43 Gb/s NRZ-OOK Direct Modulation of a Heterogeneously Integrated InP/Si DFB Laser

A. Abbasi, *Student member, IEEE*, S. Keyvaninia, J. Verbist, *Student member, IEEE*, X. Yin, *Member, IEEE*, J. Bauwelinck, *Member, IEEE*, F. Lelarge, G-H. Duan, *Senior Member, IEEE,* G. Roelkens, G. Morthier, *Senior Member, IEEE*

***Abstract*—We discuss how InP membrane laser diodes, heterogeneously integrated on SOI can be designed for high speed operation and how one can take advantage of the heterogeneous integration. This is illustrated with several static and dynamic characteristics of fabricated 1550nm lasers. We show non-return to zero on-off keying at 43 Gb/s and report link experiments over 2 km of nonzero dispersion shifted fiber with the directly modulated laser diodes.**

***Index Terms*—Direct modulation, distributed feedback lasers, hybrid integrated circuit fabrication**

I. INTRODUCTION

As data centers contain ever more servers (1 million servers or more per datacenter) and occupy ever larger physical spaces (several tens of thousands of square meters), with distances between buildings reaching a few km and data rates increasing to 400 Gb/s or even 1 Tb/s in the near future, optical interconnects are growing fast in importance for the networking inside and between these data centers.

Single mode fiber is more and more preferred as the transport medium for the optical interconnect. As the number of interconnects within a data center is getting immensely large, single mode fiber is resulting in lower cost than multi mode fiber. Moreover, scalability issues and future proofness of the interconnects enforce the use of wavelength division multiplexing, which is much more easily implemented using single mode waveguides and single mode fibers. Standardisation efforts are taking place on a 400 Gb/s Ethernet and the long reach standard will most likely be based on 8 lanes (wavelengths), each intensity modulated with 50 Gb/s on-off-keying.

Power consumption is an important issue for the data centers. In the US, the power consumption by data centers already represents several % of the total electricity consumption and the percentage is only expected to rise. The data center networks are roughly responsible for one quarter of that power consumption. It is vital (both from an ecological and an economic point of view) that this power consumption is limited and doesn't rise any further with further traffic increases. It is thus also essential that the transmitters used in the optical interconnects have very low power consumption.

There are several options for the transmitter of optical interconnects. For short distances, either with single or multi mode fiber, directly modulated VCSELs are the transmitter of choice due to their low cost, low power consumption, easy coupling to fiber and high modulation bandwidth. Both 850nm and 1550 nm VCSELs have been shown capable of 56 Gb/s direct modulation. [1-2]. However, VCSELs have a limited output power of a few mW, making them less suited for longer distance interconnects, their wavelength is not easy to control and they are not easily integrated into a multi wavelength WDM transmitter.

Edge emitting laser diodes (and in particular DFB lasers or a wavelength tunable variant) normally give higher output power and are much better suited for integration into a WDM transmitter. However, their power consumption is larger and coupling of their output to a single mode fiber is a little bit more complicated. The lasers can be modulated either directly or externally and modulators can also be monolithically or hybridly integrated with the laser diode. While different types of external modulators (InP- or Si-based) have been demonstrated at bitrates of 50 or 56 Gb/s [3], these modulators typically come with large footprint, extra insertion loss and require relatively large RF powers. ([4]). Direct modulation is theoretically possible with much lower power consumption and smaller footprint. In theory, very large modulation bandwidths are possible as well. InP based DFB laser diodes have already been directly modulated at 56 Gb/s using on-off-keying [5], while DBR laser diodes have been used in a recent demonstration of a 56 Gbaud, 112 Gb/s PAM-4 modulation [6]. Several transmission experiments have been demonstrated using either VCSELs, lasers with external modulators or directly modulated laser diodes. Typical transmission distances in these experiments are a few 100 m up to 2 km, consistent with distances of optical interconnects inside datacenters. Fiber losses are of minor importance over these distances, and fiber dispersion is limited, especially when operating at the 1300nm

A. Abbasi, J. Verbist, G. Roelkens and G. Morthier are with the Photonics Research Group, Department of Information Technology, imec and Center for Nano- and Biophotonics, Ghent University, Ghent B-9000, Belgium (e-mail: Amin.Abassi@UGent.be;Jochem.Verbist@UGent.be; , Gunther.Roelkens@UGent.be; Geert.Morthier@UGent.be).

J. Verbist, X. Yin, J. Bauwelinck are with Ghent University – imec, IDLab, Department of Information Technology, 9000 Ghent, Belgium (e-mail: Jochem.Verbist@UGent.be; Xin.Yin@UGent.be Johan.Bauwelinck@UGent.be).

