2 × 56 Gbps Electroabsorption Modulated III-V-on-Silicon DFB Laser

A. Abbasi(1), L. Abdollahi Shiramin(1), B. Moeneclaey(2), J. Verbist(2), X. Yin(2), J. Bauwelinck(2), D. Van Thourhout(1), G. Roelkens(1), G. Morthier(1)

(1) Photonics Research Group, Ghent University—IMEC, Ghent, Belgium (amin.abbasi@ugent.be)

(2) IDLab, Ghent University - imec, Ghent, Belgium

Abstract We present an InP-on-Si DFB laser integrated with electro-absorption modulators on each side, using a single epitaxial structure for laser and modulators. Two electrically isolated tapers couple the light to the Si waveguide, while simultaneously acting as modulators.

Introduction

The exponential growth of data traffic creates a huge demand for very high bitrate optical interconnects, a.o. for intra-datacenter and inter-datacenter interconnects. The IEEE 400 GbE standard is going to be implemented in the next generation short reach interconnects[1] and it requires low cost, small footprint and high speed optical transceivers. An electro-absorption modulator (EAM) integrated with a laser is a great candidate for most proposed 400 GbE cases, which are using intensity modulation and direct detection[2]. Although Pulse-Amplitude-Modulation (PAM-4) is receiving a lot of attention, Non-return-to-zero on-off-keying (NRZ-OOK) is generally preferred for this optical modulation scheme because of simpler and cost effective electronics, both at the transmitter and the receiver side.

Externally modulated lasers (EMLs) based on an InP monolithic integration have been demonstrated at 2x56 Gbps using EA modulators at both sides of the DFB laser[3]. Recently, heterogeneous integration of III-V-on-Si got a lot of attention because of its distinctive features. Silicon-on-insulator (SOI) provides an alternative platform to InP that, from a design perspective, adds more functionally and freedom to a photonics integrated circuit (PIC). Due to the high index contrast of the silicon-on-insulator, it allows to fabricate all sorts of passive components (e.g., wavelength multiplexers and polarization control elements) with very small dimensions and low loss. The compatibility with CMOS fabrication tools also allows very large volume fabrication. Based on this technology, we previously demonstrated direct laser modulation at 56 Gbps by exploiting the photon-photon resonance effect[4] as well as a single EAM modulator integrated with a DFB laser working at 56 Gbps[5].

In this paper, a dual electroabsorption modulator architecture with a single DFB laser, similar to that of ref. 3, is presented, integrated on a silicon photonic integrated circuit. Each EAM can be operated independently at 56 Gbps with 1.5 V_{pp} drive signals. The EAMs are in essence reverse biased tapers, used to couple light from the InP membrane to the Si waveguide[6].

Fabrication and static characterization

The EML transmitter is realised by integrating the III-V epitaxial structure on top of the SOI waveguides using adhesive bonding and subsequent processing[6]. Optimized low reflection coupling between the InP waveguide and the 400nm thick silicon waveguide is obtained by adiabatic tapering of both the InP mesa and the Si waveguides. The DFB laser section is 340 µm long and each taper is 200 µm long. In order to electrically isolate the two tapers from the laser before P-contact metallization, 45 degree isolating patterns are created on the III-V waveguides using contact UV lithography followed by ICP dry etching through the InGaAs P^{++} contact layer (200 nm) and partially through the P-InP top cladding layer (300 nm) (Fig. 1).

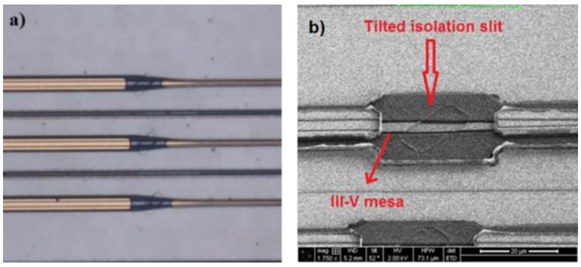

Fig. 1: Microscope image of the isolation area after the P-contact metallization (a), SEM image of the isolation area (45° angled rectangle is used to reduce optical back reflection) (b).

The etched area is 20 µm wide and 500 nm deep. This provides a DC isolation resistance of 16 kΩ between both EAMs.

The active layer consists of 6 InGaAsP quantum wells sandwiched between two 100 nm thick

InGaAsP separate confinement heterostructure layers. The threshold current of the laser at room temperature is 22 mA and a series resistance of 8 Ω was measured. At 0 V EAM bias the output power in the silicon waveguide is above 1 mW at 50 mA bias current for each side. As shown in Fig. 2, the laser spectrum is single mode at 1564 nm with more than 45 dB side mode suppression ratio. The output power from both grating couplers is nearly identical.

