50 fJ-per-bit, High Speed, Directly Modulated Light Sources for On-chip Optical Data Communications

O. Raz, H.J.S. Dorren
Eindhoven University of Technology, Den Dolech 2, 5600MB, Eindhoven, The Netherlands
R. Kumar, G. Morthier
INTEC, Ghent University—IMEC, St-Pietersnieuwstraat 41, 9000 Ghent, Belgium
P. Regreny, P. Rojo-Romeo
Institut des Nanotechnologies de Lyon INL-UMR5270, CNRS, Ecully F-69134, France
o.raz@tue.nl

Abstract: By employing optical injection-locking the direct modulation bandwidth of a 10µm diameter disc laser is increased to 15GHz. In addition, modulation at 20Gb/s is demonstrated with only 1mW DC bias & 190mV data signals (50fJ/bit)

OCIS codes: (130.3120) Integrated optics devices; (200.4650) Optical interconnects; (140.3520) Lasers, injection-locked

1. Introduction

Future multi teraflops chips are envisioned to include a photonic communication layer [1]. Silicon on insulator (SOI) is considered the most suitable photonic wave guiding layer [2] as it is CMOS compatible. Since silicon is a poor light emitting material, research effort is focused on making high speed and low power silicon modulators in SOI. These have been demonstrated in both reverse and forward bias operation regime [3], and all rely on an external light source. As has been recently published [3], SOI modulators are limited in one or more of the following aspects: operation bandwidth, footprint, required drive voltage, extinction ratio, and/or insertion losses. The reported silicon modulators are an engineering compromise between the above mentioned restrictions. For example, achieving high extinction ratio leads to increased insertion loss and limited modulation speed.

The power consumption of the photonic links is driven by the detection sensitivity of the receiver. If the modulator's insertion loss is high, more optical power is needed at its input. Lower insertion losses modulators have poorer extinction ratio. A typical reported [3] extinction ratio of 1-2dB requires an extra 8dB (for a 1.5dB ER) of optical power at the receiver to achieve the same bit error rate, again requiring more optical power. The extinction ratio can be improved by increasing the voltage swing, but this requires high voltage RF amplifiers which consume precious chip footprint and power. An alternative solution for on chip optical data generation can be found with directly modulated InP membrane disc lasers. These lasers operate at very low currents (threshold is ~0.2 mA), are extremely compact (~100µm^2) and can also be fabricated with CMOS compatible techniques [4]. Moreover, as shown in this paper, the required voltage swing to achieve high extinction ration is only several hundreds of milli Volts, compatible with standard CMOS logical levels. In order to overcome previously reported limited direct modulation properties of InP disc lasers [4] we suggest an alternative method - injection locking. Such an approach has been successful in obtaining multi tens of GHz bandwidth in both DFB [5] lasers and VCSELs [6].

In this paper we demonstrate for the 1st time, operation of injection locked InP membrane disc lasers, with a 15GHz 3dB bandwidth. We give first BER measurements of a directly modulated injection locked disc laser source at 10 and 20Gb/s. The receiver sensitivity penalty (compared to commercial LiNbO3 Mach-Zehnder) is 5 and 7 dB respectively. The disc laser consumes only ~1 mW of electrical power for biasing and 350 & 190 mV p-t-p voltage swing, for the data signals for 10 & 20Gb/s respectively, making the energy consumption per bit as low as ~50 fJ, and the transmitter compatible also with future CMOS logic level voltages. The demonstrated injection locked directly modulated InP disc laser can meet or exceed the performance of state-of-the-art reported silicon modulators [3] in operating speed (10 Gb/s error free, low BER at 20 Gb/s), extinction ratio (6.2 dB@10Gb/s), drive voltage (350 mV@10Gb/s), power consumption (1 mW), external laser power (1 mW) and footprint (100 µm^2). By further integrating a 2nd disc laser, for seeding, the need for an external laser is removed, simplifying packaging and dramatically lowering the power consumption for the entire system.

