56 Gb/s Electro-Absorption Modulation of a Heterogeneously Integrated InP-on-Si DFB Laser Diode

A. Abbasi[1,*], B. Moeneclaey[2], J. Verbist[1,2], X. Yin[2], J. Bauwelinck[2], G. Roelkens[1], G. Morthier[1]
[1]*Photonics Research Group, INTEC, Ghent University—IMEC, 9000 Ghent, Belgium*
[2]*Ghent University - imec, IDLab, Dep. INTEC, 9000 Ghent, Belgium*
**aamin@intec.ugent.be*

Abstract: Electro-absorption modulation of a heterogeneously integrated InP/Si DFB laser is demonstrated by reverse biasing the InP tapers, used to couple the light between the InP and the Si waveguides. Modulation at 56 Gb/s is demonstrated.
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1. Introduction

Modulation of laser diodes at data rates of 50 Gb/s and higher is attractive for applications in intra and inter datacenter interconnects. It is expected e.g. that future 400 Gb Ethernet for long and extended reach will be based on lane speeds of 50 Gb/s and the use of NRZ-OOK [1]. Direct and external modulation at such bitrates has been demonstrated with traditional InP devices [2-3].

There is however an increasing interest in using silicon photonics for optical interconnects. Due to the high index contrast of the silicon-on-insulator (SOI) platform, it allows to fabricate all sorts of passive components (e.g., wavelength multiplexers) with very small dimensions. The compatibility with CMOS fabrication tools would also allow very large volume fabrication. For directly modulated lasers and external modulators, integration on SOI makes it possible to co-integrate with the driver electronics. The short electronic connections in this case allow to avoid impedance controlled interconnects, resulting in much lower power consumption for the transmitters and much higher electrical bandwidth as a result of the lower RC constant.

As a result of the strong interest in silicon photonics, there has been also significant progress in III-V on silicon lasers. Direct modulation of such heterogeneously integrated DFB lasers at 40 Gb/s has been demonstrated recently [4]. Electro-absorption modulation using a 100 μm long hybrid III-V/Si modulator has been demonstrated at 50 Gb/s and small signal bandwidths beyond 67 GHz were demonstrated with the concept [5]. However, the modulator requires special epitaxy and travelling wave electrode design.

Here we present a simpler scheme for the electro-absorption modulation of the output of a heterogeneously integrated DFB laser. The transmission through one of the tapers that is used to couple the light between the InP and the Si waveguide is modulated by applying a reverse voltage, through the electro-absorption effect. The active layer for the DFB laser and the EA modulators (or tapers) is identical and the only difference of the new devices with the previously reported InP-on-Si lasers is that the top contacts for the DFB laser and the tapers are now separate. Using this simple approach, we were able to demonstrate modulation at 56 Gb/s.

2. Device structure and static characteristics

The device structure is shown schematically in Figure 1(a) and is identical to the heterogeneously integrated DFB lasers that have been discussed before in several publications (see also [6]), except that the two 200 μm long InP tapers on either side of the DFB lasers are electrically isolated and can be separately biased and modulated. Trenches were etched in the top InGaAs p-contact layer and part of the p-InP layer and the isolation between DFB and taper section was measured to be 3 kΩ. The active layer consists of 8 InAlGaAs quantum wells. Threshold currents at room temperature of 20 mA, output powers in the silicon waveguide above 3 mW at 100 mA, and a series resistance of 7 Ω were measured for the lasers. Typical optical emission spectra have been shown before. The spectra show a wide stop band and a side mode rejection of over 40 dB.

For the electro-absorption experiments, lasers with emission wavelength closer to the bandgap were selected. The bias current to the DFB was fixed to 50mA and -0.3V negative bias was applied on the taper connecting the DFB to the single mode fiber (via a grating coupler in the SOI). The lower bias current and the negative bias reduced the DC power in the silicon waveguide by 10 dB as compared to the output power reported in [6] at 100 mA bias current. Figure 1(b) shows the normalized output power versus the reverse (DC) bias applied to the taper for 4 different bias currents to the DFB laser. An extinction ratio of 15 dB is obtained for a voltage swing of 1.5V and there is little dependence on the laser bias current, indicating that absorption saturation is not occurring.

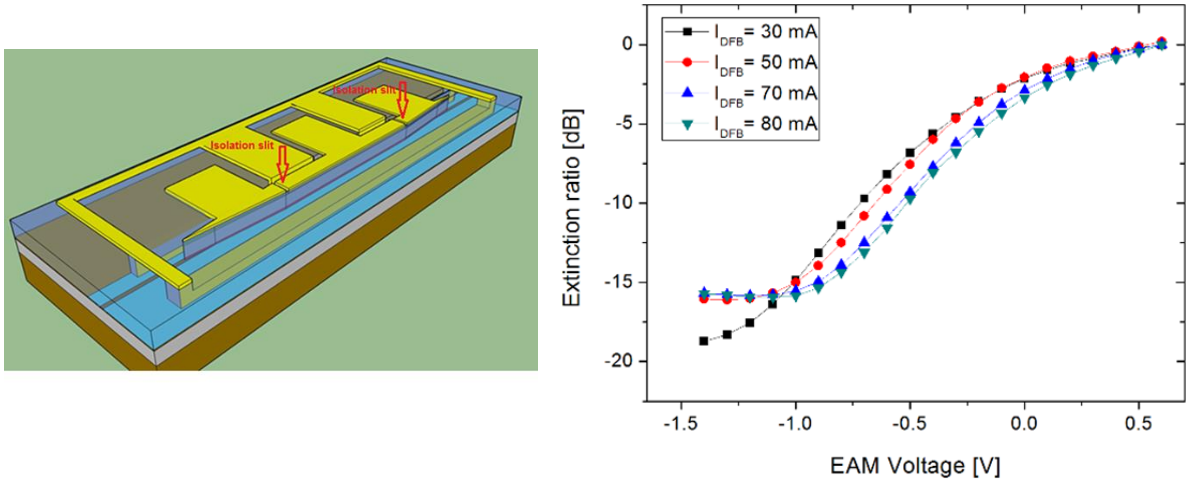

Figure 1. Schematic of the device structure (left) and normalized DC output power versus reverse bias on the taper (right).