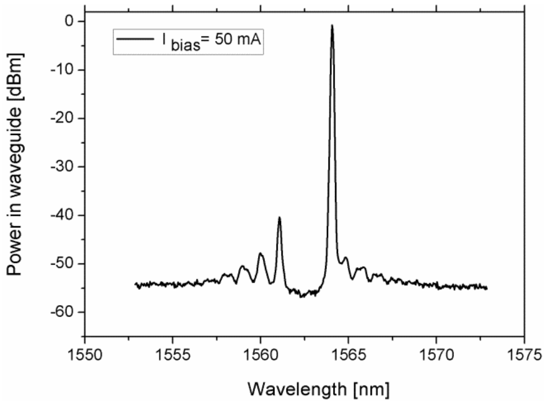

Fig. 2: The laser spectrum at 50 mA bias current and 0 V EAM bias voltage.

Since the same epitaxial structure is used for both the laser and the EAMs, lasers with emission wavelength closer to the bandgap were selected to ensure a low insertion loss and high modulation efficiency of the EAM. The bias current to the DFB was fixed to 50 mA. The normalized output powers from each EAM output are depicted in Fig. 3 versus the reverse bias voltage of the EAMs. An extinction ratio of ~17 dB is obtained for a voltage swing of 2 V for both tapers.

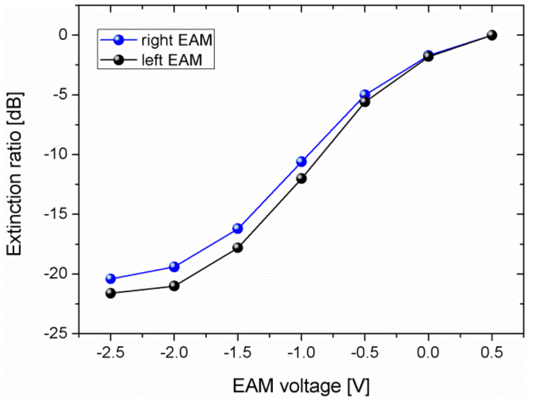

Fig. 3: Static extinction ratio for both EAMs, I_{DFB} = 50 mA, T = 20 °C.

Dynamic characterization

Two identical RF GSG probes with 100 µm pitch are used to measure the small signal electro-optic response of the device with a KEYSIGHT PNA-X 67 GHz network analyzer (Fig. 4). 0.7 V reverse bias was applied on each taper. The 3 dB modulation bandwidths for both EAMs are about 20 GHz. In order to measure the RF cross talk between EAMs, a single sinusoidal tone with 1 V voltage swing is applied to one of the tapers and then measured at the other taper using GSG probes. More than 40 dB RF isolation was measured in both directions up to 25 GHz.

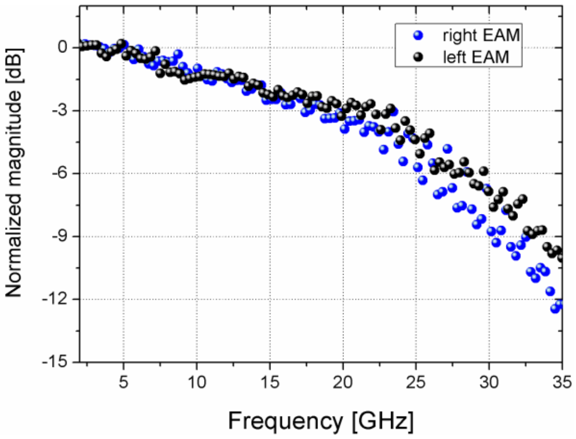

Fig. 4: Small signal frequency response of each EAM at 0.7 V reverse bias voltage, I_{DFB} = 50 mA, T = 20 °C.

Two channels of a Keysight M8195A AWG are used to generate NRZ-OOK PRBS sequences of 2^7-1 and 2^{15} at different bitrates with a voltage swing of 1.5 V_{pp}. The DFB laser was biased at 50 mA and 0.7 V reverse bias voltage was applied to both tapers. An Erbium Doped Fiber Amplifier (EDFA) is used to compensate for the grating coupler loss and to boost the optical signal. An optical filter (0.3 nm bandwidth) is used to suppress the amplified spontaneous emission of the EDFA. The signal is directly detected by a commercial photodiode and trans-impedance amplifier (TIA) with a bandwidth of 32 GHz. Then the electrical signal is captured by a real time oscilloscope (Keysight DSA-Z63) with a sample rate of 80 GS/s. The measurement is performed for both the back-to-back case and after transmission over 2 km of non-zero dispersion shifted fiber (NZ-DSF) with a dispersion of 4.5-6 ps/nm.km at the laser wavelength. Eye diagrams are shown in Fig 5 for both left and right EAMs at 56 Gbps.

