Integrated Transmitter for 100 Gb/s OOK Connectivity Based on Polymer Photonics and InP-DHBT Electronics

V. Katopodis(1), Ch. Kouloumentas(1), A. Konczykowska(2), F. Jorge(2), P. Groumas(1), Z. Zhang(3), A. Beretta(4), A. Dede(4), J.-Y. Dupuy(2), V. Nodjiadjim(2), Giulio Cangini(5), G. Von Büren(5), E. Miller(5), R. Dinu(5), N. Keil(3), H.-G. Bach(3), N. Grote(3), A. Vannucci(4), and H. Avramopoulos(1)

(1) National Technical University of Athens, Zografou 15573, Athens, Greece, vkat@mail.ntua.gr
(2) III-V Lab, Route de Nozay, Marcoussis, 91460 France
(3) Fraunhofer Institute for Telecommunications, HHI, Berlin 10587, Germany
(4) Linkra Srl, Via S.Martino 7, 20864 Agrate Brianza (MB) Italy
(5) GigOptix Inc.19910 North Creek Parkway Suite 100, Bothell, WA, 98011, USA

Abstract *We present the first integrated 100 Gb/s NRZ-OOK transmitter for datacom/telecom applications based on electro-optic polymers and hybrid integration of an InP laser diode and InP-DHBT electronics. Successful operation is confirmed through BER measurements and eye-diagrams at 80-100 Gb/s.*

Introduction

Although the current implementations of 100G systems rely mainly on 4x25 Gb/s technologies that allow the use of lower bandwidth modulators and driving electronics, the efforts to remove barriers to higher bandwidth transmitters are strong and ongoing. Two are the main reasons for this: a robust solution for serial 100 Gb/s transmission of non return-to-zero on-off keying (NRZ-OOK) streams has the potential to revolutionize 100G technology, especially in datacom applications, due to its advantages in terms of number of components, footprint, simplicity, power consumption, and eventually cost. Moreover, the availability of high-speed modulators and of the underlying technology for high-speed electronics can define a new base for operating symbol rates, and be further combined with higher-order modulation formats towards 400 Gb/s and 1 Tb/s systems.

So far, two modulator technologies have shown a strong potential for 100 Gb/s NRZ-OOK operation: the InP travelling wave electro-absorption modulators (InP-TWEAMs) [1-2] and the electro-optic (EO) polymer-based Mach-Zehnder modulators (MZMs) [3-4]. Compared to the InP-TWEAMs, the polymer-based MZMs can have faster response and the clear advantage of being able to support higher-order formats, too, involving both intensity and phase modulation. However, their 100 Gb/s potential has been shown only through bandwidth measurements and is still to be confirmed with true digital data.

Regarding electronics on the other hand, the InP-double heterojunction bipolar transistor (InP-DHBT) is a proven technology for 100 Gb/s multiplexers (MUX) and driver amplifiers [1-2]. Further steps towards chip miniaturization, power efficiency and, most significantly, co-integration with the photonic part of the transmitter have still to be made, though, in order to improve performance and reduce cost.

In this work we innovate along these directions and present the first integrated transmitter for 100 Gb/s NRZ-OOK operation. It is based on the hybrid integration of a polymer MZM with a laser diode and electronic MUX/driver circuits in a single box. Evaluation in the 80-100 Gb/s range reveals the high-quality of the device and the viability of the technology.

Concept and device

Fig. 1 depicts the main building blocks and the final assembly of the transmitter. Specifically, Fig. 1a presents the optical part (sub-assembly)

