Frontiers in III-V laser integration on silicon photonic integrated circuits

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***Abstract**: III-V-on-silicon laser sources are key components for future silicon photonic integrated circuits. I will review our work on III-V-on-silicon lasers, covering different wavelength ranges (near-infrared to mid-infrared), different laser architectures (DFB, ECL, MLL, VCSELs, etc.) and integration methods (butt-coupling, die-to-wafer bonding and transfer printing).*

1. INTRODUCTION

Photonic integrated circuits (PICs) have become a commercial reality in a number of markets, especially in telecom and datacom. PICs enable complex optical and opto-electronic functions on a very compact footprint with high reliability. And because of wafer-scale manufacturing, the cost of a PIC can be significantly lower than with conventional technologies (relying on bulk optical or other assembly platforms) for the same function. Silicon photonics is the field that takes advantage of more than 50 years of massive investment in silicon technology for electronic ICs. It leverages the vast know-how of the CMOS world to develop PICs in the technologies of existing CMOS fabs. It is a relatively young field: research activities geared up less than 20 years ago and widespread industrial interest less than 10 years ago. Nevertheless, the field of silicon photonics has been growing at an amazing rate, both scientifically and industrially. Today more than 15 CMOS fabs (industrial fabs or semi - industrial R&D fabs) around the world have developed a mature process flow for silicon photonics. Some of them are manufacturing products that are competitive in the market today. However, today's silicon photonics manufacturing platforms do not allow for integration of light sources at wafer level. This limits the value proposition of a silicon photonics solution because of which a considerable fraction of innovation opportunities is missed. Therefor the integration of semiconductor laser sources on a silicon photonics platform is a very active research area.

2. III-V-ON-SILICON HETEROGENEOUS INTEGRATION APPROACHES

There is a consensus that monolithically integrated Group IV lasers are still far from being practical, and that III-V semiconductor materials and devices are needed. Currently, the method that has the highest maturity – pioneered by Luxtera - is the use of a micro-packaged laser (coined a LaMP), comprising a III-V laser diode on a micro-optical bench with a ball lens, isolator and mirror to focus the light on a grating coupler on the Si PIC. While this approach has several advantages (mature InP technology, wafer-level assembly, packaging, test and burn-in), the complexity of the LaMP itself and its sequential active alignment on the silicon photonic wafer make it an expensive solution. Moreover, the use of a grating coupler as an optical interfacing limits the coupling efficiency and bandwidth. Also, waveguide-in/waveguide-out components such as semiconductor optical amplifiers (SOAs) are not possible, and these are key components in advanced photonic integrated circuits. Therefore, more intimate integration approaches are being pursued, ranging from flip-chip integration of bare III-V devices over III-V die-to-wafer/wafer-to-wafer bonding to micro-transfer-printing (μTP) and hetero-epitaxial growth. Front-end hetero-epitaxial growth of III-V semiconductors represents the ultimate path to integrate light sources on silicon photonics and proof-of-concept devices have been demonstrated, but many technological hurdles need to be overcome before this becomes a viable technology for integration in a silicon photonics process flow. Therefore, in the presentation we will focus on flip-chip integration, wafer-to-wafer (or die-to-wafer) bonding and a μTP approach for wafer-scale III-V light source integration. These techniques are versatile in the type of III-V semiconductor material that is integrated. While this is obvious for flip-chip integration, we demonstrated die-to-wafer bonding for the integration of GaAs, InP and GaSb-based devices on silicon waveguide circuits and are developing the micro-transfer-printing technique for the same material systems.

3. DEVICE REALIZATIONS

Examples of III-V-on-silicon device realizations are shown in Figure 1. The applications of such devices are not limited to optical communication: especially in the field of integrated optical sensors (gas sensors, lab-on-a-chip, …) there is a great interest for such devices. This typically necessitates operating at wavelengths outside the classical telecommunication window. Examples include the realization of III-V-on-SiN VCSILs operating at 850 nm wavelength (for reading out SiN biosensors, see Fig. 1(top)) and 2 μm wavelength range tunable lasers (for spectroscopic gas sensors, see Fig. 1(middle)). Also, the integration of III-V optical amplifiers on silicon waveguide circuits enables the realization of high performance laser sources in the telecommunication wavelength range, taking advantage of the low silicon waveguide loss (˜0.5 dB/cm) and high-quality silicon photonic optical filters. An example of this is a III-V-on-silicon modelocked laser with low repetition rate, necessitating long optical cavities (see Fig. 1(bottom)).

