Multi-Channel 11.3-Gb/s Integrated Reflective Transmitter for WDM-PON

C.P. Lai[(1)], R. Vaernewyck[(2)], A. Naughton[(1)], J. Bauwelinck[(2)], X. Yin[(2)], X.Z. Qiu[(2)], G. Maxwell[(3)], D.W. Smith[(3)], A. Borghesani[(3)], R. Cronin[(3)], K. Grobe[(4)], N. Parsons[(5)], E. Kehayas[(6)], P.D. Townsend[(1)]

[(1)] Photonic Systems Group, Tyndall National Institute, University College Cork, Ireland, caroline.lai@tyndall.ie
[(2)] INTEC/IMEC, Ghent University, Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium
[(3)] CIP Technologies, Adastral Park, Martlesham Heath, Ipswich, IP5 3RE, UK
[(4)] ADVA Optical Networking SE, Fraunhoferstr. 9a, 82152 Martinsried, Germany
[(5)] Polatis Ltd., Cambridge Science Park, Cambridge, CB4 OWN, UK
[(6)] Constelex Technology Enablers Ltd., Sorou 12, Marousi, 15125, Athens, Greece

Abstract *We present a multi-channel transmitter that employs an arrayed reflective electroabsorption modulator-based photonic integrated circuit and low-power driver array. Error-free 11.3-Gb/s per channel performance is achieved over 96 km of SSMF, with negligible crosstalk (<1-dB penalty) in multi-channel operation.*

Introduction

To address rising energy and bandwidth demands, service providers are pursuing the deployment of wavelength-division multiplexing (WDM) in next-generation passive optical networks (PONs). At the optical line terminal (OLT) in the head-end, which must support traffic from many users, a major challenge is the lack of cost-effective, compact, low-power integrated WDM access components[1]. We have previously proposed a cost-, footprint-, and power-optimised colourless WDM-PON solution[2]. Our PON architecture uses line cards integrated with small-footprint multiwavelength transceiver modules, thus necessitating low-cost highly integrated reflective multi-channel transceiver arrays. These components will rely on hybrid array-integrated photonic integrated circuits (PICs) with reflective electroabsorption modulator (REAM)-based amplitude modulators with multi-frequency lasers, as well as custom low-power electronic driver and receiver integrated circuits.

A key enabling component technology for the OLT design is a novel reflective multi-channel transmitter, which features a PIC array of REAMs integrated with an ultra-low-power electronic driver. Here, we report on such an integrated transmitter, in which each channel operates at the targeted line rate of 11.3 Gb/s to account for the potential use of forward error correction. Error-free operation (bit-error rates (BERs) less than 1×10^{-12}) is confirmed for all operational channels. No significant crosstalk effects were observed, and the penalty from multi-channel operation as compared to the single-channel performance is less than 1 dB (at BER=10^{-9}). Furthermore, a 1-dB power penalty is measured after transmission over 80 km of standard single mode fibre (SSMF), and error-free performance is maintained up to 96 km. To the best of our knowledge, this is the first demonstration of an 11.3-Gb/s arrayed transmitter for WDM-PON applications, integrated with a 10-channel REAM driver array featuring a power consumption that is 50% better than the state-of-the-art[3].

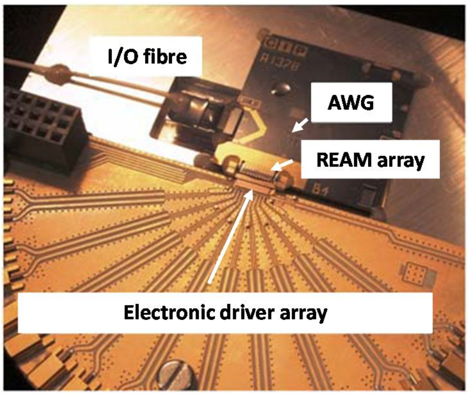

Fig. 1: Photograph of transmitter assembly.

Description of Reflective Transmitter

The multi-channel transmitter assembly is composed of a single array of ten ridge structure-based InP REAMs hybrid integrated with an arrayed waveguide grating (AWG) multiplexer, and the 10×11.3-Gb/s REAM driver array. Fig. 1 shows a photograph of the main component blocks. The 10-channel AWG has 100-GHz spacing and is athermalised using polymer-filled slots to avoid wavelength drift with temperature. The REAM array is mounted on a silicon submount and aligned to the AWG silica planar motherboard. The integrated assembly features a single input/output (I/O) fibre such that the transmitter operates in reflective mode.

