Electronically Tunable DFB Laser on Silicon

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***Abstract*—We report on the demonstration of an InP-on-silicon electronically tunable DFB laser. 2 nm continuous wavelength tuning is achieved with a single tuning current. Tuning is inherently fast, which makes the laser device an attractive candidate for use in optical packet or burst switching systems.**

***Index Terms*—tunable laser, distributed feedback laser, fast wavelength tuning, tunable twin-guide, heterogeneous integration, silicon photonics**

I. Introduction

The ever increasing demand for bandwidth has renewed the interest in optical packet switching as networking technique in data center environments [1]. Envisioned implementations of optical packet or burst switching systems are typically based on fixed-wavelength routers and reconfigurable line cards that make use of fast tunable lasers with nanosecond switching times [2]. Optical packets have durations of several hundreds of nanoseconds, such that wavelength switching should also occur on that timescale. So far VCSELs have been the light sources of choice for short-reach interconnects but they are not suited for wavelength-division multiplexing (WDM) nor do they allow fast wavelength switching. For high bitrate interconnects over longer distances in data center networks they are therefore getting replaced by edge-emitting devices such as DFB and DBR lasers.

In this paper we demonstrate for the first time, to the best of our knowledge, a continuously and electronically tunable DFB laser heterogeneously integrated on a silicon photonics platform. Recently, we demonstrated sub-nanosecond wavelength switching and 12.5 Gbit/s direct modulation with an AWG-based wavelength selectable InP-on-silicon filtered feedback laser [3]. In earlier work, a tunable III-V-on-silicon sampled grating DBR laser using quantum well intermixing was demonstrated [4]. In both cases wavelength tuning was discrete, without straightforward potential to improve for continuous tuning. The laser structure presented here overcomes this problem and is inherently better suited for high-speed direct modulation because of the distributed feedback nature and the relatively short cavity length.

II. Device Design and Fabrication

A schematic of the laser device is shown in Fig. 1. A so-called tunable-twin guide (TTG) InP/InGaAsP membrane [5] is integrated on top of a silicon-on-insulator (SOI) waveguide circuit that contains a $\lambda/4$ phase-shifted Bragg grating. The TTG membrane comprises a p^{++}-type InGaAs top contact layer, a p-type InP top cladding layer, a MQW region (with 6 InGaAsP-based QWs and 5 barriers, bandgap wavelength 1550 nm) sandwiched between 2 SCH layers, an n-type InP middle cladding layer, an InGaAsP (bandgap wavelength 1400 nm) tuning layer, a p-type InP bottom cladding layer and a p^+-type InGaAsP (bandgap wavelength 1300 nm) bottom contact layer. Through carrier injection in the tuning layer, the effective index of the optical mode can be modified, in turn modifying the lasing wavelength. Due to the electronic tuning nature, tuning speeds may be very high, with switching times on the order of nanoseconds.

For the design of the laser structure, the modal overlap with the active layer (MQW + SCH), tuning layer and silicon waveguide is optimized. An inherent trade-off is in place, where a sufficiently large grating coupling coefficient $\sim 100/\text{cm}$ and a minimum 10% confinement factor in the

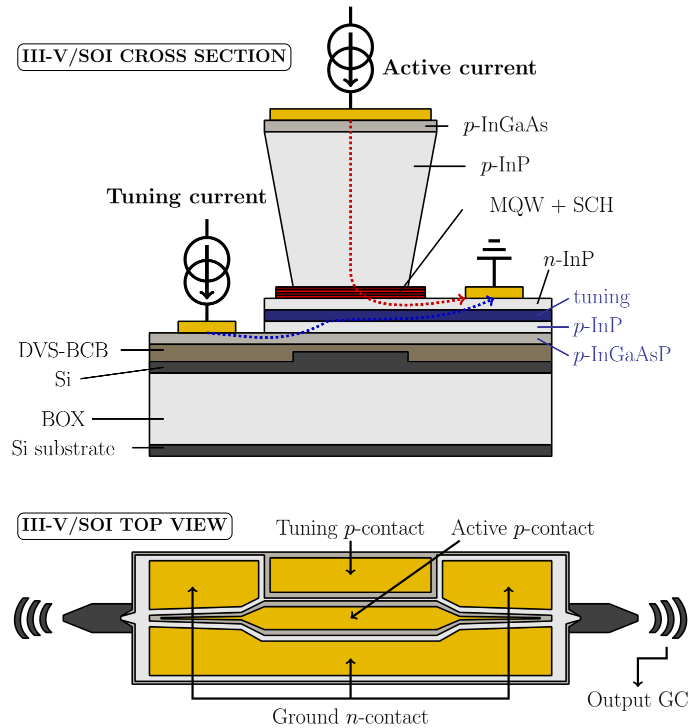

Fig. 1. Schematic of the electronically tunable DFB laser, with indication of the different metal contacts. A double adiabatic tapered coupler is used for light coupling between the InP and silicon waveguide. For clarity the planarization and passivation layers and metal contact pads are not shown.

