Simulating a High Extinction Ratio Interferometric Electroabsorption-Modulated Laser Transmitter

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***Abstract*—We present the design and simulation of a high-speed laser integrated transmitter, capable of high extinction ratios whilst maintaining good optical modulation amplitude, even at short modulator lengths. The key to this device's performance is the configuration of its components, wherein two electroabsorption modulators - modulated with data and data-bar – are combined with a multi-mode interferometer.**

***Index Terms*—InP, electroabsorption modulator, externally modulated laser, interferometric, extinction ratio**

I. Introduction

Optical transceivers are key components in telecoms and datacoms applications, and demand from technologies, such as AI, high-performance computing (HPC) and next generation mobile networks, apply pressure to improve data speeds. Electroabsorption modulated lasers (EMLs), comprising monolithically integrated distributed feedback lasers (DFBs) and electroabsorption modulators (EAMs) fabricated on InP, are widely used in these applications as they offer a highly compact and energy efficient means to modulate optical signals at very high speeds [1], [2]. Future EML developments to try and operate at even higher bit rates and baud rates face a challenge in that this may push EAM designs to shorter lengths to reduce capacitance at the cost of the extinction ratio (ER). An interferometric version of the EML has been proposed [3] and demonstrated to reduce EML power consumption, potentially allowing higher speed modulation [4]. This initial demonstration had an asymmetric Mach-Zehnder (MZ) interferometer comprising an EAM in the arm that had most light directed along it and a DC phase shifter on the other arm so that destructive interference could enhance the extinction afforded by the EAM. In this work, we simulate an interferometric EML (i-EML) with two potential improvements. Firstly, the interferometer utilises light from both ends of the DFB laser to reduce the number of multimode interference couplers (MMIs) needed [5]. Secondly - as in [3] - we consider a design with EAMs in both arms of the interferometer that are driven in antiphase with one another to minimise the destructive interference in the on-state, thereby improving the output ER and optical modulation amplitude (OMA).

II. Design and Theory

A schematic of the i-EML layout is illustrated in Fig. 1. The key components of the i-EML are: a DFB with a quarter wavelength phase shift - designed for high single-mode yield,

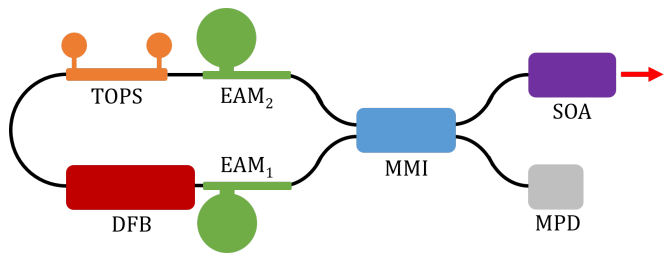

Fig. 1: Schematic layout of the i-EML. Optical output of the device is indicated by red arrow.

giving equal output powers at each end – two EAMs, a thermo-optic phase shifter (TOPS), a 2x2 MMI, a monitor photodiode (MPD), and a semiconductor optical amplifier (SOA). Both EAMs are identical, with a voltage dependent transmission and phase; in the simulations, we utilise a lookup table based on experimentally measured optical loss versus bias voltage data from a previously fabricated and tested EAM, taken at low optical power to minimise thermal effects. Similarly, a lookup table for measured chirp versus bias voltage is used to calculate the phase shifts accompanying the intensity modulation. The transmissions through the two EAMs is controlled by their respective DC bias voltages, V_{DC_1} and V_{DC_2}, and a common peak-to-peak modulating voltage, V_{pp}. The light that passes through the TOPS acquires and additional phase shift, ϕ_{TOPS}, which can be adjusted by varying the voltage over the TOPS. The power entering the SOA, P, can be calculated according to

$$P = P_0 \Big\{ (1-k)T_1 + kT_2 + 2\sqrt{k(1-k)T_1T_2}\cos\left(\phi_1 - \phi_2 - \phi_{TOPS}\right) \Big\}, \tag{1}$$

where P_0 is the power leaving each end of the DFB, k is the MMI split ratio, T_1 and T_2 are the voltage dependent transmissions of each EAM, and ϕ_1 and ϕ_2 are the voltage dependent phase shifts of each EAM.

The key principal in enhancing the ER with this device is to create destructive interference in the off-state by tuning ϕ_{TOPS}; this effect can be further enhanced by modulating one EAM with the data-bar of the other – this affords us the desired destructive interference in the off-state whilst minimising it in the on-state. The phase shifts accompanying the intensity modulation in each EAM can also help by simultaneously minimising and maximising the destructive interference in the on- and off-state.

