

III-V-on-silicon photonic integrated circuits for optical interconnects

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Abstract—We review our work on the heterogeneous integration of III-V laser sources on the silicon photonics platform. These building blocks enable the realization of fully integrated silicon photonic transceivers for optical interconnect applications.

Keywords—optical interconnect; heterogeneous integration; avalanche photodiode

I. INTRODUCTION

Silicon photonics is emerging as an important technology for the realization of high aggregate bitrate transceivers for optical interconnect applications. This is mainly driven by the fact that CMOS fabrication technology can be used to realize these photonic integrated circuits, resulting in cost reduction when manufactured in high volume. Also, the dense integration with silicon electronics offers the potential to substantially reduce the power consumption. The current silicon photonics technology offering comprises low loss waveguide circuits, high efficiency fiber-to-chip coupling structures and high performance silicon modulators and germanium p-i-n photodiodes operating at 28Gbps and beyond. The laser source integration has so far mostly relied on flip-chip integration of III-V semiconductor devices, which is not a scalable approach and adds substantial cost to the transceiver fabrication. In this paper we will discuss our work on a scalable laser integration approach based on III-V to silicon die-to-wafer bonding.

II. III-V-ON-SILICON SINGLE WAVELENGTH AND MULTI-WAVELENGTH LASER SOURCES

A. III-V-on-silicon single wavelength lasers

The standard single wavelength laser structure is a distributed feedback laser, comprising of a first order feedback grating and a quarter wave shift. While such devices can be realized using III-V technology, they require e-beam definition of the grating, facet coating and spotsize converters to efficiently interface with silicon photonic integrated circuits. Using heterogeneous integration DFB laser arrays can easily be integrated on silicon, in which case the grating structures can be defined in the silicon waveguide layer and no facet coatings are required since a low-reflection spot size converter can be integrated for the interfacing with the silicon waveguide circuit, as shown in Figure 1. 14mW output power at room temperature, 9% wall plug efficiency and a side mode

suppression better than 50dB are experimentally obtained [1]. So far 18Gbps direct modulation of these III-V-on-silicon devices has been demonstrated over a 5km link.

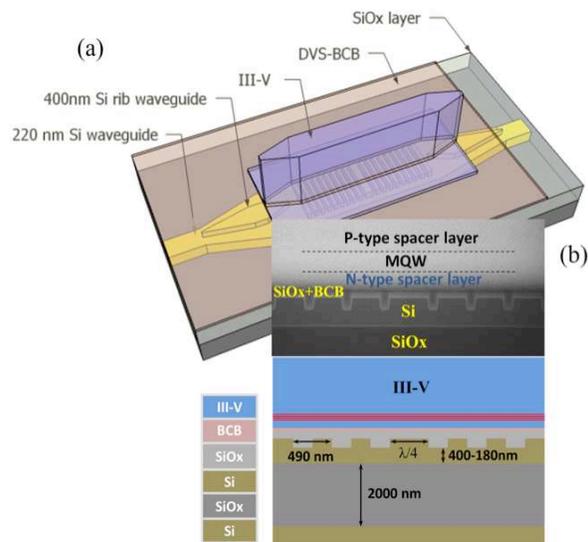


Figure 1: (a) layout of III-V on silicon DFB laser with the first order grating defined in the silicon waveguide layer; (b) SEM cross-section of the III-V-on-silicon laser structure

B. III-V-on-silicon multi-wavelength lasers

Besides single wavelength lasers also multi-wavelength laser sources have been demonstrated using the III-V-on-silicon platform. This includes 4-channel lasers based on ring resonator and arrayed waveguide grating filters implemented inside the laser cavity, with channel spacings of 250GHz and 200 GHz respectively. Figure 2 shows the ring cavity layout and the multi-wavelength output spectrum. Several mW optical output power and more than 40dB side mode suppression ratio are obtained [2]. A way to achieve a broad comb of spectral lines (which are coherent) is to implement a III-V-on-silicon mode-locked laser. High performance lasers can be realized because of the low linear and nonlinear losses of silicon waveguides. An example of a colliding pulse ring cavity mode-locked laser implemented on the III-V-on-silicon platform is shown in Figure 3, together with the high resolution optical output spectrum [3]. The optical output power is above 1mW.