F. Lelarge and G.-H. Duan are with III-V lab, a joint lab of 'Alcatel-Lucent Bell Labs France', 'Thales Research and Technology' and 'CEA Leti', Campus Polytechnique, 1, Avenue A. Fresnel, 91767 Palaiseau cedex, France. (E-mail: francois.lelerge@3-5lab.fr, guanghua.duan@3-5lab.fr)

S. Keyvaninia was with the Photonics Research Group and is currently with FhG-HHI.

wavelength in standard single mode fiber or when using dispersion shifted fiber at the 1550nm wavelength.

In this paper, we will discuss the direct modulation experiments that were recently performed on InP membrane laser diodes heterogeneously integrated on silicon-on-insulator waveguides. As will be discussed in the next section, the use of InP membranes on a silicon-on-insulator waveguide platform results in several advantages for high speed direct modulation. In Section III, we will provide details about the design and the fabrication of the heterogeneously integrated InP-on-Si laser diodes that we have been using in our high speed experiments. In Section IV, we report on the high speed direct modulation experiments (up to 43 Gb/s) that have been performed with the laser diodes as well as on the transmission experiments over single mode fiber. The paper ends with a conclusion section in which we also discuss further improvements to the lasers in order to allow modulation at even higher bitrates.

II. ADVANTAGES OF USING INP MEMBRANES ON SILICON-ON-INSULATOR WAVEGUIDES

A typical laser structure is shown schematically in Figure 1.a and a SEM picture of the cross section is given in Figure 1.b.

The InP membrane consists of InP epitaxial layers with a total thickness of just 2 µm and a width of around 3.5 µm, surrounded largely by the polymer BCB, results in a strong confinement of the optical mode to the active layer of the InP membrane. This is especially the case when the active layer consists of many quantum wells (8 or 9, e.g.).

At the same time however, the BCB bonding layer can be made very narrow (below 10 nm), which results in a significant overlap of the waveguide mode with the diffraction grating, etched on the top of the silicon waveguide. As the refractive index contrast between the silicon and the BCB or oxide is very large and there is a large overlap of the waveguide mode, a large coupling coefficient for the diffraction grating and thus a low mirror loss is guaranteed. Together with the large optical confinement factor, this results in a low threshold gain.

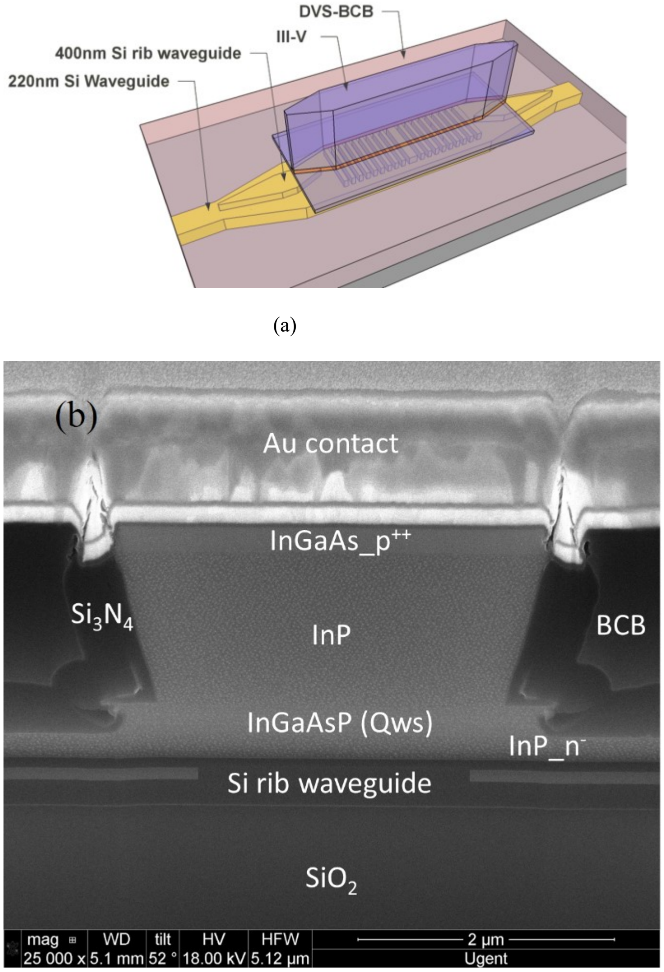
The active layers used in our lasers are strained layer multiple quantum well (SL-MQW) InGaAsP or InAlGaAs active layers. The gain in such layers is very often considered to be a logarithmic function of the carrier density, and the differential gain becomes inversely proportional with the carrier density. Consequently, a low threshold gain will lead to a high differential gain.