III. Results

An analytical model is developed in Python to map and explore key figures of merit (FOMs), namely ER, OMA, and optical crossing percentage (CP), which can be calculated efficiently by sweeping multiple parameters in a nested loop; insights from this exploratory phase help us to understand the behaviour of the i-EML and devise methods to optimise its performance. The key parameters we explore in this work are V_{DC_1}, ϕ_{TOPS}, and k, and EAM length, L, with P_0=10mW, V_{pp}=1V, and $V_{DC_2} = V_{DC_1}$. The ER, OMA, and CP are calculated as functions of V_{DC_1} and ϕ_{TOPS} using Eq. 1; these FOMs - with combinations of fixed k and L - are overlaid in Fig. 2. Notably, Fig. 2 shows that only a small value of k is

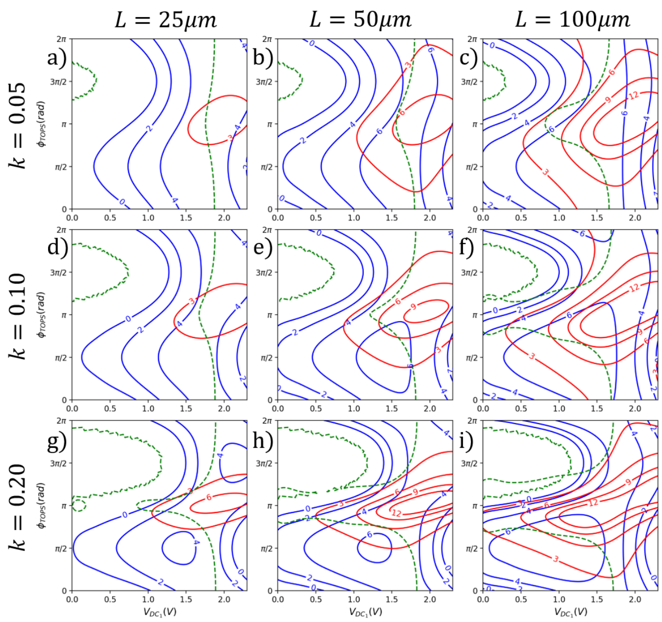

Fig. 2: Contour plots of ER (dB) (red, solid) and OMA (dBm) (blue, solid) as functions of V_{DC_1} and ϕ_{TOPS} for k=0.05, k=0.10 and k=0.20 (rows top to bottom respectively) and L=25μm, L=50μm and L=100μm (columns left to right respectively). The CP=50% contour is indicated by the green dashed lines.

required to create a strong enough interference to achieve high ER, e.g. with L=50μm, one can access ER>6dB, ER>9dB and ER>12dB with k=0.05, k=0.10 and k=0.20 respectively (ignoring CP). However, as k is increased, regions of high ER, high OMA and CP$\sim$50% begin to separate.

To more clearly understand how ER and OMA behave as we vary k and L, we benchmark the performance of the i-EML against an EML – comprising a single EAM and identical DFB, and equivalent to the i-EML with k=0 – in Fig. 3. At each value of k, the value of V_{DC_1} and ϕ_{TOPS} are selected such that ER is maximised whilst CP$= 50 \pm 1\%$. Fig. 3 shows that the optimal value of k to maximise ER is lower for longer EAM lengths; in shorter EAMs, the off-state power is higher relative to the on-state power, so a larger intensity of light

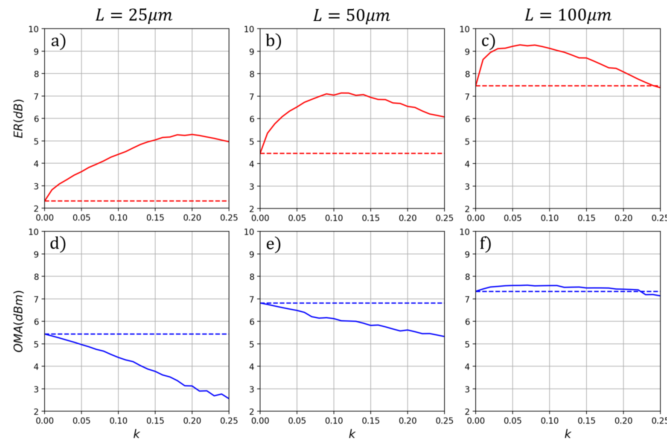

Fig. 3: ER (red, solid) and OMA (blue, solid) of the i-EML with optimised setup conditions (V_{DC_1} and ϕ_{TOPS}) as a function of k, with L=25μm (a, d), L=50μm (b, e), and L=100μm (c, f). These results are benchmarked against the ER (red, dashed) and OMA (blue, dashed) of conventional EMLs with the same EAM length and DFB design, equivalent to the i-EML with k=0.

from the second EAM is required to create the destructive interference. In addition, the ER enhancement of the i-EML compared to the conventional EML becomes more pronounced at shorter EAM lengths – albeit at the cost of OMA – an important result as we consider shorter EAMs for ultrafast modulation speeds. These calculated OMA values are before the SOA, which in practice would boost the output OMA.

IV. Conclusion

We have presented a theoretical overview of a novel transmitter design, wherein high ER and good OMA can be simultaneously achieved with an interferometric configuration of two EAMs driven in antiphase of one another. This approach predicts improved performance for EAM lengths that are shorter than typically used, which could enable higher-speed operation thanks to their reduced capacitance. These results suggest that a highly asymmetric MMI design is an attractive solution to achieve such high performance, whilst maintaining good eye quality. We hope that further exploration of devices like these will pave the way towards ever-higher transmitter speeds.

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