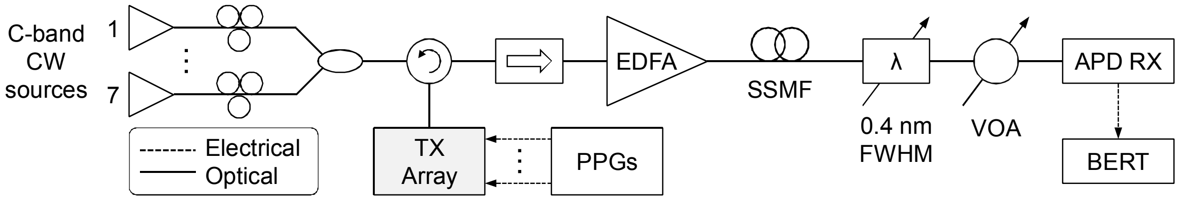

Fig. 2: Experimental setup for evaluating the integrated transmitter array at 11.3 Gb/s.

The 10-channel REAM electronic driver array was fabricated using 0.13-μm SiGe BiCMOS technology. Each individual driver operates at 11.3 Gb/s with controllable output voltage swing between 1.5-3 Vpp. The REAM bias can be set between 0.75-2.1 V. The driver includes: an input that is differentially matched to 100 Ω; a predriver block to amplify the input signal, to drive the large capacitive input of the actual driver, and to control the pulse width (to compensate for any REAM nonlinearity); and the REAM driver with adjustable bias and modulation current. The transmitter is controlled via a serial peripheral interface. Each channel's bias and modulation current can be set separately to optimise each REAM's performance. The driver's design aims to reduce power consumption whilst offering a sufficient voltage swing to the REAM in order to deliver a suitable signal modulation depth. The driver array exhibits a record low power consumption of <220 mW per channel. Complete details on the driver were reported previously[3].

The naked die of the REAM driver array is wire-bonded to a printed circuit board with RF connectors and connected to the PIC motherboard; the bond wire lengths were minimised to reduce inductance. During packaging of the first prototype, three channels were damaged; thus, the following experiment evaluates the seven functional channels of this proof-of-concept assembly.

Experimental Setup

The experimental setup is shown in Fig. 2. Seven C-band CW carriers, aligned to the transmitter's 100-GHz AWG (λ=1543.59-1548.37 nm), are generated. The optical carriers are passively combined and injected into the reflective transmitter (TX) via a circulator which is connected to the assembly's I/O fibre. The 11.3-Gb/s nonreturn-to-zero (NRZ) (2^{31}-1 pseudorandom bit sequence (PRBS)) drive signals for the transmitter array are simultaneously generated by separate decorrelated pulse pattern generators (PPGs). Each channel uses a differential drive with a DC- or AC-coupled 500-mVpp swing.

The transmitter's modulated signals emerge from the output port of the circulator. The dynamic insertion loss of the arrayed assembly is approximately 25 dB per channel, so the output signals are then amplified by an erbium-doped fibre amplifier (EDFA). We envision reducing this loss in future prototypes by optimising coupling losses between the REAM array and the silica waveguides, as well as monolithically integrating the REAMs with semiconductor optical amplifiers[4]. The array's transmission performance is evaluated using SSMF lengths varying from 0 km (back-to-back (B2B)) to 96 km (a second EDFA was required at 96 km). The launch power into the SSMF was kept <6 dBm to mitigate nonlinear effects.

At the receiver side, a tuneable wavelength filter with 0.4-nm full-width half-maximum (FWHM) emulates the bandwidth of a 100-GHz AWG and minimises the amplified spontaneous emission falling on the receiver (RX). The chosen wavelength channel is sent to a variable optical attenuator (VOA), then to a 10-Gb/s APD RX coupled to a bit-error-rate tester (BERT) for BER analysis. The optical-signal-to-noise ratio was kept sufficiently high (>28 dB) such that the receiver thermal noise floor provided the dominant impairment in the system.

Experimental Results

Single-channel back-to-back performance of the transmitter was evaluated first by turning on each channel separately, permitting individual assessment of the array's seven operational channels (Ch1-7) at 11.3 Gb/s. The driver allows each REAM channel to have a reverse bias of approximately 1.7 V with 2.5 Vpp modulation swing. Error-free operation of each channel at 11.3 Gb/s was achieved with BERs<1×10^{-12}, showing comparable sensitivity performance across all the channels. Fig. 3 shows <2-dB difference in sensitivity between the seven channels. Correspondingly, Fig. 4 presents the single-channel B2B optical eye diagrams for the seven channels. Significant eye openings were obtained for all seven channels. For the above REAM bias and modulation settings, the measured extinction ratios (ERs) for the seven channels range from 7.6 dB to 9.8 dB. Ch2 shows the worst sensitivity (by 1 dB), which can be observed from the slightly-degraded eye.