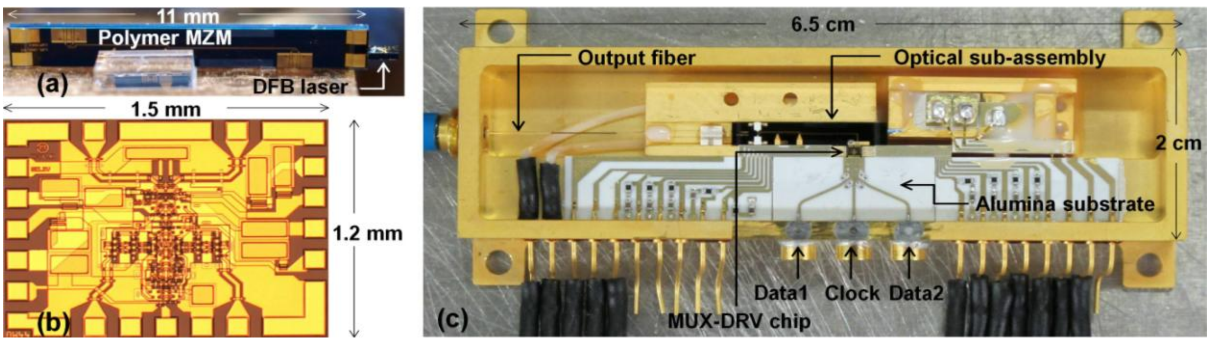

Fig. 1: Main building blocks and final assembly of the 100 Gb/s transmitter: (a) Optical sub-assembly consisting of the polymer MZM and the hybridly integrated DFB laser, (b) circuit microphotograph of the MUX-DRV chip, and (c) transmitter assembly in the box. Photographs of individual blocks and final assembly are not shown in scale.

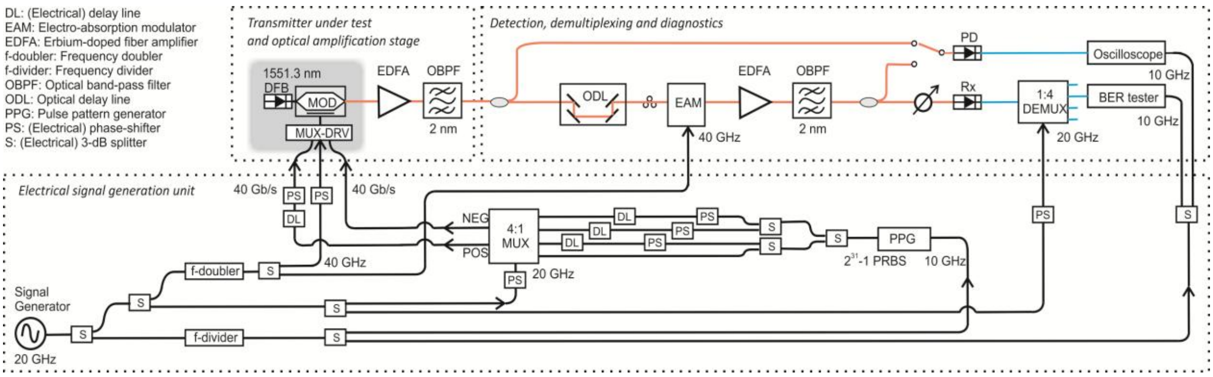

Fig. 2: Experimental set-up. The indicated frequencies and data rates correspond to 80 Gb/s operation and were scaled accordingly for operation at 90 and 100 Gb/s.

consisting of the polymer MZM chip and the hybridly integrated 1550 nm distributed feedback (DFB) laser. The structure of the EO polymer platform has been described in [5]. Its propagation loss is 1 dB/cm. The length of the single-drive MZM is 11 mm and the required V_{pi} is 3.5 V owing to the strong field confinement and the high EO coefficient of the waveguide core (65 pm/V at 1550 nm). The possibility for integration with InP elements has been recently shown using the butt-coupling technique [5]. The achievable coupling loss at the polymer/InP interface is ~2 dB because of the imperfect overlap of the mode profiles. Due to the intrinsic properties of the polymer system, the EO effect is present only for transverse magnetic (TM) modes, thus necessitating the rotation of the transverse electric (TE) emitting laser by 90^{o}.

Fig. 1b presents in turn the layout of the main electronic circuit, which is the improved version of the one reported in [6]. It is fabricated using the 0.7 µm InP-DHBT technology and integrates the 2:1 time division multiplexing (MUX) and the driver amplification (DRV) functionalities so as to limit to the minimum the interfaces at 100 Gb/s. It operates with two input data signals and a clock signal at half the final rate, and can provide a 2x2 V_{pp} signal at the output. As the polymer MZM is single-drive, only one of the complementary output streams is used. The lumped architecture of the driving output buffer allows for a very compact layout with 1.5x1.2 mm² footprint. The power consumption of the circuit is lower than 2 W.

