PAM-4 and Duobinary Direct Modulation of a Hybrid InP/SOI DFB Laser for 40 Gb/s Transmission over 2 km Single Mode Fiber

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Abstract: We demonstrate 40 Gb/s PAM-4 and Duobinary direct modulation of a heterogeneously integrated InP on SOI DFB laser. Transmission measurement was performed using a 2 km NZ-DSF with a PRBS 2^{15} and 1.5 V_{pp} swing voltage.

OCIS codes: (130.3120) Integrated optics devices; (140.5960) Semiconductor laser; (230.0230) Optical devices.

1. Introduction

To overcome the server-to-server communication bottleneck in data centers, high bitrate and low-cost transceivers are required. Optical intensity modulation and direct detection (IM/DD) provides a cost-effective and power-efficient approach [1,2]. High bitrate direct modulation of VCSELs can meet the datacenter requirements [3] given their low threshold current and fast dynamics, but on the other hand, reaching high aggregate bitrate transceiver requires wavelength division multiplexing, which is non-trivial using VCSEL sources. Moreover, they typically have lower output power [4]. For applications that require high optical power and stable single mode operation, DFB lasers present an alternative [5]. Also, silicon photonics technologies have matured to accommodate interconnect requirements. The aim is to use a Si photonics platform for the whole optical transceiver system, because of its potentially low cost and dense integration capacity. Recently, 28 Gb/s NRZ direct modulation of hybrid integrated III-V-on-silicon distributed feedback lasers has been demonstrated [6]. In this paper, we present multilevel pulse amplitude modulation of a heterogeneously integrated InP/SOI DFB laser at 40 Gb/s. Specifically, we present PAM-4 modulation together with the corresponding BER vs. optical received power characteristics. Furthermore, we show that duobinary modulation generated using the bandwidth limitation of the laser provides a viable alternative approach to reach 40 Gb/s bit rate.

2. Fabrication

The hybrid III-V-on-silicon laser consists of a DFB grating defined on a 400 nm thick silicon waveguide layer using 193 nm deep UV lithography with the III-V gain region bonded on top. By adhesively bonding the InP epitaxial layer stack to the planarized patterned SOI using DVS-BCB, the coupling coefficient of the laser can be controlled by varying the thickness of the bonding layer. Taper structures are used to couple the DFB to the passive silicon waveguide layer. Fig. 1(a) shows a top view of the fabricated devices connected to silicon fiber-to-chip grating couplers. The longitudinal cross-section of the device is shown in Fig. 1(b). The separation between the III-V and silicon is 50 nm and the gratings are etched 180 nm deep and have a duty cycle of 50%. A quarter wave shift is implemented in the middle of the laser cavity to achieve stable single mode operation. The III-V layer stack consists of 6 InGaAsP quantum wells (photoluminescence peak at 1.55 µm) sandwiched between InGaAsP separate confinement heterostructure layers (bandgap wavelength 1.17 µm) and InP cladding layers.

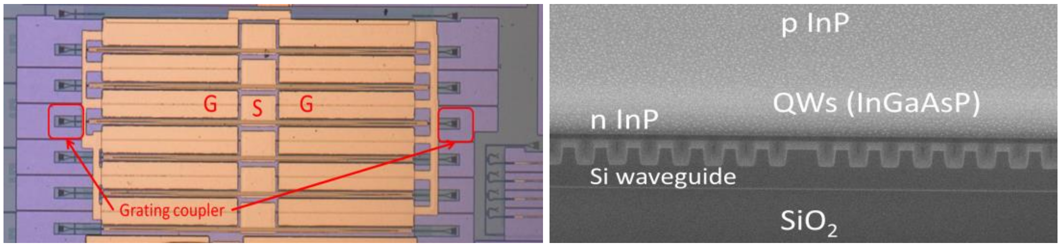

Fig. 1. Top view of the fabricated DFB lasers (a) SEM image of the longitudinal cross section in the middle of the laser (b).

