Above 40 Gb/s Direct Modulation of a Heterogeneously integrated III-V-on-silicon DFB Laser

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Abstract: Short-reach optical communication based on directly-modulated lasers is getting a lot of attention. We review our recent work on InP membrane laser diodes, heterogeneously integrated on SOI for high-speed communication. Transmission measurements will be discussed based on this technology.

OCIS codes: (140.3490) Lasers, distributed-feedback; (060.4510) Optical communications.

1. Introduction

Exponential growth of the internet for mobile and cloud services is the main driver for high capacity data communication systems. For the most bandwidth hungry systems such as inter and intra-datacenter networks, compact, low-cost and low-power transceivers are needed. Standards for 400 GbE are emerging and some companies have even expressed interest in a Terabit Ethernet standard [1]. Since systems with fewer numbers of channels (i.e. lower complexity, less power consumption and smaller size) are desired, 400-Gbit/s Ethernet transceivers are being introduced based on 8 channels at 50 Gb/s NRZ-OOK and 4 channels with 100 Gb/s PAM-4 modulation [2]. Modulation at 56 Gb/s and beyond with external modulators (Mach-Zehnder and electro-absorption modulators) has been reported [3, 4]. These optical components may not be suitable for short-reach links, where the link distance covers just a few km. Indeed, they result in higher power consumption and come with extra insertion loss compared to direct modulation. Directly modulated VCSELs on the other hand can be a good choice but it is not easy to integrate them into a WDM transmitter and they also may not give enough output power for longer reach links [5]. DFB lasers are much better suited for photonic integration towards WDM and easily provide the required output power for longer distance interconnects. Such laser diodes are in principle also more suited for co-integration with driver electronics implemented in BiCMOS [6]. The shorter electrical connections would then allow avoiding impedance controlled interconnects, resulting in lower power consumption and larger electrical bandwidth.

In the past years, we have been working on directly-modulated InP DFB membrane lasers, heterogeneously integrated onto silicon-on-insulator (SOI) and we'll discuss the progress in that area below. SOI waveguides allow high-density integration of photonic components due to the high omnidirectional index contrast. Passive components like optical filters and multiplexers, as well as the definition of small features such as first order Bragg gratings are achievable using deep UV lithography. Besides passive components, also high-speed photodetectors can be integrated.

2. Design and fabrication

The hybrid laser diode InP/Si waveguides are designed to support a super-mode that is predominantly confined in the III-V, but still has good overlap with the silicon grating. Coupling between the InP mesa and the 400nm thick silicon waveguides is obtained by adiabatic tapering of both the InP mesa and the Si waveguides [7]. The laser light is coupled from the Si waveguide to single mode fiber using surface grating couplers. The wavelength selection is realised by the underlying Bragg grating etched on the Si waveguides. Adhesive bonding is used to integrate the III-V material on the silicon waveguide circuit [7]. A schematic of the laser structure and the guided mode profile are shown in Fig. 1. Very thin bonding layers (as thin as 10 nm) are used to obtain a large coupling coefficient (135 cm^{-1} or higher). The active layer consists of strained MQW material and both InGaAsP and InAlGaAs MQW stacks have been used. The large coupling coefficient gives a small cavity loss, which together with the large confinement factor for the active layer results in a low threshold gain and a large differential gain. The tapers at both ends of the cavity, where the coupling between the InP membrane and the Si waveguide is happening, were so far always pumped and modulated together with the DFB section. We expect to see a flatter electro-optical response if the tapers remain unmodulated (electrically isolated from the DFB cavity). We are investigating the unmodulated tapers scenario and results will be discussed in the conference.

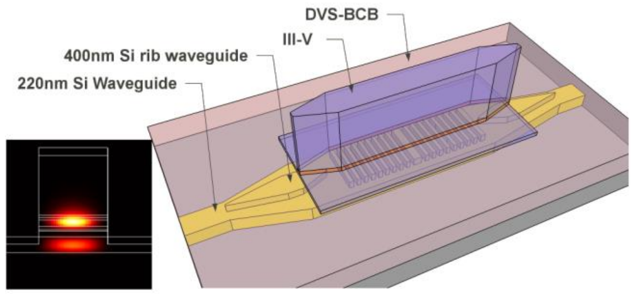

Fig. 1. Simulated mode profile of the InP/Si waveguide (left), schematic of the DFB laser with coupling tapers (right).

3. InGaAsP MQW lasers

The first III-V epitaxial layer which was used in our experiments consisted of a 200 nm thick n-InP contact layer, two 100 nm thick InGaAsP separate confinement heterostructure layers (bandgap wavelength 1.17 µm), 6 InGaAsP quantum wells (6 nm thick, emission wavelength 1.55 µm) surrounded by InGaAsP barriers, a 1.5 µm thick p-InP top cladding and a 300 nm InGaAs contact layer. The total thickness of the bonding layer (BCB and oxide) is 50 nm. This results in lasers with typical threshold current below 20 mA, a power in the Si waveguide of 6 mW at 100 mA and a side mode suppression ratio (SMSR) of 45 dB at a stage temperature of 20℃. The both the laser and the tapers are pumped. The latter act as semiconductor optical amplifer (SOA). The length of the laser is 340 µm and that of the tapers is 220 µm. From the width of the stopband, a coupling coefficient of 135 cm^{-1} was estimated. This laser showed a 3dB small signal modulation bandwidth of 15 GHz at a 100 mA bias current (Fig. 2).