It is well known that the intensity modulation response of single section DFB laser diodes is a second order function with a resonance frequency given by:

$$2\pi f_r = \left[\frac{\Gamma v_g \, dg/dN}{qV}\left(I - I_{th}\right)\right]^{1/2} \qquad (1)$$

In which Γ is the confinement factor, V the volume of the active layer, dg/dN the differential (material gain) of the active layer and $I\text{-}I_{th}$ the current minus the threshold current. The resonance frequency can thus be maximized by maximizing Γ/V and dg/dN. Although the 3-dB modulation bandwidth is not identical to the resonance frequency, a high resonance frequency normally results in a high modulation bandwidth.

The coupling of the light from the InP membrane laser to the underlying silicon waveguides gives another advantage: it is relatively easy to make an external cavity to the laser by adding a reflector in the silicon waveguide. As has been shown several years ago [7], a DFB laser connected to an external cavity exhibits a second resonance peak in its modulation response, a photon-photon resonance or external cavity resonance at a resonance angular frequency given by the inverse of the roundtrip time in the external cavity. For this photon-photon resonance (or PPR in short) to be able to extend the modulation bandwidth, both the strength, the phase and the roundtrip time need have the right values and such external cavities can be well designed in the silicon waveguides. In fact, the surface grating couplers that are used to couple the laser light to a fiber also give a 4% reflection in our designs and it is thus the grating coupler which acts as external reflector to the DFB lasers and which gives the PPR resonance.



(a)

(b)

Fig. 1. Schematic structure of a heterogeneously integrated InP-on-Si DFB laser diode (a), SEM picture of the cross section of a fabricated device (b).

Finally, the small top and bottom surface area of the InP membranes result in a small parasitic capacitance, while the series resistance of the laser diodes is of the same magnitude as for traditional InP lasers. Hence, the lasers should come in principle with a low RC value and a high cut-off frequency for the current injection into the active layer.

III. DESIGN, FABRICATION AND STATIC CHARACTERISTICS

The design and fabrication of the laser diodes have been extensively discussed in other papers [8-9]. As usual, we bond InP dies onto SOI dies using adhesive bonding with BCB as adhesive. The bonding is done using machine bonding with a close to 100% bonding yield. Coupling between the InP waveguide and the 400nm thick silicon waveguide occurs by means of tapers (as described in [8]), and coupling from the silicon waveguide to optical fiber occurs by means of surface grating couplers [10], which are separated by 1000 μm. The DFB laser part (not including tapers) is typically 340 μm long, with an InP mesa width of 3.5 μm.

In the past years, we fabricated lasers with both InGaAsP and InAlGaAs active layers. We will focus in this paper on the DFB lasers with an active layer consisting of InAlGaAs strained layer multiple quantum wells, since the main results for the lasers with InGaAsP active layer have been described in [9]. The geometrical structure and dimensions of the InAlGaAs DFB lasers are exactly the same as those of the InGaAsP lasers. However, by largely removing the planarizing oxide on top of the silicon, a very thin bonding layer of just below 10 nm is obtained, resulting in a coupling coefficient of 200 cm^{-1}, which is higher than the κ of 125 cm^{-1} that was obtained for the InGaAsP lasers. Because of this larger coupling coefficient, this laser has a somewhat lower feedback sensitivity.

The first fabricated laser diodes have single current contacts for both the DFB laser part and the tapers (which will thus act as semiconductor optical amplifiers). Typical threshold currents are 35 mA (including the taper current) and the series resistance is typically 6Ω. A typical optical spectrum, showing single mode operation with over 40 dB side mode rejection, as well as a wide stopband, is shown in Figure 2. The coupling coefficient value of 200 cm^{-1} was derived from the stopband width. The output power (in the silicon waveguide) is reaching 5 mW at an injected current of 100 mA. All measurements reported in this paper were done at a fixed temperature of 20 °C for the silicon substrate.