Fig. 1c shows the final assembly of the transmitter inside the FeNiCo package. Alumina-based striplines with 50 Ohm impedance interconnect the GPPO connectors to the MUX-DRV circuit, and wire-bonds with length below 150 µm interconnect the MUX-DRV output to the polymer MZM. Apart from the MUX-DRV circuit, the DC connectors shown in Fig. 1c are used for the operation of the DFB laser, the bias phase-shifter of the MZM and the thermo-electric cooler (TEC) of the device. Finally, a lensed fiber is employed for coupling the light out of the polymer waveguide with 1.5 dB coupling loss. The total optical loss inside the package is ~8.5 dB including the MZM insertion loss, and results in 0.8 dBm output power of the continuous wave (cw) at the transmission peak of the modulator.

Experimental set-up and results

Fig. 2 presents the experimental setup for the transmitter evaluation at 80-100 Gb/s. The outlined frequencies of the sinusoidal signals and bit-rates of the data signals correspond to 80 Gb/s and were scaled accordingly for 90 and 100 Gb/s operation. The signal generator drove the PPG, the oscilloscope, the bit-error rate (BER) tester, the 4:1 MUX, the 1:4 DEMUX and the MUX-DRV of the transmitter using a frequency divider, a frequency doubler and power splitters. The PPG generated the 2^{31}-1 long pseudo-random bit sequence (PRBS) at 10 Gb/s, and fed the 4:1 MUX through parallel phase shifters (PS) and delay lines (DL) that allowed for bit-level synchronization and pattern decorrelation, respectively. Subsequently, the 40 Gb/s outputs at the positive (POS) and negative (NEG) ports of the 4:1 MUX were used as the two input 40 Gb/s data streams for the transmitter after further decorrelation and bit-level synchronization. At the transmitter output, the 80 Gb/s optical signal at 1551.3 nm was amplified and filtered. Part of it was detected by a 70 GHz photodiode for eye-diagram-based studies, while the rest of it was forwarded for BER measurements. Due to the unavailability of an ultra-high speed electrical DEMUX, an electro-absorption modulator (EAM)-based optical scheme was applied for 1:2 demultiplexing. At the output of the EAM, the 40 Gb/s tributaries were amplified, filtered and detected by a 40 GHz photoreceiver. The electrical signal was further demultiplexed by an electrical 1:4 DEMUX, and the final 10 Gb/s tributaries were evaluated by the BER tester.

Fig. 3 presents the eye-diagrams of the optical signal at 80, 90 and 100 Gb/s, as well as

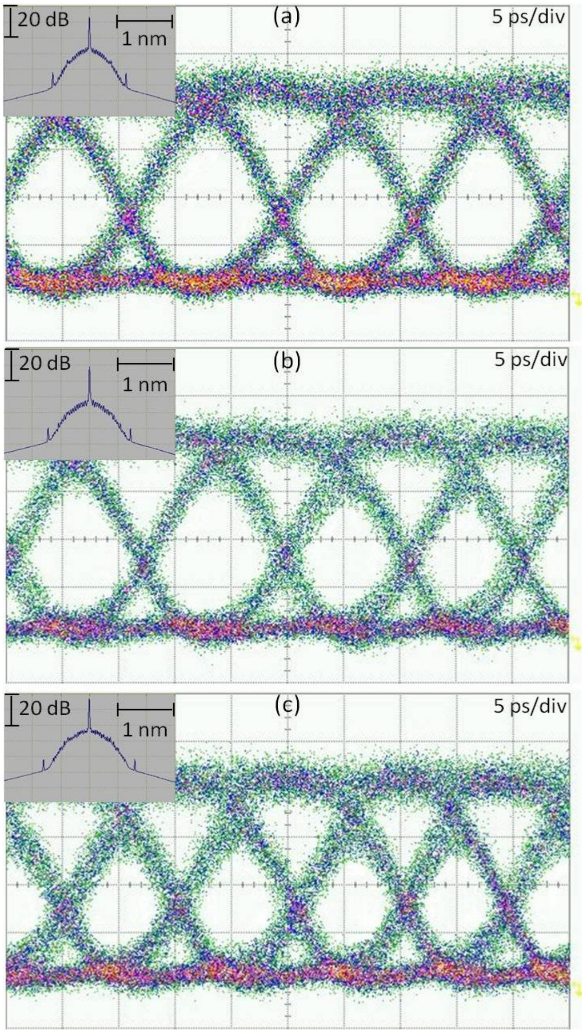

Fig. 3: Eye-diagrams at the transmitter output at: (a) 80 Gb/s, (b) 90 Gb/s, and (c) 100 Gb/s. The corresponding spectra are centered at 1551.3 nm and are shown in the insets with 0.01 nm resolution.

