

# Discretely tunable III-V/SOI SG-DFB laser

S. Dhoore,<sup>1,2</sup> G. Roelkens,<sup>1,2</sup> and G. Morthier<sup>1,2</sup>

<sup>1</sup> Photonics Research Group, INTEC-department, Ghent University-IMEC, Belgium

<sup>2</sup> Center for Nano- and Biophotonics (NB-Photonics), Ghent University, Belgium

*Discrete wavelength tuning with a heterogeneously integrated III-V/SOI sampled grating distributed feedback (SG-DFB) laser is demonstrated. The laser device is tunable over a wavelength range larger than 55 nm in wavelength steps of 5 nm and only employs two injection currents. A maximum fiber-coupled output power of -1.8 dBm is obtained as well as a high side mode suppression of more than 33 dB for all wavelength channels. The demonstrated laser is expected to find application in future flexible optical network architectures.*

## Introduction

With the increasing demand for bandwidth, widely tunable laser diodes are expected to play an increasingly important role as light sources in future advanced data center and metro networks. Additional functionality in flexible optical network architectures can for instance be achieved through fast bandwidth relocation by dynamically increasing the number of links between hot spots in the network [1]. Optical switches or cross connects that can be used for this purpose require very fast and widely tunable laser diodes with high power efficiency [2].

Recently, significant research has been done in the area of III-V/SOI laser diodes, in which laser structures are realised through integration of III-V epitaxy on the SOI platform through direct or adhesive wafer bonding techniques [3]. In this way the laser devices can be co-integrated with silicon passive waveguide circuits, high-speed silicon modulators and germanium photodetectors. As opposed to traditional InP-lasers, membrane III-V/SOI lasers allow the realization of gratings with a high coupling coefficient and strong optical confinement in the gain material.

Different III-V/SOI tunable lasers have been demonstrated already. These laser structures typically make use of one or more ring resonator filters with heaters that allow to thermally tune the lasing wavelength [4, 5]. An alternative laser structure that consists of 2 sampled grating DBR mirrors, a gain and a phase section, has been used to demonstrate over 13 nm wavelength tuning [6].

In this paper, we present the experimental demonstration of a novel widely tunable sampled grating distributed feedback (SG-DFB) laser integrated on SOI. The laser is tunable over a wavelength range larger than 55 nm in discrete wavelength steps of 5 nm, with all wavelength channels having a side mode suppression ratio (SMSR) of more than 33 dB.

## Design & fabrication

The layout of the SG-DFB laser is schematically shown in Figure 1. The presented laser is implemented as a two-section DFB laser and constitutes a III-V gain region that is adhesively bonded on top of SOI waveguide structures with sampled gratings patterned

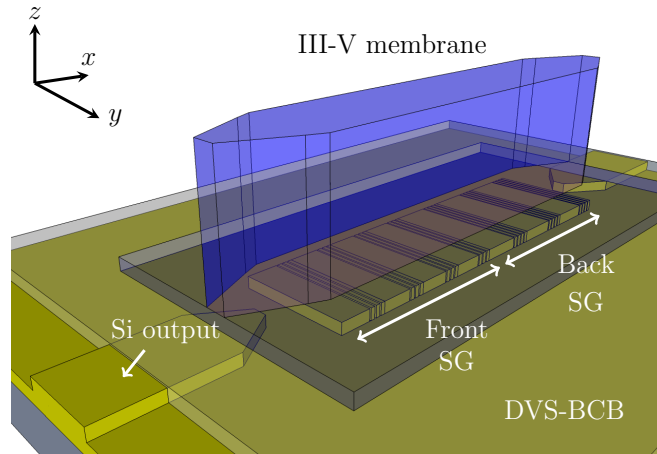


Figure 1: Layout of the SG-DFB laser. The front and back SG have a slightly different sampling period to exploit the Vernier effect for wide wavelength tuning.