IV. HIGH SPEED MODULATION EXPERIMENTS

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 3dB modulation bandwidth of 27 GHz at 100 mA (Figure 3). This bandwidth is achieved because of an external cavity resonance at around 25 GHz. It is remarked that the external feedback has to have the right strength to extend the modulation bandwidth. If it is too strong, there will be a strong resonance at a frequency 1/(2πτ), but also a strong anti-resonance at half the resonance frequency. This anti-resonance will cause a deep dip in the modulation response around the frequency 1/(4πτ) which will cause the 3-dB bandwidth to be just slightly above the relaxation oscillation resonance frequency. If the external feedback is too weak, the resonance at frequency 1/(2πτ) however will not be strong enough to lift the modulation response at frequencies around the resonance frequency and again the modulation bandwidth will not be extended a lot beyond the modulation bandwidth without external cavity. This is explained in more detail in the appendix. Lasers with larger small signal bandwidth (32 GHz) have also been characterized. However, the small signal response shown in Figure 3 is the one with the least amplitude variation between 0 and 30 GHz and was found to be the one giving the best large signal response. It is remarked that the small signal response depends not very much on the mount or ambient temperature. Figure 4 shows the small signal response of a different laser with similar small-signal characteristics for different mount temperatures. There is very little variation with temperature. This can be understood by the fact that the phase change of the external reflection with a temperature change ΔT is given by:

$$\Delta\phi = \Delta\left(\frac{2\pi}{\lambda}2n_{ext}L_{ext}\right) = \frac{4\pi \mathrm{n_g} L_{ext}}{\lambda}\left[\frac{\Delta n_{ext}}{n_g} - \frac{\Delta\lambda}{\lambda}\right] \qquad (2)$$

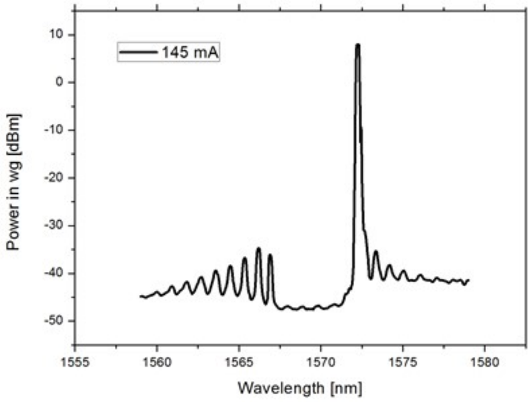


Fig. 2. Typical optical spectrum of the DFB lasers with InAlGaAs active layer, measured at 145 mA.

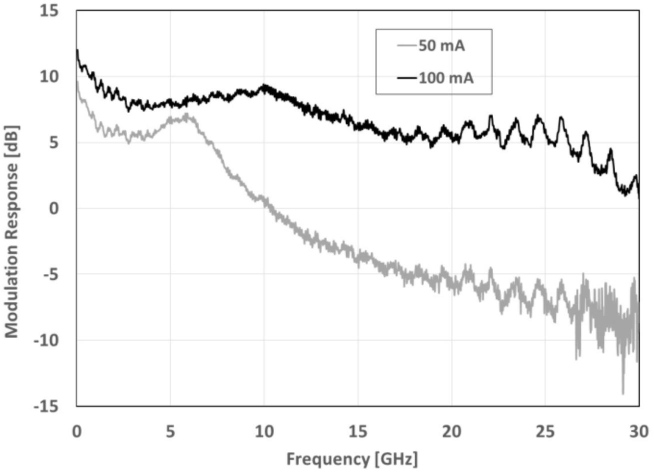


Fig. 3. Small signal modulation characteristics at 50 and 100 mA.

With n_{ext} and L_{ext} the effective index and length of the external cavity waveguide (SOI), n_g the group index of the SOI waveguide, Δn_{ext} the change of the effective index due to the temperature change and λ the lasing wavelength. For the lasing wavelength of a DFB laser, one also has $\Delta\lambda/\lambda=\Delta n_{e,InP}/n_{g,InP}$. For a silicon wire waveguide, $\Delta n_{ext}/n_g \approx \Delta n_{e,InP}/n_{g,InP} = \Delta\lambda/\lambda$. And thus is the expression on the r.h.s. of (1) negligible.

First large signal modulation experiments were done at 40 Gb/s. The eye diagrams for this bitrate are shown in Figure 5, for the back to back case as well as after transmission over 2 km of NZDSF fiber. Figure 6 shows the recorded Bit Error Rate (BER) for the different cases. The low frequency part in the modulation response causes patterning effects, especially for larger word lengths. This can be seen very well in the BER curves; there is a significantly higher BER for larger word lengths, but only a small penalty associated with the transmission over the 2km of fiber. It is also remarked that the different eye diagrams and BER curves were recorded without any use of Feed Forward Equalisation (FFE, [10]).

Modulation at 43 Gb/s was also possible, but with larger BER values and only for a word length of 2^7-1. Figure 7 shows the eye diagrams for a word length of 2^7-1 and Figure 8 the BER curves.