3. Experimental setup

The experimental setup used to characterize the modulation performance of the devices is shown in Fig. 2. An electrical PAM-4 signal is generated by a Keysight M8195A AWG and then amplified by a SHF-S708 high speed RF amplifier. A low noise DC current is combined with the RF data using a bias-tee and the output is used to drive the laser through a GSG RF probe. The laser is biased at 100 mA and a 1.5 V_{pp} data signal is used. The average laser output power coupled to the silicon waveguide is 6 mW in this case. The optical data signal is propagated through a 2 km non-zero dispersion shifted fiber (NZ-DSF) with a dispersion coefficient of 4.5 ps/nm*km at 1550 nm. At the receiver side, a variable optical attenuator (VOA) and a 40 GHz Discovery Semiconductors photodiode together with a SHF high-speed amplifier are used to boost the received signal to the desired level. The electrical data is captured by a Keysight DSA_Z 63 GHz real time oscilloscope. The saved data was then off-line processed for BER estimation with and without equalization.

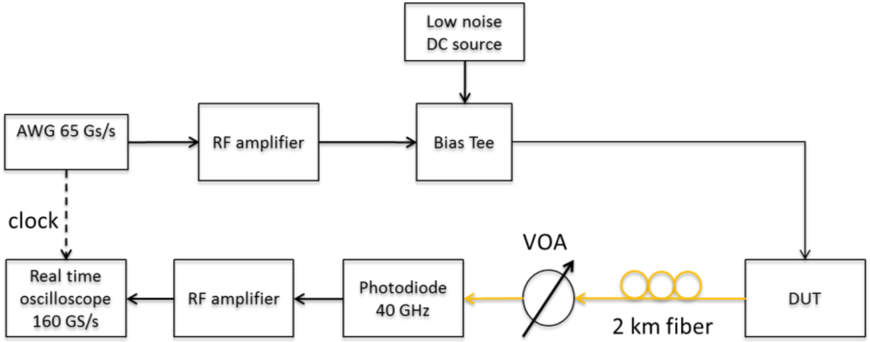

Fig. 2. Experimental setup

3. Results and discussion

The eye diagrams for PAM-4 back-to-back and after 2 km NZ-DSF transmission measurements are depicted in Fig. 3. PRBS sequence lengths of 2^7-1 and 2^{15} are used. In Fig. 3(a,b), eye diagrams of the 2^7-1 with and without the fiber are shown respectively. The same trend is depicted in Fig. 3(c,d) for 2^{15} pattern. Comparing the eye diagrams back-to-back and after 2km NZ_DSF a deterioration can be observed, linked to the interaction between chromatic dispersion in the fiber and inherent chirp of the laser. The resulting BER evaluated for both PRBS pattern lengths in the B2B and 2km fiber transmission cases are presented in (Fig. 3(e)). Forward Error Equalization (FEE) equalization with 10 taps is used at the receiver side.

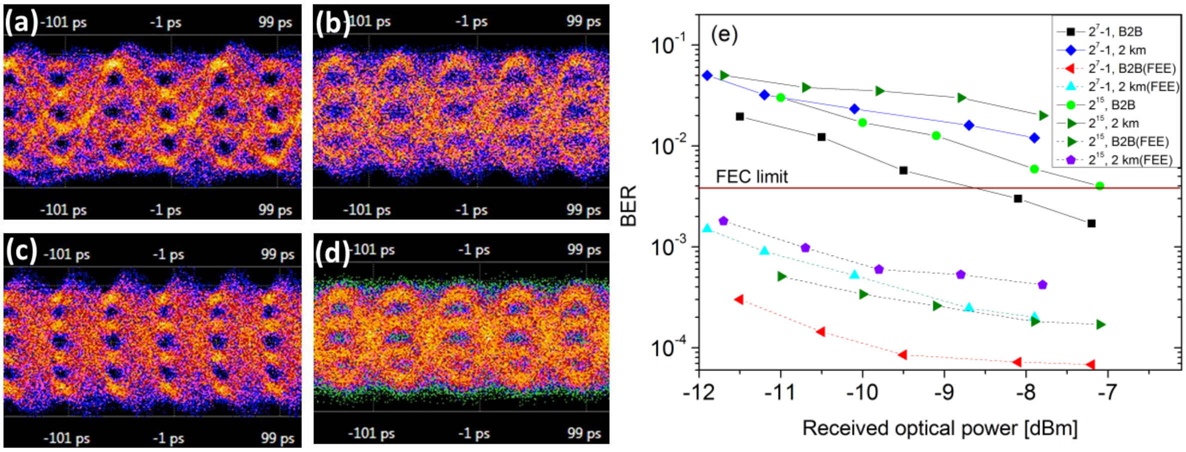

Fig. 3. Eye diagrams for PAM-4 at 20 GBaud (left), BER measurements for back-to-back and 2 km NZ-DSF configuration (right).

