# Enhanced Modulation Bandwidth of Heterogeneously Integrated III-V-on-silicon DFB Laser for 40 Gb/s NRZ-OOK Direct Modulation

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***Abstract:*** *We present 40 Gb/s non-return-to-zero on-off keying direct modulation of a heterogeneously integrated III-V-on-silicon DFB laser. Leveraging the photon-photon resonance effect, the modulation bandwidth is increased to 27 GHz. We demonstrate error free transmission over 2 km non-zero dispersion shifted fiber.*
***Keywords:*** *Distributed feedback laser, Non-return zero, direct modulation, bit error rate*

## 1. Introduction

Silicon photonics technology has attracted much attention for the realization of high aggregate bitrate transceivers for optical interconnect applications. Dense integration of many optical components, using a CMOS line to realize these components and the possibility to co-integrate with electronic circuits, make this platform potentially very important. Nowadays, optical interconnects have relied mostly on directly modulated VCSELs as transmitters. But both the maximum transmission length and the output power, which also determines the maximum reach, are limited for these laser diodes [1, 2]. For very high-speed modulation, e.g. the 400 GbE IEEE Standard, it is possible to use wavelength multiplexed DFB laser arrays, with each laser being modulated directly or externally. However, external modulators increase the circuits' footprint and cost and introduce extra insertion loss [3].

Directly modulated DFB transmitters are mainly developed in the InP platform, where the active area of the laser and passive waveguides are in III-V material [4, 5]. Although these lasers can reach very high bitrates with reasonable power consumption, membrane lasers heterogeneously integrated on silicon-on-insulator (SOI) allow optimizing the performance even more for fast modulation, as the optical confinement in the gain region can be stronger than in a classical III-V laser, enhancing the modulation bandwidth. The output of the III-V-on-silicon laser can be coupled to high performance silicon waveguide circuits. It has been shown earlier that the use of an external, low-loss cavity can further enhance the modulation bandwidth [6] and low-loss external cavities can readily be implemented in the SOI waveguide platform. In this paper, we discuss our recent results at 40 Gb/s NRZ-OOK modulation. We demonstrate error free transmission over a 2 km NZ-DSF at 40 Gb/s.

## 2. Device structure and fabrication

The III-V-on-silicon DFB laser structure is schematically shown in Fig. 1. The DFB grating and coupling tapers are patterned on 400 nm Si rib waveguides in a CMOS pilot line by a 180nm dry etch, after which the waveguide structures are planarized. The fabrication process begins by adhesive bonding of unprocessed III-V epi on the SOI circuit. The 400 nm thick Si waveguides are used to enable an efficient coupling between the III-V mesa and the Si rib waveguide by adiabatic taper structures. More details on the III-V processing can be found in [7]. The device is passivated by PECVD deposition of 600nm thick $Si_3N_4$ and by spin coating of 2 µm of DVS-BCB (Fig. 1). GSG pads were defined at the final stage of the metallization for high-speed measurements. The laser light is coupled from the Si waveguide to a single mode fiber using surface grating couplers.

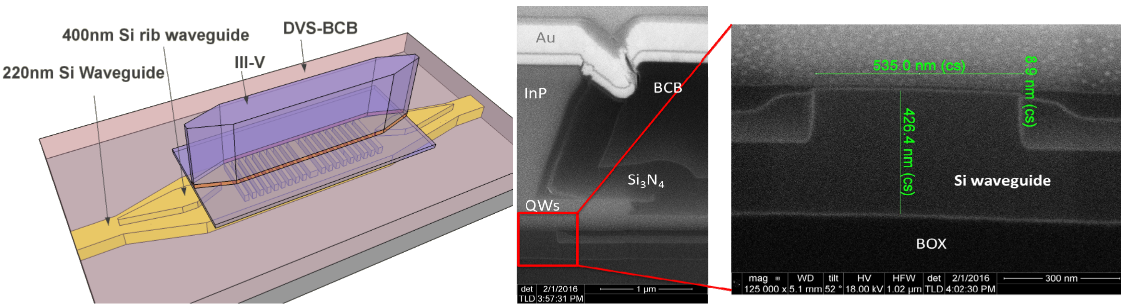


Fig. 1. Schematic of the III-V-on-silicon laser structure (left), cross-section of the fabricated DFB laser (middle), the magnified image of the Si/InP interface (right). The bonding layer is less than 10 nm.