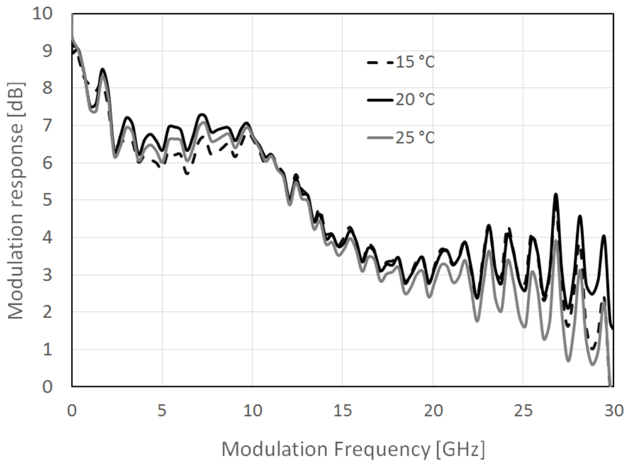


Fig. 4. Small signal modulation characteristics at 100 mA for different mount temperatures.

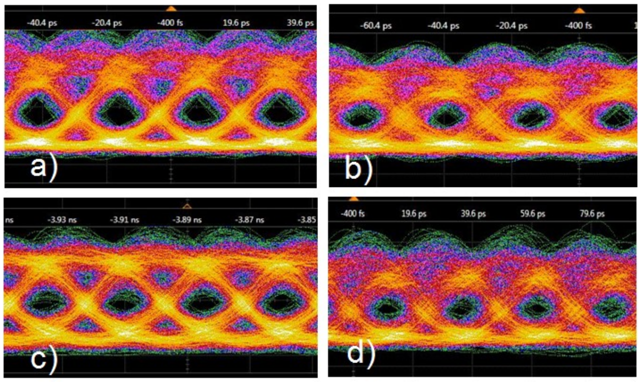


Fig. 5 Eye diagrams for 40 Gb/s large signal modulation: (a) for a word length of 2^7-1 and back to back, (b) for a word length of 2^7-1 and after 2km of NZ-DSF fiber, (c) for a word length of 2^{31}-1 and back to back, and (d) for a word length of 2^{31}-1 and after 2 km of NZ-DSF fiber.

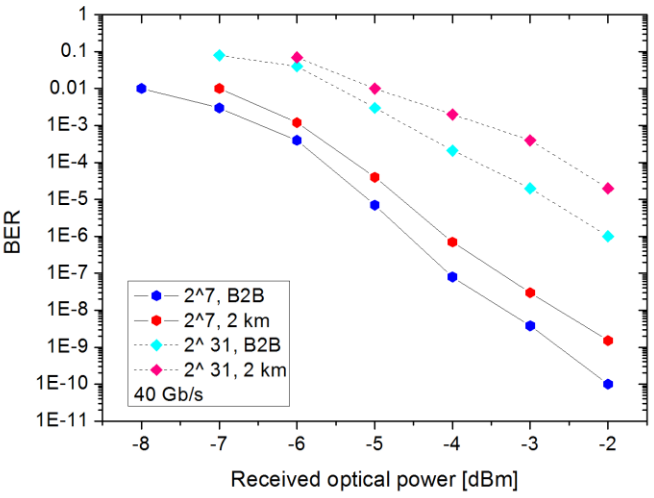


Fig. 6. BER curves for the different cases considered in Figure 4.

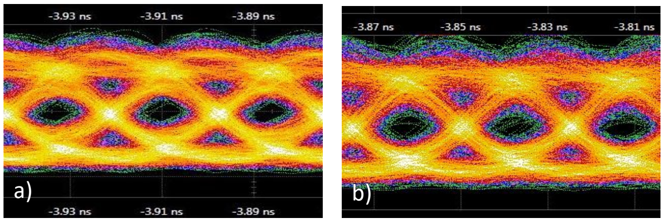


Fig. 7. Eye diagrams for 43 Gb/s large signal modulation: (a) for a word length of 2^7-1 and back to back, (b) for a word length of 2^7-1 and after 2km of NZ-DSF fiber,.

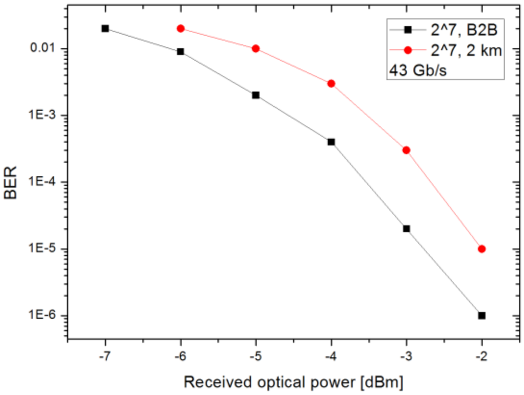


Fig. 8. BER curves for the different cases considered in Figure 4.