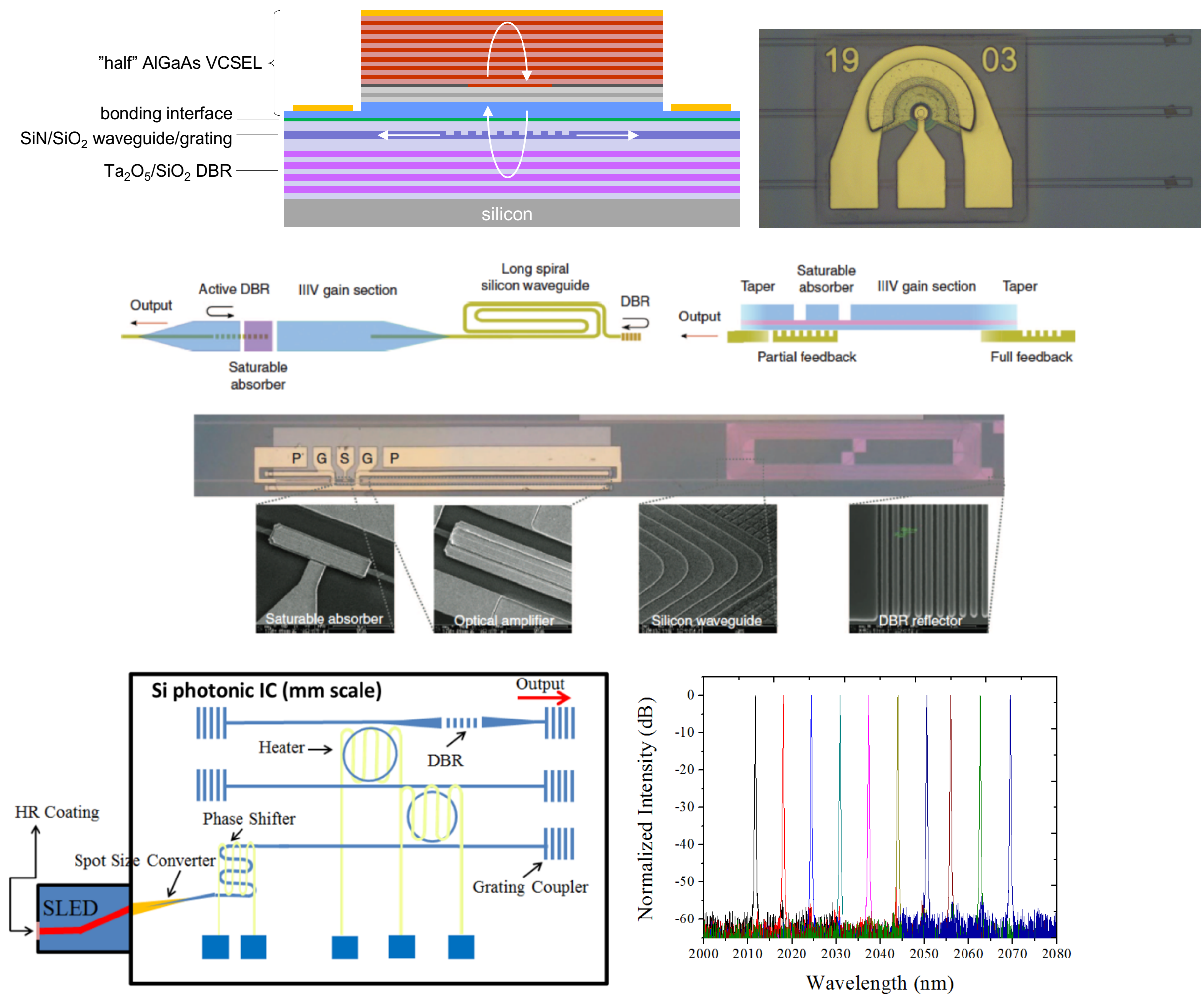

Fig.1 Top: Cross-section of the VCSIL showing the hybrid-vertical-cavity and the intra-cavity waveguide/grating for in-plane emission and microscope image of a VCSIL with the intra-cavity waveguide and one of the grating outcouplers visible. **Middle**: III-V-on-silicon modelocked lasers with 1 GHz repetition rate. **Bottom**: 2.x um GaSb/Si widely tunable laser with 60 nm tuning.