Experimental demonstration of a micro-transfer printed InP-on-Si_3N_4 widely tunable laser

B. Pan[1], J. Bourderionnet[2], V. Billault[2], D. Guenole[2], M. Dahlem[3], D. C. Altamirano[3], C. Cummins[3], S. S. Saseendran[3], P. Helin[3], J. Ramirez[4], D. Néel[4], E. Soltanian[1], J. Zhang[1] and G. Roelkens[1]

1. Photonics Research Group, Department of Information Technology, Ghent University - imec, 9052 Ghent, Belgium
2. Thales Research and Technology, 1 Avenue Augustin Fresnel, Palaiseau, 91767, France
3. IMEC, Kapeldreef 75, Heverlee, 3001, Belgium
4. III-V Lab, 1 Avenue Augustin Fresnel, Palaiseau, 91767, France
biwei.pan@ugent.be

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***Abstract*—We demonstrate an InP-on-Si_3N_4 widely tunable laser on imec's 200-mm low-loss Si_3N_4 platform through micro-transfer printing. The device shows a wavelength tuning range of 54 nm in C + L band with a side mode suppression ratio over 40 dB.**

***Keywords*—heterogeneous integration, micro-transfer printing, tunable lasers, silicon nitride photonics**

I. Introduction

Silicon nitride photonics is emerging to build advanced photonic devices and on-chip photonic systems by using its advantages on low propagation loss, high on-chip power handling and wide transparency window from visible to infrared. As a result, state-of-the-art performance of photonic integrated circuits are enabled on Si_3N_4 platforms, including frequency comb generators [1], optical gyroscopes [2] and microwave photonic oscillators [3]. However, as Si_3N_4 is a passive material, all active building blocks such as laser sources, modulators and photodetectors, have to rely on the integration of devices implemented on other material platforms. To this purpose, several technologies have been developed, including micro-optic benches, flip-chip bonding, wafer/die-to-wafer bonding, and micro-transfer printing. Among them, micro-transfer printing supports the heterogeneous integration of pre-fabricated functional photonics and electronics chiplets [4], enabling the simultaneous integration of multiple devices on chip without greatly increasing the fabrication complexity. Furthermore, it provides high throughput integration through printing large coupon arrays [5]. These advantages are desired for Si_3N_4 photonic integrated circuits that require the integration of multiple active functions.

In this paper, we demonstrate a heterogeneously integrated widely tunable laser on imec's 200-mm low pressure chemical vapor deposition (LPCVD) Si_3N_4 platform through micro-transfer printing a pre-fabricated InP SOA coupon realized by III-V Lab. The post-printing process is minimized to the final metal redistribution. The quality control of both the Si_3N_4 waveguide circuits and III-V gain devices can be realized in their own foundry, which greatly enhances the integration yield and paves the way for large scale integration. This device could enable fully integrated on-chip systems such as microwave photonics engines, optical clocks, optical gyroscopes and LiDAR.

II. Laser Structure

Fig. 1(a) shows a microscope picture of the proposed InP-on-Si_3N_4 widely tunable laser. The laser cavity consists of a pre-fabricated InP SOA coupon micro-transfer printed in a local recess. On the left side, there is a tunable dual-add-drop micro-ring resonators (MRRs) filter followed by a total reflection loop mirror for mode selection and wavelength tuning. On the right side, a Mach–Zehnder interferometer (MZI) coupler with a Sagnac loop is employed to form an on-chip mirror with controllable reflectivity. By using a 400-nm thick Si_3N_4 core layer, a single mode waveguide supports a bending radius as small as 50 μm, which limits the device footprint. The total size of the laser is 5.6 × 0.86 mm^2. A detailed description of the Si_3N_4 platform and the laser cavity can be found in our previous publication [6]. In this paper, an optimized micro-heater design is implemented to improve the thermal tuning efficiency of Si_3N_4-based building blocks, including MRRs, MZI and phase tuning section, and to maintain a high quality factor of the laser cavity. As shown in Fig. 1(b), a TiAu heater is implemented on top of Si_3N_4 strip waveguide to realize thermo-optical phase tuning. The thickness of the oxide cladding layer between the micro-heater and the Si_3N_4 waveguide is carefully chosen to trade off thermal efficiency and metal-induced optical losses.