Three level duobinary data modulation and detection using lower bandwidth devices has been reported recently [7]. Since the laser S_{21} electro-optic response looks similar to the 5th order Bessel function with 3dB bandwidth of 15 GHz, we were able to exploit this fact and generate an electrical duobinary using the laser as the a pass filter. The duobinary signal presents three levels. The lower and upper signal levels represent sequences of 0s and 1s respectively whereas a transition from 0 to 1 or from 1 to 0 is mapped on the central level. As such, knowledge of the previous transmitted bit is needed in order to decode the current one but differential coding can be used to prevent error propagation. Eye diagrams for 40 Gb/s duobinary are shown in Fig. 4. Signal post processing, decoding and BER estimation were performed offline using VPIlabExpert for different PRBS lengths of 2^7-1 and 2^{15}(Fig. 4(e)). The duobinary BER is marginally worse than PAM-4 for the same PRBS lengths even if its baudrate is double.

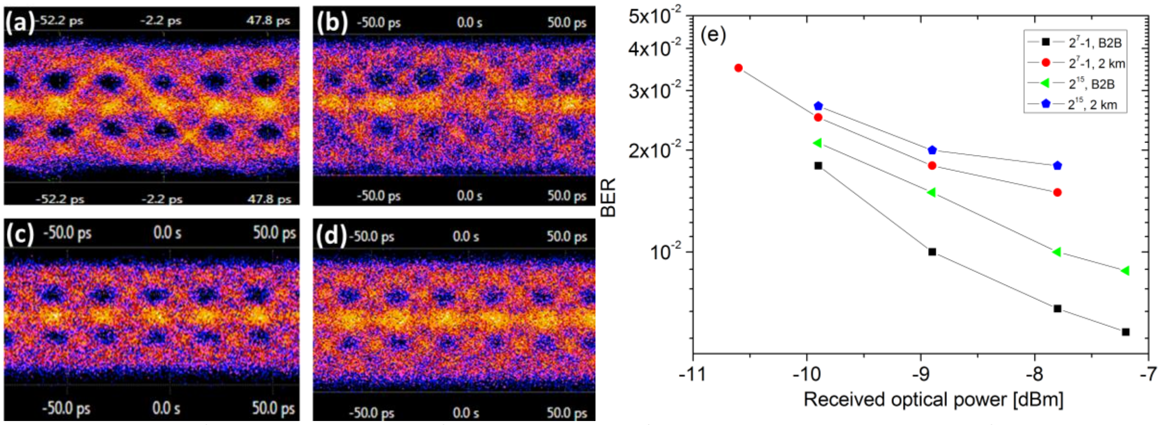

Fig. 4. Eye diagrams for duobinary at 40 Gb/s (left), BER measurements for back-to-back and 2 km NZ-DSF configuration (right).

4. Conclusion

We demonstrate 40 Gb/s direct modulation of a hybrid InP/SOI DFB laser using multilevel PAM-4 data format. Two PRBS sequence lengths of 2^7-1 and 2^{15} have been used to perform the transmission over 2 km NZ-DSF. Three level duobinary modulation was measured at 40 Gb/s using a device with 15 GHz bandwidth 3 dB.

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References

[1] C. Steven, Proc. OFC, SC239, (2011)
[2] P. Pepeljugoski et al., Proc. ECOC, Tu4G3, (2010)
[3] F. Karinou et.al., IEEE Photon. Technol. Lett., (27), No. 17, (2015)
[4] M. Muller et.al., in Proc. 22nd IEEE Int. Semicond. Laser Conf., Kyoto, Japan (2010)
[5] N. Nakamura et.al., in OFC, W2A.53 (2015)
[6] A. Abbasi et.al., Opt. Express (23), 26479-26485 (2015)
[7] Z. Li et.al., Opt. Express (16), 20249-56 (2015)