V. CONCLUSION

We have demonstrated direct (current) modulation of heterogeneously integrated InP-on-Si DFB laser diodes at bitrates of 40 Gb/s. This bitrate was achieved without the use of special drivers with Feed Forward Equalisation and error-less transmission over 2km over nonzero dispersion shifted fiber was demonstrated as well at this bitrate. Using FEC at the receiver, error free transmission could be obtained also at 43 Gb/s for short word lengths.

Further optimisation of the maximum achievable bitrate is possible by using shorter DFB lasers with one highly reflecting facet (in order to decrease the threshold gain and increase the differential gain). This will result in a higher relaxation oscillation resonance. In combination with a higher photon-photon resonance (obtained with a shorter external cavity), this will result in a higher 3dB modulation bandwidth. The use of a driver with FFE [10] should allow to obtain higher bitrates, even with the laser diodes on which we reported in this paper.

APPENDIX INFLUENCE OF EXTERNAL FEEDBACK ON INTENSITY MODULATION RESPONSE

A small signal analytical solution for the modulation response of a laser diode subject to external feedback can be derived from the rate equations, as given in e.g. [11], for the case when the external reflection is in phase with the output of the facet ($\omega_{opt}\tau=2m\pi$). One finds the following intensity modulation versus angular frequency Ω:

$$\frac{\Delta S}{\Delta I}=\frac{\dfrac{dG}{dN}\dfrac{S_0}{qV}}{\left[j\Omega+\dfrac{1}{\tau_d}+\dfrac{dG}{dN}S_0\right]\left[j\Omega+k_c\left(1-e^{-j\Omega\tau}\right)+\varepsilon G_{th}S_0\right]+\dfrac{dG}{dN}G_{th}S_0}$$

With S being the number of photons inside the laser cavity, G the modal gain per time unit, N the average carrier density in the active layer, τ_d the differential carrier lifetime, ε the gain suppression and V the volume of the active layer. k_c is the external feedback coefficient (per unit time) and τ the roundtrip time in the external cavity [7].

Numerical results using this analytical formula are shown in Figure A.1 for 4 different values of k_c and for a delay τ of 20 ps.

From Figure A.1, it is clear that a too large feedback coefficient k_c results in a too strong antiresonance at $\Omega\tau=\pi$, and that this antiresonance is detrimental for the modulation bandwidth. However, also a too weak coefficient k_c gives a modulation bandwidth which is a bit smaller than that of the laser without external cavity.

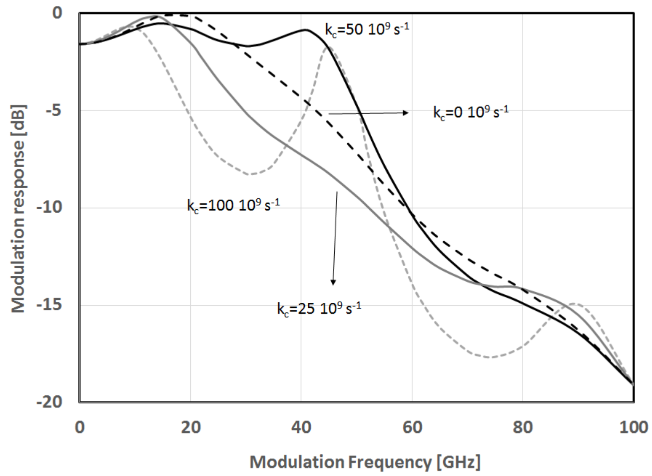


Fig. A.1. Intensity modulation plot derived from equation (A.1) for τ=20ps and k_c=0,25, 50 and 200 (times 10^9 s^{-1}).

It is remarked at this point that the feedback coefficient k_c depends both on the external reflection r_{ext}, and on the laser structure. For a DFB laser in particular, the feedback coefficient k_c decreases with increasing κL value (see e.g. [11]). The external reflection that is required to obtain a flat modulation response up to the photon photon resonance thus depends strongly on the DFB laser structure.

For feedback which is not in phase ($\omega_{opt}\tau\neq 2m\pi$), a similar analysis can be performed, albeit with more complex expressions. It is found in [12] that the modulation response of a DFB laser with passive feedback from an external reflector depends strongly on the phase of the feedback. It can however by shown that the phase of the feedback to a DFB laser doesn't change with mount or substrate temperature.

ACKNOWLEDGMENT

The authors acknowledge the Belgian IAP network Photonics@be 14/GOA/034 and the UGent special research fund BOF for their support. We would like to thank L. Van Landschoot for SEM images.