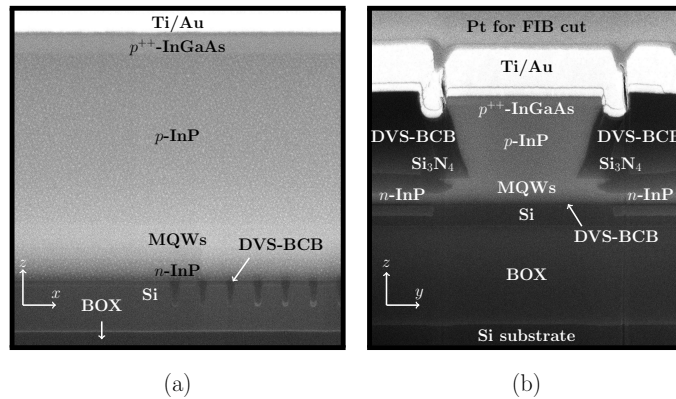


Figure 2: SEM image of the fabricated SG-DFB laser device. (a) Longitudinal cross-sectional view; (b) Transverse cross-sectional view.

on top. The gratings are defined in a 400 nm thick silicon device layer with an etch depth of 180 nm. A different sampling period in both grating sections ( $72 \mu\text{m}$  and  $80 \mu\text{m}$ ) is chosen such that the Vernier effect can be exploited for wide wavelength tuning, through a variation of the injection current into the two sections. The gratings are  $3.5 \mu\text{m}$  wide and have a period of 480 nm with a duty cycle of 75%. This corresponds to a Bragg wavelength of 1565 nm ( $n_{\text{eff}} = 3.26$ ). The sampling duty cycle  $d_{\text{SG}}$  is chosen to be 10%, as this ensures a sufficiently flat envelope of the overall reflection spectrum needed for a high side mode suppression across the entire tuning range [7]. The designed free spectral range (FSR) of the front grating reflector is 5 nm, whereas the designed FSR of the back grating reflector is 4.5 nm.

Fabrication of the SG-DFB laser is similar to the fabrication of a standard III-V/SOI DFB laser [8] and involves adhesive DVS-BCB bonding of the III-V epitaxy on the SOI waveguide structures. After III-V substrate removal the laser structure is defined through a series of lithographic, wet/dry etching and metallisation steps. The  $p$ -contact consists of two individual contacts that allow independent current injection in the two sampled

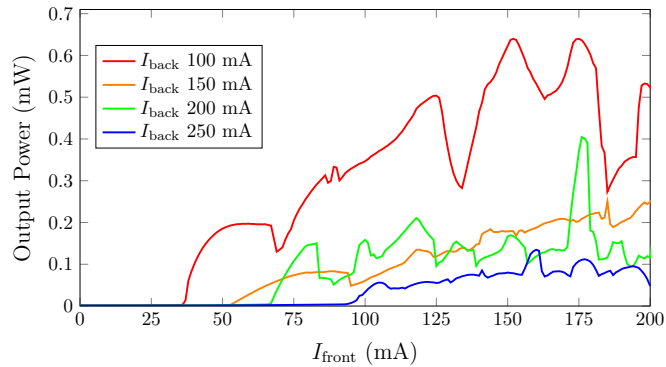


Figure 3: Light-current ( $LI$ ) characteristics of the SG-DFB laser.

grating sections. A longitudinal and transverse cross-sectional SEM image of the fabricated SG-DFB laser are shown in Figures 2 (a) and (b) respectively. The laser mesa has a V-shape, which is realised through wet etching of the top  $p$ -InP cladding. This enhances the optical confinement factor in the MQWs (12% confinement factor in the 6 quantum wells) and realizes narrow taper tips. The DVS-BCB bonding layer thickness is only 40 nm, which gives rise to a rather large effective grating coupling constant  $\kappa_{\text{eff}} = \kappa \cdot d_{\text{SG}}$  of  $31.8 \text{ cm}^{-1}$ .

## Measurement results

Characterisation of the laser is done at a stage temperature of  $10 \text{ }^\circ\text{C}$ . A standard fiber-to-chip SOI grating coupler is used to couple the laser light to a standard single-mode optical fiber. Using a current source and three electrical DC probes the front ( $I_{\text{front}}$ ) and back ( $I_{\text{back}}$ ) grating section are independently biased.

Figure 3 shows the light-current ( $LI$ ) characteristics of the SG-DFB laser. Thereby  $I_{\text{front}}$  is swept while  $I_{\text{back}}$  is kept constant. For uniform pumping ( $I_{\text{front}} = I_{\text{back}}$ ) the total threshold current is 90 mA. At  $(I_{\text{front}}, I_{\text{back}}) = (175 \text{ mA}, 100 \text{ mA})$  the fiber-coupled output power is  $-1.94 \text{ dBm}$ . The ripples in the  $LI$ -curves are attributed to mode hopping.