Subsequently, the arrayed transmitter's multi-

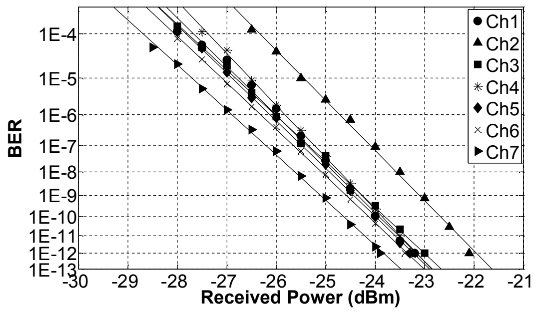

Fig. 3: BER as a function of received power for Ch1-7 in single-channel operation (B2B).

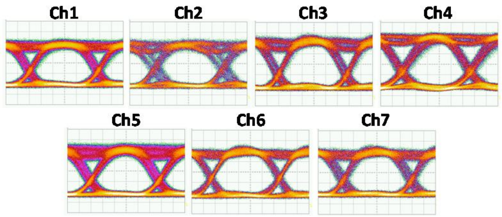

Fig. 4: 11.3-Gb/s optical eye diagrams for Ch1-7 in single-channel operation (B2B, 15.2 ps/div).

channel performance was evaluated by operating all seven channels simultaneously. The centre channel in the functional set (Ch4 within Ch1-7) was chosen as the target channel, in order to provide a worst-case study of any possible electrical or optical crosstalk arising from the non-target channels in the array. Fig. 5 provides the BER sensitivity curves for the single- and multi-channel operation cases. For B2B, we see <1-dB penalty (at BER=10^{-9}) for Ch4 with all other channels turned on. No error floor resulted from multi-channel operation, indicating no discernible crosstalk effects in the array. Instead, the observed penalty was found to be due to a slight increase in REAM temperature resulting from heating by the driver when all channels were turned on. Such a temperature increase causes a red shift of the REAM band edge, which alters the bias and modulation operating point. In principle, this effect can be alleviated by mounting the TX assembly on a thermoelectric cooler (TEC). By stabilising the device's temperature, the TEC aims to restore the optimal bias and modulation operating point. However, in the current prototype, the REAM array is in poor thermal contact with the TEC (which sits under the assembly's evaluation board), thus the thermal effects cannot be completely mitigated. Operating the REAM at the driver's lowest possible bias and modulation settings compensates for this to some degree; however, we still observed a decrease in ER (from 8.5 dB to 7.2 dB for Ch4). Ultimately, this ER reduction gave rise to a small residual penalty. In future versions of the TX, the penalty could be reduced by placing the optical devices in direct contact

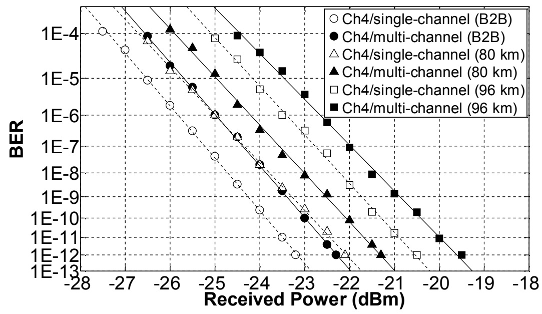

Fig. 5: BER as a function of received power for Ch4 in single- and multi-channel operation.

with the TEC or by blue-shifting the REAM band edge to achieve optimum modulation and biasing conditions at elevated temperatures.

Lastly, the array's performance was analysed after transmission over 80 km and 96 km of SSMF, respectively (Fig. 5). After 80 km (the intended reach for WDM-PON), we observed a power penalty of approximately 1 dB for the target channel. This 80-km transmission reach was consistent with prior results of EAMs at 10 Gb/s. Furthermore, error-free performance was maintained for distances up to 96 km for both the single- and multi-channel cases. At these distances, the performance degradation is due to chromatic dispersion, which leads to intersymbol interference and thus some eye closure. The extra <1-dB penalty that arises from concurrently operating several channels seen in B2B is preserved at both 80 and 96 km.

Conclusions

We have demonstrated a novel multi-channel REAM-based transmitter with integrated driver, showing error-free performance over 96 km. No significant crosstalk was observed, and a relatively small penalty was measured in multi-channel operation due to driver-induced heating of the REAM array. The co-optimisation and integration of a PIC with an electronic driver offers a cost-effective solution for reflective OLT realisations in next-generation WDM-PONs.

Acknowledgements

This work was supported by the European Commission through the C3PO project (contract 257377) under the FP7 ICT Programme. Tyndall also acknowledges funding by Science Foundation Ireland (Grant 06/IN/I969).

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