## 3. Device characterization

The device has a 6 Ω series resistance and couples above 5 mW single-mode output power in the Si waveguide for a 100 mA drive current (Fig. 2). A small signal measurement was done with a KEYSIGHT PNA-X 67 GHz network analyzer. When excluding the low-frequency part (which may be due to the modulation of tapers acting as SOAs and due to spatial hole burning in the laser cavity), we find a 6dB modulation bandwidth of 27 GHz at 100 mA (Fig. 3). This bandwidth is achieved because of an external cavity resonance at around 25 GHz. The external cavity is formed by the grating couplers, which reflect about 4% and are separated by about 1000 µm. BER and eye diagrams at 40 Gb/s were measured using an Alnair 400C PPG and a Keysight DSA_Z63 GHz real time oscilloscope. Using a PRBS pattern length of $2^7$-1, we achieved a BER of 1e-9 for a transmission over 2 km DS-SMF (Fig. 3-4). For a pattern length of $2^{31}$-1, there are patterning effects due to the earlier mentioned low frequency roll-off in the small-signal response.

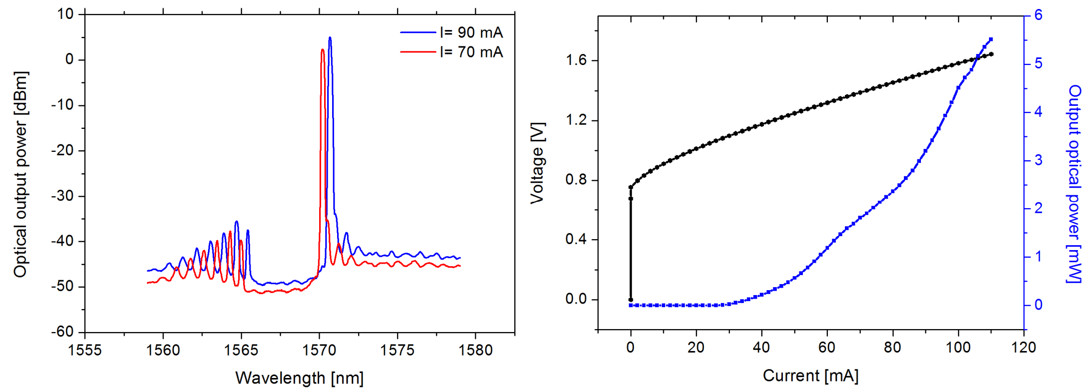


Fig. 2. Single mode spectrum (left), LIV curve of the DFB laser (right)

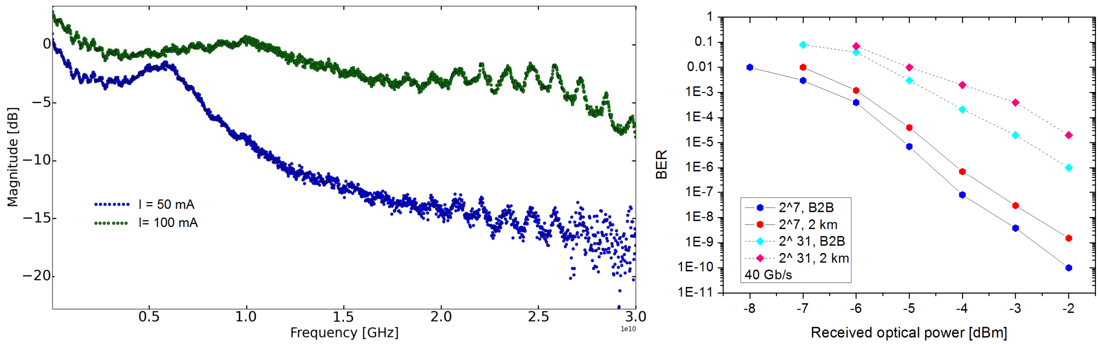


Fig. 3. Small signal response (left), BER vs optical received power at 40 Gb/s (right).

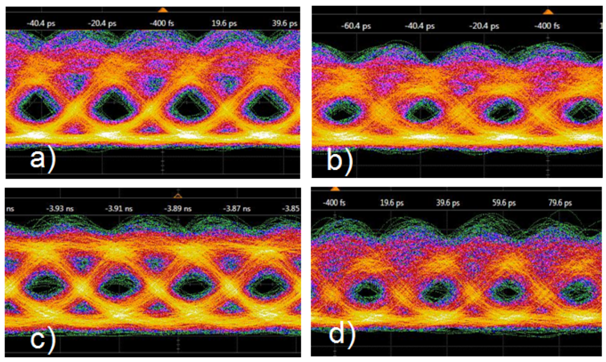


Fig. 4. Eye diagram at 40 Gb/s, for a PRBS length of $2^7$-1 for back-to-back (a) and after 2 km fiber (b), and the same for a length of $2^{31}$-1 (c,d).

## 4. Conclusion

We demonstrate 40 Gb/s NRZ-OOK direct modulation of a hybrid InP/SOI DFB laser. PRBS sequence lengths of $2^7$-1 and $2^{31}$-1 have been used to perform the transmission over a 2 km NZ-DSF.

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