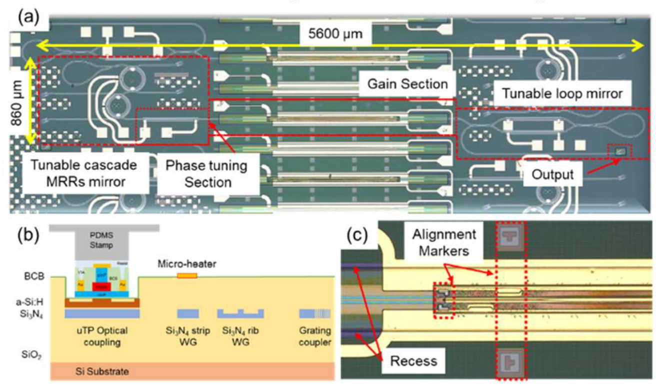

Fig. 1. (a) A microscope picture of the proposed InP-on-Si3N4 widerly tunable laser. (b) A schematic view of Si3N4 platform with micro-transfer printed InP coupon. (c) A top-view microscope picture of InP coupon on aSi:H/Si3N4 waveguide.

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A 3.2-µm bottom oxide layer between the Si_3N_4 waveguide and silicon substrate is used to reduce heater power dissipation, avoid optical coupling to the substrate, and limit the thermal resistance of the InP gain coupon.

III. Laser Characterization

In the measurement, the heterogeneously integrated tunable laser was electrically contacted through DC-probes on a temperature-controlled stage and optically probed by a cleaved standard single-mode fiber through the grating coupler on the Si_3N_4 layer. The operation temperature was set to 15 °C and controlled by a thermo-electric cooler (TEC). The fiber-chip coupling loss is calibrated through a reference single mode waveguide on the sample with the same grating coupler on both sides. The measured coupling loss of each grating coupler is approximately 10~14 dB in a wavelength range of 1510 nm to 1590 nm. Fig. 2 (a) shows a typical calibrated waveguide-coupled power-current (LI) curve at an operation wavelength of 1571 nm. In the measurements, only the gain current is tuned with fixed biases of all the micro-heaters. Periodic oscillation of the optical power is caused by refractive index change of the gain section and shift of the alignment between the longitudinal modes and MRRs resonance while tuning the gain current. The output power reaches 6.3 mW at 158.5-mA bias current and then starts to roll off mainly due to the poor heat dissipation.

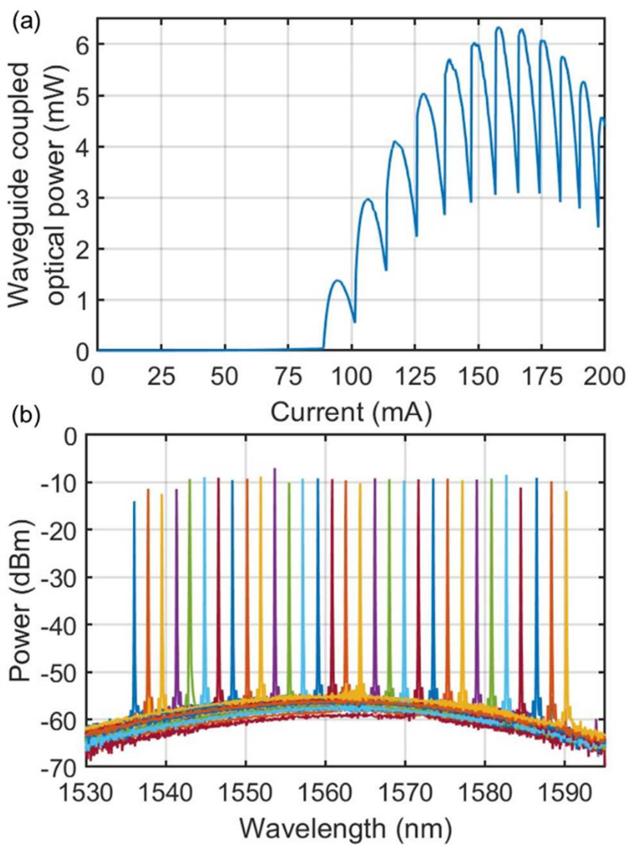

Fig. 2. (a) A calibrated waveguide-coupled optical power-current curve at an operation wavelength of 1571 nm. (b) Optical spectra at different operation wavelengths through MRRs tuning.

Fig. 2 (b) shows the optical spectra in C+L band realized by thermally tuning the two MRRs and slightly adjusting the phase tuning section. Taking the advantages of high-quality factor MRRs with strong mode selection ability and optimized micro-heaters that enables 2π phase shift, stable single mode lasing over a wavelength tuning range of 54 nm is realized with a side mode suppression ratio larger than 40 dB.

IV. Conclusion

We demonstrate a heterogeneously integrated widely tunable laser on imec’s 200 mm silicon nitride platform through micro-transfer printing a pre-fabricated InP gain coupon realized by III-V Lab. The waveguide-coupled output power reaches 6.3 mW and a wide wavelength tuning range of 54 nm in C + L band is achieved with a side mode suppression ratio over 40 dB. This technology enables wafer-scale manufacturing of Si_3N_4 photonic integrated circuits with on-chip sources, which will greatly facilitate many photonic applications that require low-loss waveguides.

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