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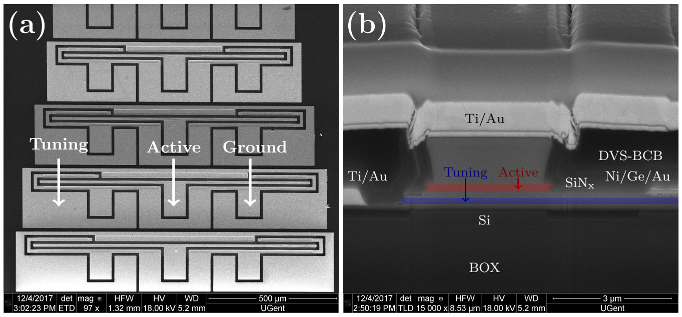

Fig. 2. Laser fabrication. (a) SEM image of a set of electronically tunable DFB lasers with different Bragg grating lengths; (b) FIB/SEM image of the laser cross section, captured in the middle of the structure.

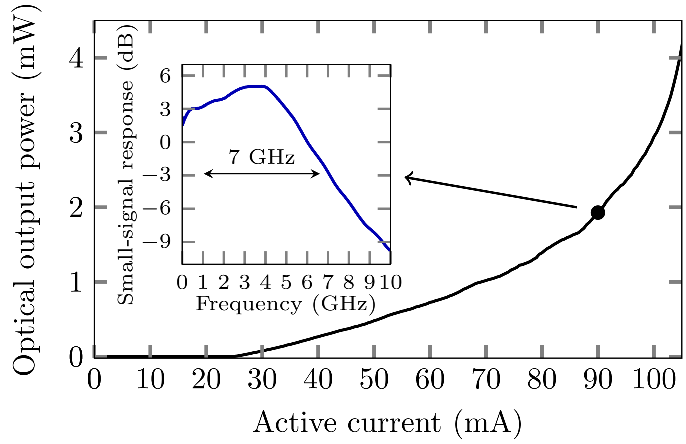

Fig. 3. Light-current characteristic, measured at room temperature (waveguide-coupled output power). The inset shows the small-signal response for an active current of 90 mA with the tuning layer unbiased.

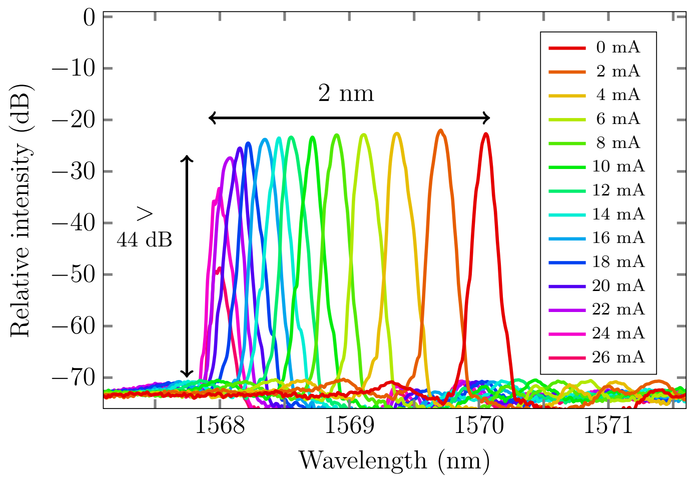

Fig. 4. Superimposed lasing spectra when the tuning current is varied from 0 mA to 26 mA, for an active current of 90 mA.

active layer is targeted. Simulations indicate that with the use of a 3 μm wide mesa and a 190 nm thick tuning layer this can readily be achieved. The Bragg grating period is 240 nm.

The device fabrication procedure is very similar to the approach outlined in [6] and uses a 10 nm thick adhesive DVS-BCB bonding layer. An in-house developed electron-beam lithography (EBL) process with subsequent reactive-ion etching (RIE) is used to define the SOI waveguide structures. The total silicon device layer thickness is 400 nm and has an etch depth of 180 nm. An SEM image of several fabricated lasers with different grating lengths is shown in Fig. 2(a). An FIB/SEM image of the laser cross section is shown in Fig. 2(b).

III. Device and Tuning Characteristics

The laser is characterized at room temperature and a reflectionless SOI grating coupler is used to couple the laser output to a single-mode optical fiber. An HP 8153A power meter is used to measure the optical output power. Two Keithley2400 current sources are used to control the active and tuning current. The differential series resistance of the active and tuning contact is 6 Ω and 11 Ω, respectively. The light-current (LI) characteristic is shown in Fig. 3. The threshold current is 26 mA for a device with a 400 μm long Bragg grating. The maximum fiber-coupled output power is 0.125 mW, which corresponds to a waveguide-coupled output power of about 4 mW, given the relatively large grating coupler loss ($\sim$ 15 dB) at the lasing wavelength. Fig. 4 shows the superimposed lasing spectra for different tuning currents at a fixed active current of 90 mA. Single-mode laser operation with a SMSR larger than 44 dB over the entire 2 nm continuous tuning range is achieved. The small-signal response is shown in the inset of Fig. 3. A 3 dB bandwidth of 7 GHz is obtained, allowing for at least 12.5 Gbit/s direct modulation and which is compatible with state-of-the-art burst-mode receivers.

IV. Conclusion

A heterogeneously integrated InP-on-silicon electronically tunable laser is realized. 2 nm continuous tuning is achieved together with a 7 GHz small-signal direct modulation bandwidth, enabling the realization of optical packet or burst switching systems for use in data center networks.

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