3. Small signal modulation characteristics

The small signal characteristics, measured at 50 mA bias current to the DFB laser and for two bias voltages on the taper are shown in Figure 2. For negative bias voltages on the taper, a 3 dB bandwidth of around 25 GHz is found, and the entire characteristic is that of an RC circuit. For the positive bias of 1V, the taper acts as a semiconductor optical amplifier and the modulation bandwidth is determined by the inverse carrier lifetime and is very small.

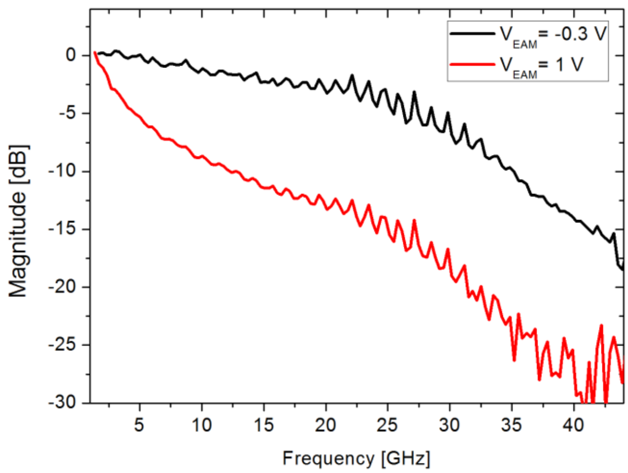

Figure 2. Small signal modulation characteristics for different bias voltages to the taper and 50 mA bias current to the DFB laser.

4. Large signal modulation characteristics and transmission experiment

Using a Keysight M8195A AWG, large signal modulation at different bitrates was performed with a voltage swing of just 0.8Vpp. The DFB laser was again biased at 50mA and -0.3V DC voltage was applied to the taper as well. Transmission over 2 km of nonzero dispersion shifted fiber (NZ-DSF) was performed as well. Open eyes were obtained up to 56 Gb/s, both for the back to back case and after transmission over 2km NZ-DSF fiber (with a dispersion of 4.5-6 ps/nm.km at the laser wavelength of 1570 nm). Figure 3 shows the eye diagrams at 50 and 56 Gb/s for a pattern length of 2^7-1. The BER curves for the back-to-back case and after transmission over the 2 km of NZ-DSF fiber are given in Figure 4. The bit error rate is below the 7% HD-FEC limit in all cases.

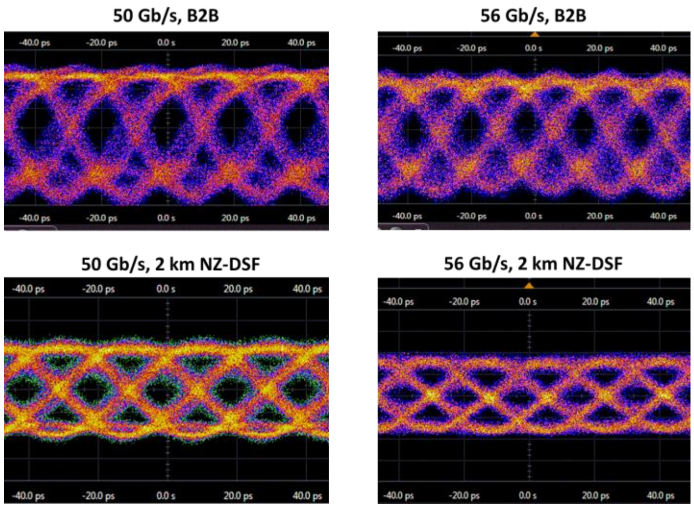

Figure 3. Eye diagrams for 50 and 56 Gb/s for the back to back case (upper eyes) and after transmission over 2 km of NZ-DSF fiber (lower eyes).

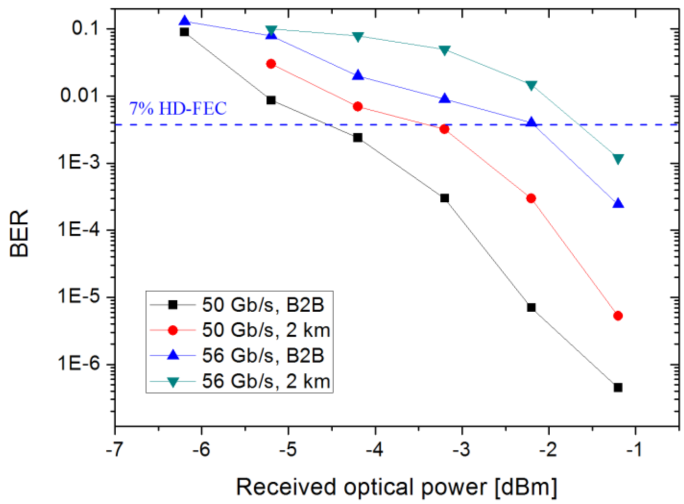

Figure 4. BER vs received optical power for 50 and 56 Gb/s for the back to back case and after transmission over 2 km of NZ-DSF fiber.

4. Acknowledgement

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5. References

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