A long data stream is stored using the real time oscilloscope and off-line Bit Error Rate (BER) analysis is performed using Matlab. BER measurement results will be presented during the conference, but a BER below the hard-decision FEC threshold was obtained in all cases. All the measurements were done while both EAMs were biased and uncorrelated data was applied on each EAM. Each optically

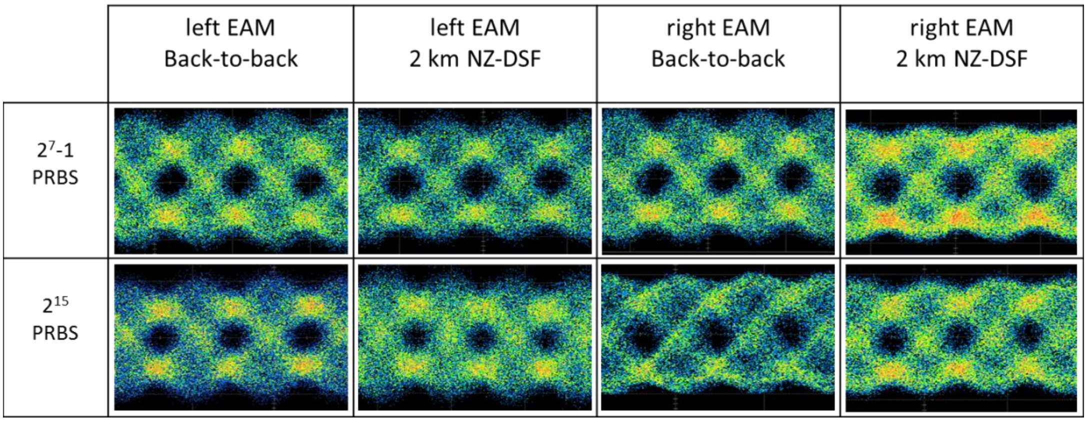

Fig. 2: Eye diagrams at 56 Gb/s NRZ-OOK with PRBS 2^7-1 pattern length (first row); PRBS 2^{15} pattern length (second row); left EAM for both back-to-back and after 2 km NZ-DSF (two left columns); right EAM for both back-to-back and after 2 km NZ-DSF (two right columns. I_{DFB} = 50 mA, V_{EAM} = -0.7 V, T = 20 °C.

modulated signal was measured separately using a single receiver. This is similar to a multilane data communication link using two optical fibers. However by using a 2D grating coupler, one could multiplex the two outputs in polarization and use a single optical fiber for the transmission at an aggregate data rate of 112 Gbps.

Conclusions

We demonstrate a 2 x 56 Gbps optical transmitter based on a single III-V-on-silicon DFB laser, integrated with electro-absorption modulators on both sides. The same epitaxial layer is used for the laser and the EAMs, which eases the fabrication process. After simultaneously applying two uncorrelated 1.5 V_{pp} drive signals to the tapers we have not observed any noticeable cross talk between each channel. The III-V-on-Si heterogeneous integration is becoming an interesting platform for short reach datacom applications, especially for inter and intra datacenter links. Multiplexing four wavelengths (four lasers) with dual EAMs will enable us to transmit a 400 Gbps data stream using a single III-V-on-Si PIC.

Acknowledgements

The authors acknowledge 3-5 Lab for supplying the III-V epitaxial wafer and the Belgian IAP network Photonics@be 14/GOA/034 and the UGent special research fund BOF for financial support. Some of the high speed equipment used in the work has been financed by the Hercules program of the Flemish government.

References

[1] http://www.ieee802.org/3/bs/, accessed May. 16th, (2016).

[2] T. Fujisawa et al, "1.3 µm 50 Gbit/s electroabsorption modulators integrated with DFB laser for beyond 100G parallel applications", Elec. Lett., Vol. **47**, no. 2, pp. 708-709, (2011).

[3] M. Theurer, et al. "2× 56 Gb/s from a double side electroabsorption modulated DFB laser", Proc OFC, Tu3D.6, Anaheim, (2016).

[4] A. Abbasi, et al, "56 Gb/s Direct Modulation of an InP-on-Si DFB Laser Diode", Optical Interconnect Conference, New Mexico (2017).

[5] A. Abbasi, et al, "56 Gb/s Electro-Absorption Modulation of a Heterogeneously Integrated InP-on-Si DFB Laser Diode", Proc OFC, Th4G.2, Los Angeles, (2017).

[6] S. Keyvaninia, et al, "Heterogeneously integrated III-V/silicon distributed feedback lasers", *Opt. Lett*., Vol. **38**, pp. 5434-5437, (2013).