Figure 4 (a) shows the superimposed lasing spectra of the different achievable wavelength channels across the entire tuning range. Lasing occurs from 1547 to 1603 nm, at a discrete number of wavelengths. The spacing between these wavelength channels is 5 nm and corresponds with the designed peak spacing. Around each wavelength channel about 1.5 nm quasi-continuous tuning is possible. Figure 4 (b) depicts the fiber-coupled output power and SMSR for all different wavelength channels. All operate in single-mode regime with a SMSR ranging from 33 dB to 48 dB. The fiber-coupled output power varies from  $-12 \text{ dBm}$  to  $-2.8 \text{ dBm}$ . The variation in the fiber-coupled output power is due to the variation of the total current for all wavelength channels and due to the influence of the grating coupler response.

## Conclusion

In summary, we have presented the experimental demonstration of a novel heterogeneously integrated III-V/SOI sampled grating distributed feedback laser. With only two input currents the laser device is discretely tunable over a wide wavelength range of 55 nm

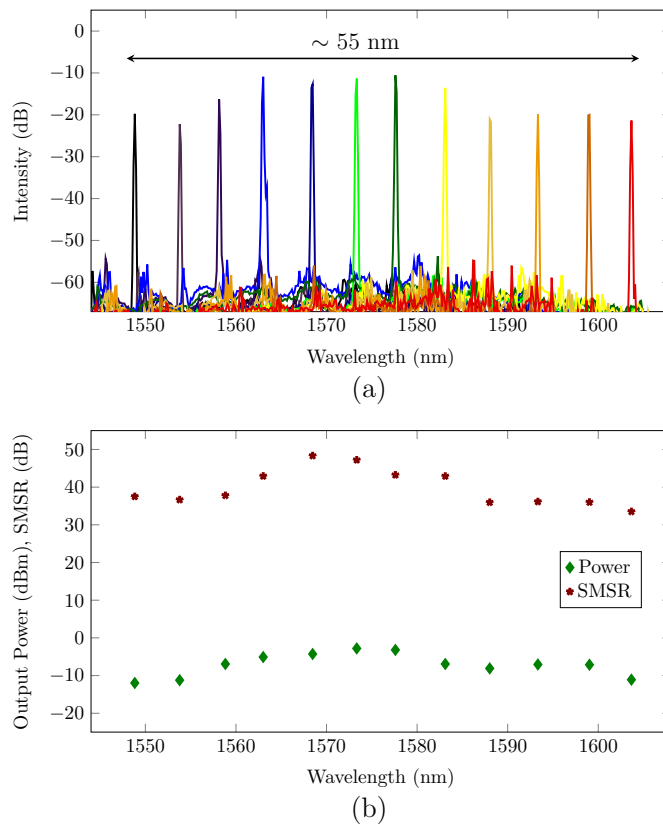


Figure 4: Tuning characteristics. (a) Superimposed lasing spectra; (b) Fiber-coupled output power and SMSR at the different wavelength channels.

in steps of 5 nm. All wavelength channels operate in single-mode regime with a SMSR larger than 33 dB.

## References

- [1] Z. Cao *et al.*, “Experimental demonstration of flexible bandwidth optical data center core network with all-to-all interconnectivity,” *Journal of Lightwave Technology*, vol. 33, no. 8, pp. 1578–1585, 2015.
- [2] C. Kachris *et al.*, *Optical interconnects for future data center networks*. Springer Science & Business Media, 2012.
- [3] G. Roelkens *et al.*, “III-V-on-silicon photonic devices for optical communication and sensing,” in *Photonics*, vol. 2, no. 3. Multidisciplinary Digital Publishing Institute, 2015, pp. 969–1004.
- [4] J. Hulme *et al.*, “Widely tunable Vernier ring laser on hybrid silicon,” *Optics Express*, vol. 21, no. 17, pp. 19718–19722, 2013.
- [5] S. Keyvaninia *et al.*, “Demonstration of a heterogeneously integrated III-V/SOI single wavelength tunable laser,” *Optics Express*, vol. 21, no. 3, pp. 3784–3792, 2013.
- [6] M. N. Sysak *et al.*, “Integration of hybrid silicon lasers and electroabsorption modulators,” *Optics Express*, vol. 16, no. 17, pp. 12478–12486, 2008.
- [7] J. Buus *et al.*, *Tunable laser diodes and related optical sources*. Wiley-Interscience New York, 2005.
- [8] S. Keyvaninia *et al.*, “Heterogeneously integrated III-V/silicon distributed feedback lasers,” *Optics Letters*, vol. 38, no. 24, pp. 5434–5437, 2013.