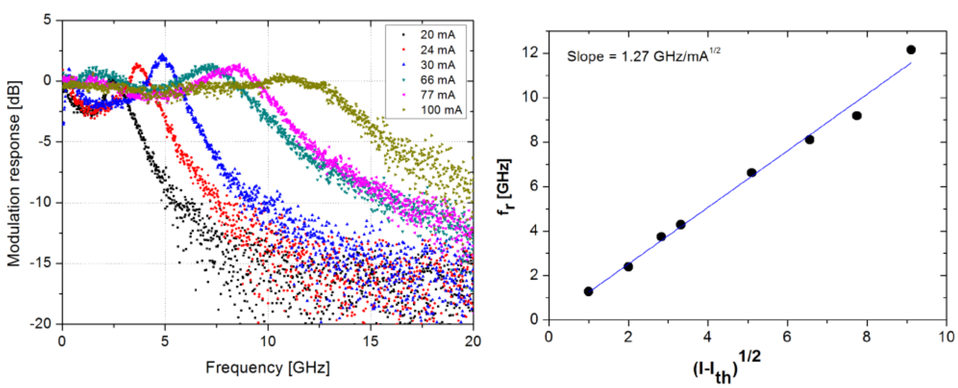

Fig. 2. Small-signal response at different bias currents (left), the dependence of relaxation oscillation frequency on the driving current (right)

NRZ-OOK large signal modulation was demonstrated up to 28 Gb/s, as well as transmission over 2km of NZ-DSF fiber (with a dispersion of 4.5 ps/nm.km) [8]. Eye diagrams are shown in Fig. 3. This laser was also used for 20 Gbaud PAM-4 modulation. Eye diagrams for the back-to-back configuration and after 2 km transmission over NZ-DSF fiber are shown in Fig. 3. Finally electrical duobinary (ED) modulation was used to push the laser modulation speed to 40 Gb/s using NRZ-OOK as an input signal and leveraging the 4th order Bessel filter shape of the laser's electro-optical response. The received data were post-processed off-line for BER estimation with and without equalisation in this case [9].

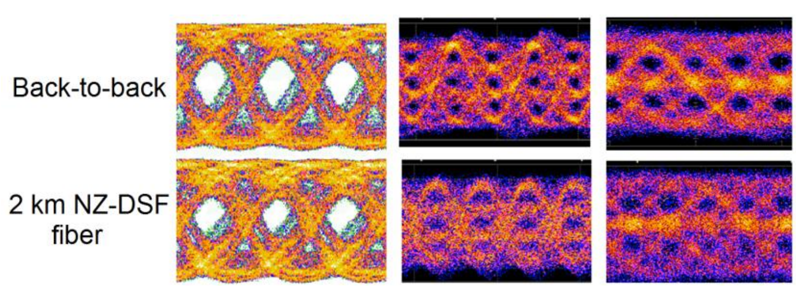

Fig. 3. Eye diagrams for 28 Gb/s NRZ-OOK (left), for 40 Gb/s PAM-4 (center) and for 40 Gb/s electrical duobinary (right).

4. InAlGaAs MQW lasers

The SOI platform on which the lasers are fabricated consists of a 400 nm crystalline Si on a 2µm thick SiO_2 layer. This silica layer poorly transfers generated heat from the InP membrane to the Si substrate. As InAlGaAs active layers perform better at higher operating temperatures, we have recently moved to Al-containing active layers with strained layer MQWs. The small signal modulation response for one of lasers is shown in Figure 4. When excluding the low-frequency part (which may be due to the modulation of the tapers acting as SOAs, or due to spatial hole burning in the laser cavity), we find a 3dB modulation bandwidth of 34 GHz. This high bandwidth is achieved thanks to an external cavity resonance at around 30 GHz [10]. The external cavity is formed by the grating couplers, which reflect about 4% and are separated by about 1000 µm. Large signal measurements are ongoing and the results will be presented during the conference.

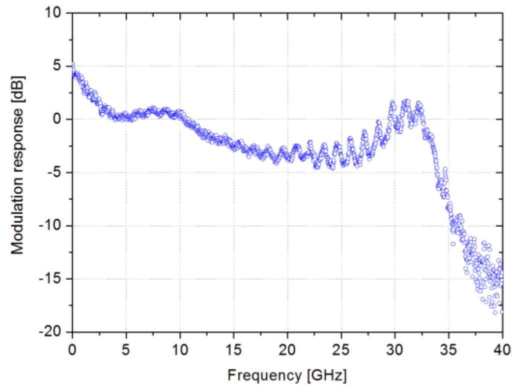

Fig. 4. Small-signal modulation response of an InAlGaAs membrane DFB laser diode with external cavity formed by the grating couplers.

5. Conclusion

InP membrane laser diodes, heterogeneously integrated on SOI, are well suited for high-speed modulation and have potential for modulation above 50 Gb/s. They are moreover ideally suited for integration into WDM sources and for co-integration with driver electronics. Further improvements are expected by further optimisation of the active layer, by modulating only the laser section and not the tapers and by reducing the laser cavity length.

6. References

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