2. Device structure and characterization

The microdisc is etched in a thin InP-based membrane, which contains 3 compressively strained InAsP quantum wells with a thickness of 6 nm in 15 nm Q1.2 barrier layers. The InP-based membrane is bonded on top of SOI with a thin layer of Benzocyclobutene (BCB). The oxide layer contains a silicon wire waveguide with a 500 nm width and a thickness of 220 nm. The laser mode is evanescently coupled to this waveguide. In figure 1 we show typical L-I & V-I curves for a 10 µm diameter disc with a threshold current of ~300µAmps. Unlike previously reported devices [4], the device exhibits very smooth bi-directional operation until ~ 2mAmps and then reverts to uni-directional lasing with a dominant counter clockwise lasing with >15dB extinction ratio between the two lasing directions.

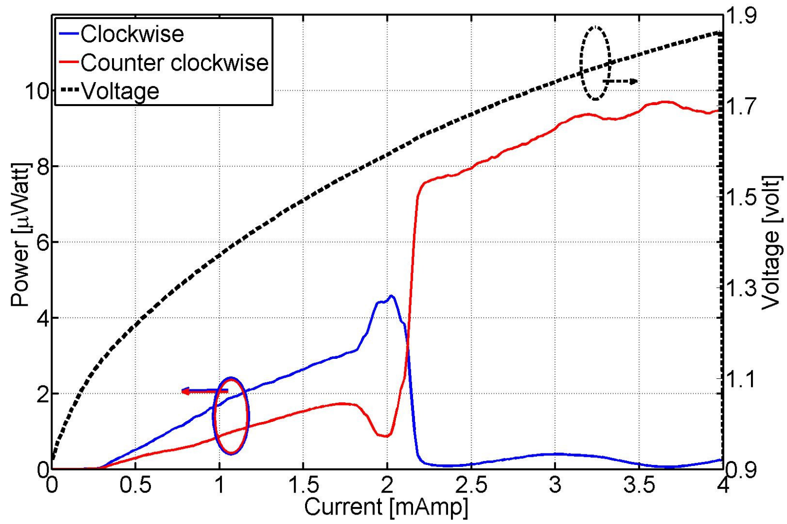

Fig. 1. L-I and V-I curves for 10µm diameter disc

3. Response to small signal modulation

In order to establish the expected improvement in direct modulation bandwidth, the electrical to optical transfer function was measured. In Figure 2 we see the measured S21 response of the 10µm disc with and without an external injection. The disc was biased at 0.75 mA (x2 threshold current) and was operating at single mode around a wavelength of 1558.8 nm. An external laser with a wavelength around this free running mode (±50 pm) and an in-silicon power of 300 µW was used to injection lock the disc. It is clear that the device response is enhanced, with the 3dB bandwidth pushed to 15 GHz, twice as much as obtained for the free running device.

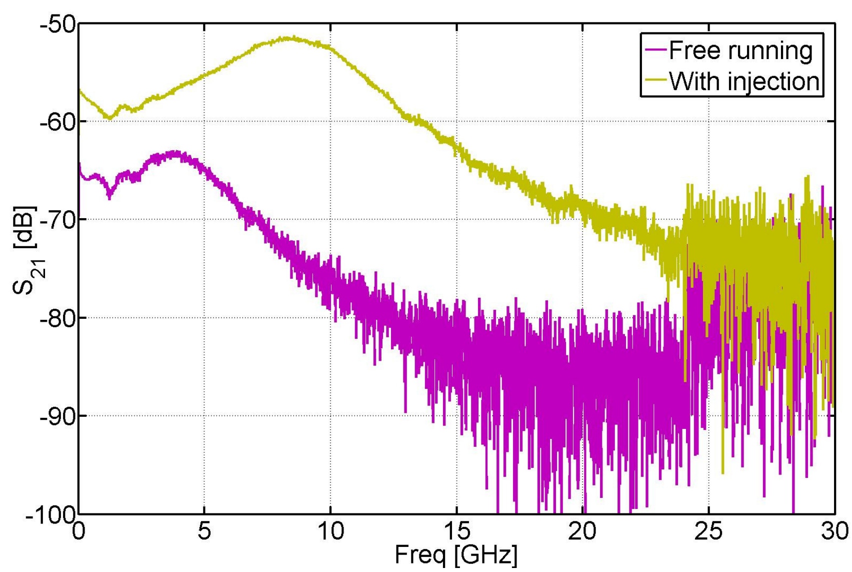

Fig. 2. Electrical to optical S21 response with and without injection

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4. Response to digital modulation