the corresponding NRZ-OOK spectra with 0.01 nm resolution. Clearly open eye-diagrams even at 100 Gb/s reveal high bandwidth operation of the individual components and the transmitter as a whole. In all cases the root mean square (rms) timing jitter was lower than 0.9 ps and the extinction ratio was higher than 13.5 dB at the expense, however, of reduced optical power at the device output (approximately -10 dBm) due to the significantly lower peak-to-peak voltage of the driving signal compared to the MZM V_{pi}.

Despite the indication for error-free operation in the complete 80-100 Gb/s range, confirmation through actual BER measurements was feasible only at 80 Gb/s due to the optical demultiplexing set-up, and specifically due to the deterioration of the EAM performance with electrical driving signals higher than 40 GHz. Fig. 4a-b depict the two 40 Gb/s tributaries of the 80 Gb/s NRZ-OOK signal at the output of the EAM, while Fig. 4c illustrates the BER curves of the eight 10 Gb/s components after further demultiplexing of each

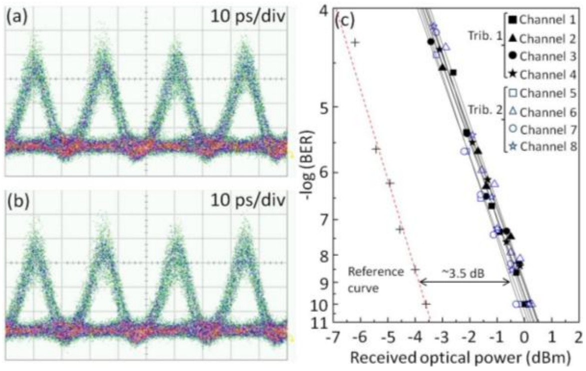

Fig. 4: BER evaluation of the 80 Gb/s signal: Eye-diagrams of the (a) 1^{st} and (b) 2^{nd} 40 Gb/s tributary at the output of the EAM, and (c) BER curves.

tributary by the electrical DEMUX. The absence of an error-floor is evident for BER down to 10^{-10}. The reference curve corresponds to the components of a 40 Gb/s RZ-OOK signal, that uses the 40 GHz optical clock produced by the EAM as input to a $LiNbO_3$ modulator. It is noted that the 3.5 dB power penalty compared to the reference curve is expected to decrease with narrower demultiplexing time windows produced by the EAM (now ~7 ps at FWHM).

Next steps

BER measurements at 100 Gb/s will follow with the availability of an electrical 100 Gb/s DEMUX unit that will be integrated with 100 GHz pin-photodiodes. Further steps will exploit the recent advancements in the monolithic integration on the EO polymer platform [5], for developing Bragg-grating-based tunable 100 Gb/s transmitters and multi-mode interference (MMI) coupler-based 4x100 Gb/s transmitters for metro, intra- and inter-datacenter applications.

Conclusions

We have demonstrated an integrated transmitter for NRZ-OOK operation directly at 100 Gb/s. It relies on the EO polymer integration platform for the photonic part and the InP-DHBT technology for the driving electronics. BER measurements and widely open eye-diagrams in the 80-100 Gb/s range reveal high-quality performance.

Acknowledgements

The work was supported by the EU-funded project ICT-POLYSYS (Contr. No. 258846).

References

[1] C. Kazmierski et al., Proc. OFC’09, OThT7 (2009).

[2] J. Li et al., Proc. ECOC’10, P4.03 (2010).

[3] J. Mallari et al., Proc. OFC’10, OThU2 (2010).

[4] W. Freude et al., Proc. IEEE Photonics Society, WB2.1 (2010).

[5] P. Groumas et al., Opt. Lett. **37**, 3465 (2012).

[6] A. Konczykowska et al., Electron. Lett. **45**, 1235 (2009).