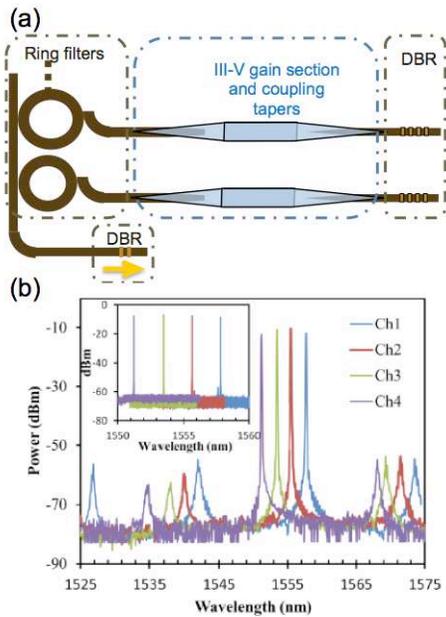


Figure 2: 4-channel multi-wavelength lasers based on ring-resonator intra-cavity filter elements: (a) layout; (b) optical output spectrum

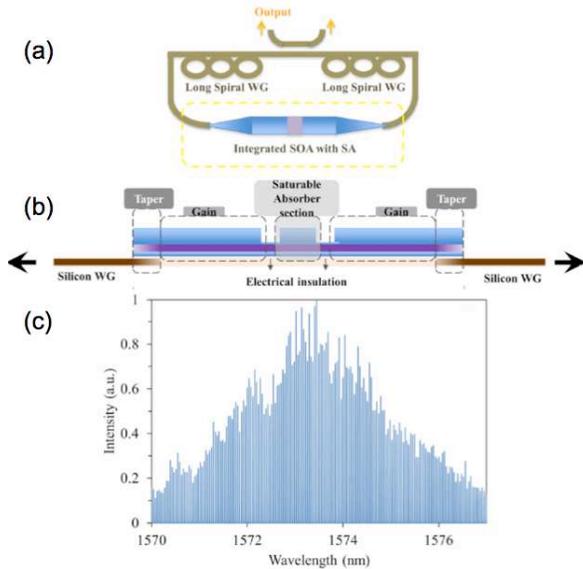


Figure 3: ring-cavity mode-locked laser geometry (a); longitudinal cross-section indicating the SOA and SA sections (b) and the generated optical output spectrum (c).

III. III-V-ON-SILICON MICRO-LASERS

The lasers presented in the previous section consisted of relatively large active regions, therefore the threshold current lies in the range of 10-30mA. In order to reduce the laser power consumption, III-V-on-silicon microlasers were developed. III-V-on-silicon micro-disk laser structures provide a good way to reduce the laser threshold [4]. Sub-mA threshold currents and 0.1mW output power have been realized this way. The drawback of this structure is the control of the laser emission wavelength, which is determined by the III-V processing accuracy and is subject to modehopping due to the strong self-heating in the micro-scale device. Therefore we developed a

novel laser structure, coined resonant cavity mirror laser, to overcome these issues. The laser cavity geometry is shown in Figure 4, illustrating the III-V gain section that couples evanescently to two underlying optical cavities implemented as 1D grating structures. The advantage of such a cavity is its small footprint (provided the cavities can create a strong reflection on resonance) and the fact that the laser wavelength is determined by silicon processing technology through proper dimensioning of the resonant cavity gratings. Threshold currents of 4 mA have been realized (in a 160 μm long device) together with a waveguide coupled output power beyond 0.1 mA [5]. Very clean single mode emission is obtained using such structures as shown in Figure 4. CW operation was not obtained due to the strong self-heating of the device.

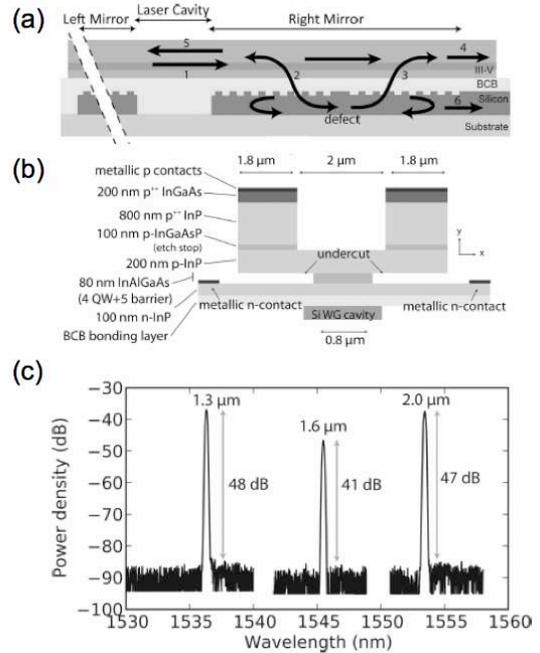


Figure 4: Resonant cavity mirror laser: (a) layout; (b) emission spectrum

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