REFERENCES

[1] J. K. D. M. Kuchta, J.V. Rylakov, F.E. Doany, C.L. Schow, J.E. Proesel, C.W. Baks, P. Westbergh, J.S. Gustavsson, A. Larsson, ‘A 71-Gb/s NRZ Modulated 850-nm VCSEL-Based Optical Link’, IEEE Phot. Techn. Lett., Vol. 27, pp. 577-580, March 2015.

[2] D. M. Kuchta, F. E. Doany, L. Schares, C. Neumeyr, A. Daly , B. Kögel, J. Rosskopf, and M. Ortsiefer, ‘Error-free 56 Gb/s NRZ Modulation of a 1530 nm VCSEL Link’, postdeadline paper ECOC2015, Valencia, Spain, Sept. 2015.

[3] M. Chacinski, U. Westergren, B. Stolz, L. Thylen, ‘Monolithically Integrated DFB-EA for 100 Gb/s Ethernet’, IEEE El. Dev. Lett., pp. 1312-1314, Vol. 29, Dec. 2008.

[4] R. S. Tucker, ‘Green Optical Communications – Part I: Energy Limitations in Transport’, IEEE JSTQE, Vol. 17, pp. 245-260, 2011.

[5] K. Nakahara, Y. Wakayama, T. Kitatani, T. Taniguchi, T. Fukamachi, Y. Sakuma, S. Tanaka, ’56-Gb/s Direct Modulation in InGaAlAs BH-DFB Lasers at 55C’, Proc. OFC’2014, paper Th3A.1, March 2014.

[6] Y. Matsui, T. Pham, W. Ling, R. Schatz, G. Carey, H. Daghighian, T. Sudo, and C. Roxlo,’ 55-GHz Bandwidth Short-Cavity Distributed Reflector Laser and its Application to 112-Gb/s PAM-4’, OFC 2016, PD paper Th5B.4, Anaheim, March 2016.

[7] G. Morthier, R. Schatz, O. Kjebon, ‘Extended Modulation Bandwidth of DBR and External Cavity Lasers by Utilizing a Cavity Resonance for Equalization’, IEEE Journ. Quant. El., Vol. 36, pp. 1468-1475, December 2000.

[8] S. Keyvaninia, S. Verstuyft, L. Van Landschoot, F. Lelarge, G.-H. Duan, S. Messaoudene, F.M. Fedeli, T. De Vries, B. Smalbrugge, E. Geluk, M. Smit, G. Morthier, D. Van Thourhout, G. Roelkens, ‘Heterogeneously integrated III-V/silicon distributed feedback lasers’, Opt. Lett., Vol. 38, pp. 5434-5437, Dec. 2013.

[9] A. Abbasi, C. Spatharakis, G. Kanakis, N. Sequeira Andre, H. Louchet, A. Katumba, J. Verbist, H. Avramopoulos, P. Bienstman, X. Yin, J. Bauwelinck, G. Roelkens, G. Morthier, ‘High Speed Direct Modulation of a Heterogeneously Integrated InP/SOI DFB Laser’, invited paper Journ. Lightw. Techn., Vol. 34, No. 8, p.1683-1687, 2016.

[10] D.M. Kuchta, T.N. Huynh, F.E. Doani, L. Schares, C.W. Baks, C. Neumeyr, A. Daly, B. Kogel, J. Rosskopf, M. Ortsiefer, ‘Error-Free 56 Gb/s NRZ Modulation of a 1530-nm VCSEL Link’, Journ. Lightw. Techn., Vol. 34, pp. 3275-3282, July 2016.

[11] F. Favre, ‘Theoretical analysis of external optical feedback on DFB semiconductor lasers’, IEEE Journ. Quant. El., Vol. 23, pp. 81-88, Jan. 1987.

[12] M. Radziunas, A. Glitzky, U. Bandelow, M. Wolfrum, U. Troppenz, J. Kreissl, W. Rehbein, ‘Improving the Modulation Bandwidth in Semiconductor Lasers by Passive Feedback’, IEEE Journ. Quant. El., Vol. 13, pp. 136-142, Jan/Feb. 2007.

Amin Abbasi received the B.Sc. degree in applied physics and the M.Sc. degree in laser physics from the University of Tabriz, Tabriz, Iran, in 2007 and 2009, respectively. He is currently pursuing the Ph.D. degree in photonics with the Photonics Research Group, Department of Information Technology, Ghent University-Imec, Ghent, Belgium. His current research interests include high speed direct modulation of heterogeneously integration of silicon-on-isolator and III–V materials and all-optical signal processing based on distributed feedback (DFB) and distributed Bragg reflector (DBR) lasers. He is a Student Member of the IEEE Photonics Society and the OSA Optical Society.

