Narrow-Linewidth Micro-Transfer-Printed III-V-on-Si Laser with 110 nm Tuning Range

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Abstract—On-chip laser sources covering a wide wavelength range is one of the key enablers to coherent optical communication systems. In this work, we demonstrate for the first time a narrow-linewidth III-V-on-Si laser with 110 nm tuning range realized using micro-transfer printing technology.

Index Terms—Silicon Photonics, Widely Tunable Lasers, Micro-Transfer Printing, Heterogeneous Integration, Coherent Optical Communication Systems

I. INTRODUCTION

By leveraging the CMOS fabrication infrastructure, silicon photonics (SiPh) enables the realization of photonic integrated circuits (PICs) on 200 mm or 300 mm Silicon-on-Insulator (SOI) wafers with high yield and uniformity. III-V semiconductors have been introduced to SiPh as Si does not provide optical gain, enabling the realization of complex PICs for a wide range of applications, such as optical communication. Various heterogeneous III-V-on-Si integration methods have been intensively investigated in the past, such as die-to-wafer bonding, flip-chip integration, and even hetero-epitaxial growth. However, these methods suffer from drawbacks like a dedicated III-V process flow and modified back-end process on 200 mm wafers in the case of bonding, limited throughput for the flip-chip method and inferior III-V material quality for hetero-epitaxial growth. Here, we use micro-transfer-printing (µTP) for the realization of a narrow-linewidth III-V-on-Si widely tunable laser (WTL) with 110 nm tuning range. The technique allows for densely integrating different non-native components on a silicon photonics platform with minimal disruption to the SiPh process flow in a high-throughput manner while not requiring the singulation and handling of individual III-V chips.

II. DESIGN AND FABRICATION

The III-V-on-Si laser structure is based on the µTP of pre-fabricated InP-based semiconductor optical amplifiers (SOAs) as the gain section in a SiPh external cavity. The µTP process is based on the use of an elastomeric poly-dimethylsiloxane (PDMS) stamp to pick-up the pre-fabricated thin-film SOAs, which are undercut by selectively etching the release layer underneath the III-V epi-layer stack, from their native III-V source wafer and to print them on the target substrate. The PICs, which have recesses in the back-end down to the 3 μm wide Si-waveguide where the SOA has to be integrated, are fabricated in imec’s SiPh pilot line on 200 mm SOI wafers with a 400 nm thick silicon device layer and a 2 μm thick buried oxide layer (BOX), including a back-end stack incorporating the heaters and metal tracks. A spray-coated DVS-BCB adhesive bonding layer enables a high-yield printing process. Fig. 1 shows the schematic of µTP of pre-fabricated III-V SOAs on imec’s 400 nm SOI platform.
The widely tunable laser shown in Fig. 2 is realized by combining two external cavity lasers in a single-mode waveguide using a 3 dB combiner, each laser with a different SOA gain peak wavelength (1525 nm and 1575 nm). An individual external cavity consists of a pair of thermally tunable micro-ring resonators (MRRs) with a slightly different radius (27 µm and 29.3 µm) to form a Vernier filter, a phase section based on thermo-optic tuning, a deep recess to print the pre-fabricated SOA (Fig. 1), and a tunable Sagnac loop mirror to optimize the reflectivity of the out-coupling mirror. A grating coupler (GC) is used as the output of the widely tunable laser. The free spectral range (FSR) of each ring is around 4 nm and the combined FSR of the Vernier filter is around 45 nm in the envisioned wavelength range. 65 mW of electrical power is required to tune a single ring over one FSR. The length of the III-V SOAs (fabricated by III-V Lab) are 1 mm, including a pair of 180 µm long adiabatic tapers for an efficient coupling between the III-V SOA and the underlying Si-waveguide. An additional pair of adiabatic 50 µm long Si-tapers is used to couple the optical mode between the 3 µm wide Si-waveguide underneath the III-V SOA and the single-mode rib waveguide. The design and fabrication of the III-V SOAs are similar to what is described in detail in [1].

III. CHARACTERIZATION

The sample is placed on a temperature-controlled stage stabilized at 15°C for characterization. The threshold current of both the lasers is around 60 mA and differential resistance of both the lasers’ SOAs is about 10 Ω while biased at 120 mA. Discrete wavelength tuning of 110 nm and fine tuning in a range of 4 nm with steps of 100 pm is shown in Fig. 3. Discrete-tuning is achieved by thermally tuning one of the micro-rings and phase section of each laser while fine-tuning is achieved by thermally tuning both the micro-rings and the phase section of each laser, simultaneously.

Fig. 3. Wavelength tuning behavior of the combined widely tunable laser (Fine-tuning is done in the steps of 100 pm over a range of 4 nm, which is equal to the FSR of one ring).

Fig. 4 shows the laser’s frequency noise power spectral density biased at 120 mA measured using an OEwaves-OE4000 Optical Phase Noise Test System while the lasing wavelength is 1530 nm. The Lorentzian linewidth corresponding to the shown frequency noise spectrum is about 20 kHz. Linewidth variations are observed over the laser tuning range, but the frequency noise spectrum consistently remains below the linewidth threshold mask provided by OIF-400-ZR [2].

IV. CONCLUSION

For the first time, we demonstrate a narrow-linewidth III-V-on-Si laser with 110 nm tuning range by micro-transfer printing pre-fabricated InP-based SOAs on a SiPh platform. This is a stepping stone towards the realization of complex PICs with integrated lasers and semiconductor optical amplifiers for a wide range of applications such as coherent optical communication.

REFERENCES