The small signal response is a good indication for the possible digital modulation bandwidth which can be obtained. Generally speaking, for Non Return to Zero (NRZ) amplitude modulation, a rule of thumb is that the analog bandwidth should be 70% of the eventual bit rate at which the NRZ data is generated. In order to establish that broadband digital modulation is possible for injection locked InP membrane lasers, we employed a pattern generator to electrically modulate the current driving the lasers. This modulation current is added to the DC bias current. Based on the S21 response it was estimated that the disc laser could support up to 20 Gb/s digital modulation. The bias current was set to 0.75 mA and the modulation signal was set to 350 mV and 190 mV for 10 and 20 Gb/s respectively. In figure 3 we compare the BER performance of an MZM modulator with that of the InP disc laser in terms of eventual receiver sensitivity for a PRBS sequence of 2^7-1(using identical signal generator /photo-detector and Bit Error Rate analyzer). At 10Gb/s the extinction ratio was measured to be 6.2dB, while the extinction ratio for the 20Gb/s case was only 1.65dB. Measured receiver sensitivity penalties at lowest BER are 5 and 7dB for 10 and 20 Gb/s speeds respectively. Operation for longer PRBS sequences, which require higher power levels at the receiver, was not performed due to limited hardware (mainly exceeding the damage threshold of the photo detectors used).

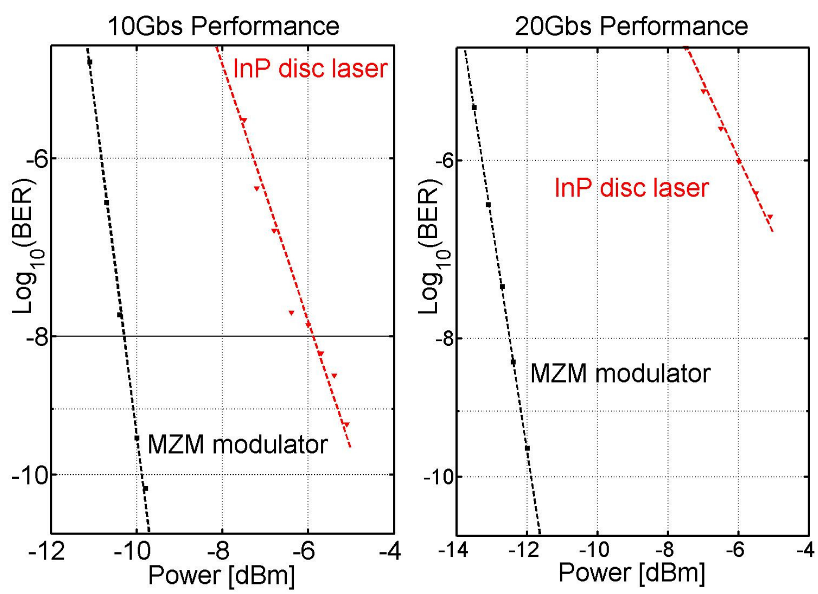

Fig. 3. 10Gb/s & 20 Gb/s BER performance

5. Conclusions

We demonstrate how by optical injection locking the analog modulation bandwidth of an InP disc laser can be doubled to reach 15GHz, 3dB bandwidth. Low BER values (almost error free), at a bit rate of 20Gbs can be obtained and error free operation is shown at 10 Gb/s with an extinction ratio of 6.2dB. Remarkably, the required electrical signaling for both 10 and 20 Gb/s data transmission require only 1 mW of DC biasing and a voltage swing of several hundreds of milli Volts, which is compatible with future generations of CMOS logical levels.

6. References

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