}}; \quad 20\,^\circ\mathrm{C} \leq T \leq 70\,^\circ\mathrm{C} \quad . \tag{1}$$

From (1) it is evident that the optimum EAM bias voltage increases by 0.3 V per 10 °C rise in temperature. By actively controlling the EAM bias voltage in accordance with

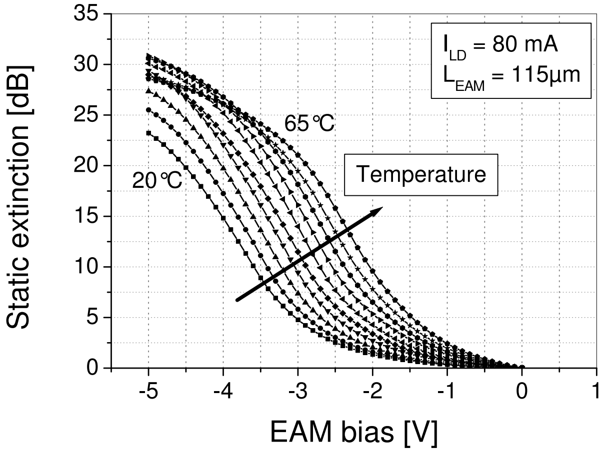

Fig. 3: Static light extinction curves of the 1550 nm EML in steps of 5 °C. Measurements pertain to a laser current of 80 mA.

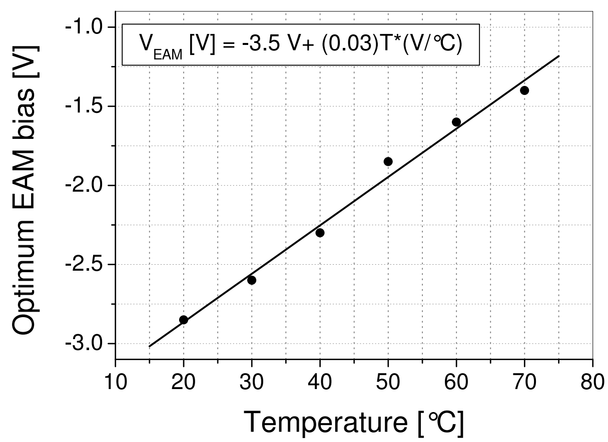

Fig. 4: Linear empirical fit for active EAM bias control to achieve wide temperature operation. The solid circles correspond to the bias voltages used for the measurements.

the temperature, one can expect that average optical power and dynamic extinction remain constant. A plot of the empirical fit is shown in Fig. 4. The solid circles in Fig. 4 correspond to the EAM bias voltages used for subsequent large-signal modulation measurements presented in Fig. 5. The empirical relationship given by (1), is applicable between 20 °C and 70 °C.

The average fiber-coupled optical power and the corresponding dynamic extinction ratios have been summarized in Fig. 6. It is quite evident that the average power and the dynamic extinction remain almost constant from 20 °C to 70 °C. Dynamic extinction ratios of at least 8 dB and an average fiber-coupled optical power of at least 0.85 mW can be observed. The optical eye diagrams obtained in all the measurements were limited by the quality of the electrical drive signal which in part degraded the obtained dynamic extinction. Thus, the dynamic extinction values obtained can be treated as a lower bound. For commercial datacom applications, besides average optical power and dynamic extinction, dispersion penalty of the EMLs has to be fairly constant over the temperature range of interest. Accordingly, the transmission performance of the EMLs shall be addressed after investigations.

5. Conclusion

Temperature-independent operation of monolithically integrated InGaAlAs/InP based electroabsorption modulated lasers employing an identical active layer has been experimentally demonstrated between 20 °C and 70 °C in the 1550 nm wavelength window at a data rate of 40 Gbps. This was achieved by actively controlling the reverse bias voltage applied across the electroabsorption modulator. Average fiber-coupled power of at least 0.85 mW and dynamic extinction ratios of at least 8 dB for a voltage swing of 2.5 V were obtained from 20 °C to 70 °C. The experimental results demonstrate the excellent dy-

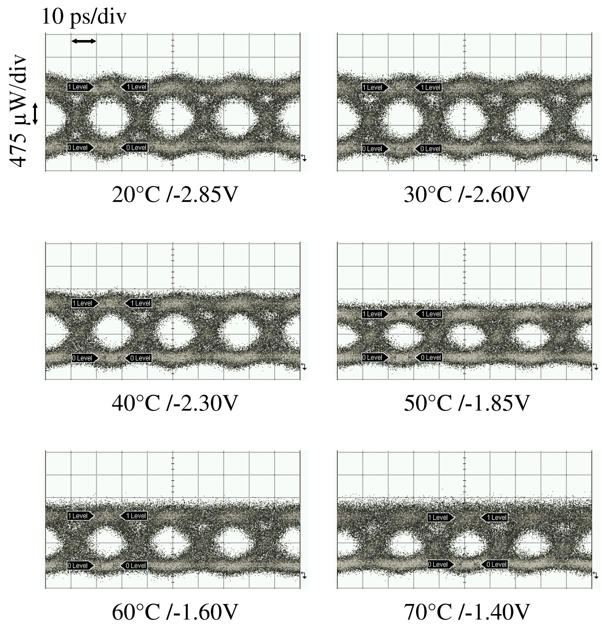

Fig. 5: Experimental 40 Gbps eye diagrams of the 1550 nm EML with active bias control. The peak-to-peak modulation voltage was V_{pp} = 2.5 V with the laser biased at 80 mA. The operating temperature of the EML and the corresponding EAM bias are indicated below the eye diagrams.

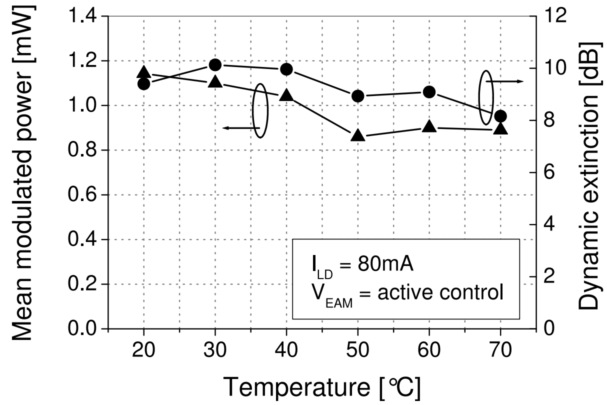

Fig. 6: Mean modulated fiber-coupled optical power and corresponding dynamic extinction ratios of 40 Gbps large-signal modulation results. By actively controlling the EAM bias, dynamic extinction and average fiber power stay reasonably constant from 20 °C to 70 °C.

namic performance of the devices and their potential for next generation high-speed data links.

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