Shahram Keyvaninia biography not available at time of publication.

Xin Yin (M'06) received the B.E. and M.Sc. degrees in electronics engineering from the Fudan University, Shanghai, China, in 1999 and 2002, respectively, and the Ph.D. degree in applied sciences, electronics from Ghent University, Ghent, Belgium, in 2009. Since 2007, he has worked as a staff researcher in IMEC-INTEC and since 2013 he has been a professor in the INTEC department at Ghent University. His current research interests include high-speed and high-sensitive opto-electronic circuits and subsystems, with emphasis on burst-mode receiver and CDR/EDC for optical access networks, and low-power mixed-signal integrated circuit design for telecommunication applications. He led a team which won the GreenTouch 1000x award together with Bell Labs/Alcatel-Lucent and Orange Labs in Nov. 2014 and he is a member of the ECOC technical program committee.

François Lelarge biography not available at time of publication.

Guang-Hua Duan (S'88–M'90–SM'01) received the Doctorate degree in 1991 from the Ecole Nationale Supérieure des Télécommunications (Telecom-ParisTech), France, in applied physics. He was habilitated to direct researches by Université de Paris-Sud in 1995. He is now the leader of the research Group "Silicon Photonics" within III-V Lab, which is a joint Joint laboratory of Nokia, Thales and CEA Leti, and also the head of the Research Department "Heterogeneous integration of III-V on silicon" within Nokia Bell Labs. He is also a Guest Professor in Ecole Supérieure d'Elecricité, and Ecole Supérieure d'Optique, giving lectures in the fields of electromagnetism, optoelectronics and laser physics. Previously, he had been an Assistant, then an Associate Professor at Telecom-ParisTech from 1992 to 2000. He was with the University of Maryland as a Visiting Associate Professor from 1998 to 1999. He joined Opto+, Alcatel Research & Innovation Center in Marcoussis on October 2000. He is author or co-author of more than 100 journal papers, 250 conference papers, 30 patents and a contributor to 4 book chapters.biography not available at time of publication.

Jochem Verbist received a B.Sc. degree in Electrical Engineering from Ghent University, Belgium, in 2011 and M.Sc. degree in 2013. Since 2014, he has been pursuing the Ph.D. degree in Electrical Engineering with both the IDLab Design group and the Photonics Research Group, Ghent University-INTEC-Imec, Belgium, as part of the GOA– electronic/photonic integration platform. His current research focuses on low-power optical transceivers with advanced modulation formats on silicon and the electronic/photonic co-design of electronic drivers for high speed optical telecommunications systems. He is a student member of IEEE Photonics Society.

Johan Bauwelinck [M'02] received a Ph.D. degree in applied sciences, electronics from Ghent University, Belgium in 2005. Since Oct. 2009, he is a professor in the INTEC department at the same university and since 2014 he is leading the IDLab Design group. His research focuses on high-speed, high-frequency (opto-) electronic circuits and systems, and their applications on chip and board level, including transmitter and receiver analog front-ends for wireless, wired and fiber-optic communication or instrumentation systems. He has promoted 18 PhDs and co-authored more than 150 publications and 10 patents in the field of high-speed electronics and fiber-optic communication.

Gunther Roelkens received a degree in electrical engineering from Ghent University, Belgium, in 2002 and a PhD from the same university in 2007, at the Department of Information Technology (INTEC), where he is currently associate professor. In 2008, he was a visiting scientist in IBM TJ Watson Research Center, New York. He is assistant professor at Eindhoven University of Technology, The Netherlands. His research interest includes the heterogeneous integration of III-V semiconductors and other materials on top of silicon waveguide circuits and electronic/photonic co-integration. He was holder of an ERC starting grant (MIRACLE), to start up research in the field of integrated mid-infrared photonic integrated circuits.

Geert Morthier (M'93–SM'01) received the degree in electrical engineering and the Ph.D. degree from the University of Gent in 1987, 1991, respectively. Since 1991 he is a member of the permanent staff of IMEC. His main interests are in the modelling and characterisation of optoelectronic components. He has authored or co-authored over 150 papers in the field and holds several patents. He is also one of the two authors of the Handbook of Distributed Feedback Laser (Artech House, 1997). From 1998 to end of 1999, he has been the project manager of the ACTS project ACTUAL dealing with the control of widely tunable laser diodes, from 2001 to 2005 he was project manager of the IST project NEWTON on new widely tunable lasers and from 2008 to 2011 he was project manager of the FP7 project HISTORIC on microdisk lasesrs. In 2001 he was appointed parttime professor at Ghent University, where he teaches courses on optical fiber communication and lasers.