Two-step Transfer Printed External Cavity Lasers on Commercial Silicon Nitride Platform

A. Fernández Gamez[1,2,3], T. Reep[1,2], S. Poelman[1,2], M. Billet[1,2], D. Pastor[3], P. Muñoz[3], C. Domínguez[4], J. D. Doménech[5] and B. Kuyken[1,2]

[1] Photonics Research Group, Department of Information Technology (INTEC), Ghent University — imec, Technologiepark-Zwijnaarde 126, 9052 Ghent, Belgium
[2] Center for Nano- and Biophotonics (NB-Photonics), Ghent University, Technologiepark-Zwijnaarde 126, 9052 Ghent, Belgium
[3] Photonics Research Labs, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
[4] Grupo de Transductores Químicos (GTQ), Instituto de Microelectrónica de Barcelona (IMB-CNM, CSIC), 08193 Cerdanyola del Vallès, Barcelona, Spain
[5] R&D Department, VLC Photonics S.L., Camino de Vera s/n, 46022 Valencia, Spain

Ultra-low linewidth external cavity lasers have been pivotal in enabling current coherent optical communications. However, the growing demand for connected devices calls for more compact and efficient light sources. Recent advances in heterogeneous integration techniques, such as micro-transfer printing, offer a promising pathway for embedding light sources in CMOS-compatible platforms.

In this work, we present the first demonstration of heterogeneous integration of active devices on the commercial 300 nm thick silicon nitride platform from VLC Photonics S.L and Instituto de Microelectrónica de Barcelona (IMB-CNM). Specifically, we designed and characterized the external cavity lasers based on the Vernier effect, utilizing a two-step transfer printing technique for precise coupling between an indium phosphide amplifier and silicon nitride waveguides. A 400 nm thick silicon interposer layer was employed as an interface to ensure efficient evanescent mode coupling between passive and active components.

The developed lasers achieved a tunable range of 34 nm, with corresponding Schawlow-Townes linewidths of 90 kHz.

Introduction

The rapid increase in internet users demanding high-speed, high-bandwidth online communication—anticipated to reach exabyte levels each month [1] emphasizes the need for scalable, low-latency, and energy-efficient technology solutions.
Leveraging existing silicon foundries presents a promising pathway to meet these demands cost-effectively. However, silicon's indirect bandgap makes it unsuitable as an efficient light source. In contrast, group III-V materials, like indium phosphide, possess a direct bandgap and are therefore more efficient for photonic applications. Yet, the lattice mismatch between III-V materials and silicon poses significant challenges for direct growth on silicon wafers.

To address these challenges, this paper explores the use of micro-transfer printing technology to integrate indium phosphide-based semiconductor optical amplifiers (SOAs) onto a commercially available silicon nitride wafer. Micro-transfer printing operates similarly to a "pick-and-place" process, where pre-processed devices or thin-film materials—held in place by encapsulation tethers—are picked up from a source wafer and transferred onto a target wafer using an elastomer stamp.

Device Design

In the target wafer, a silicon nitride cavity is configured with two coupled mirror resonators and a Sagnac loop mirror as described in Figure 1a, which extends the cavity length and reduces laser linewidth [2]. The mirrors exhibit slightly different free spectral ranges (FSRs), creating a Vernier effect, which is illustrated in Figure 1b, which facilitates longitudinal mode filtering across a tunable range.

To couple the light form the silicon nitride to the amplifier, narrow tapers are designed to first achieve evanescent coupling between the silicon nitride waveguide and the intermediate silicon layer. Because the refractive index difference between silicon and indium phosphide (InP) is smaller, this intermediate silicon layer acts as a bridge, enabling more efficient coupling to the InP amplifier (n ≈ 3.15 at 1.55 µm). This approach mitigates the refractive index mismatch issues, leading to improved overall mode coupling efficiency.

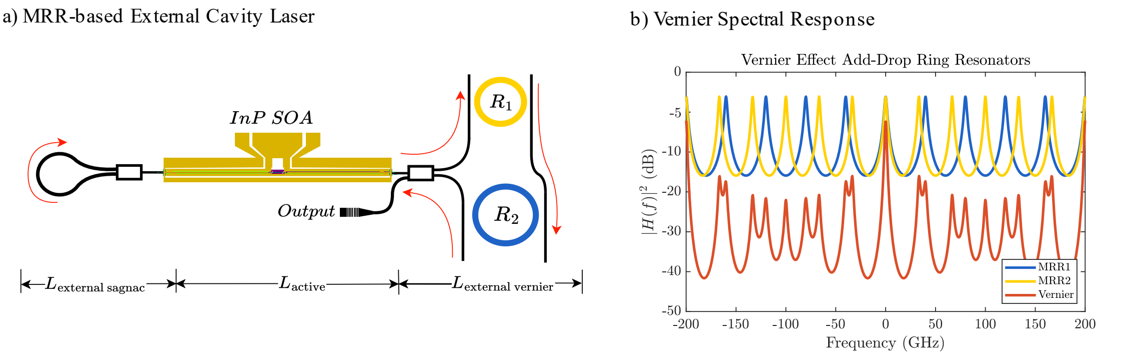

Figure 1. External cavity laser diagram. a) MRR-based external cavity laser b) Vernier spectral response illustration.

Device Fabrication

The front-end manufacturing was conducted by the Instituto de Microelectrónica de Barcelona – Centro Nacional de Microelectrónica (IMB-CNM) as part of an MPW service organized by VLC Photonics S.L. While the backend was done at NaMiFab facility at Ghent University. The complete process flow is summarized in Figure 2.

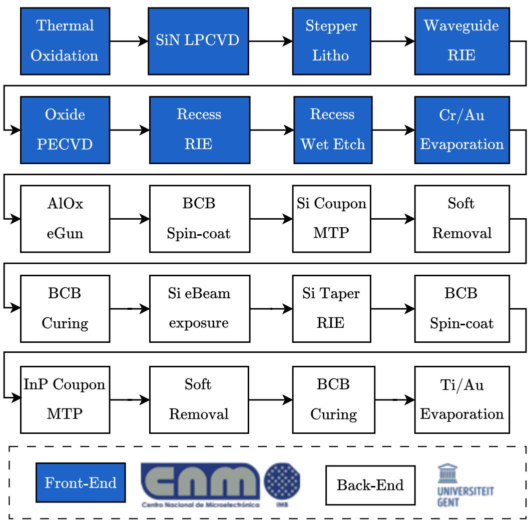

Figure 2. Process flow diagram.

The two-step transfer printing process starts with 35 nm aluminum oxide layer deposited via electron beam evaporation to serve as an etch stop layer. Next, a uniform layer of benzocyclobutene (BCB) is spin-coated as an adhesive layer. Then thin film of 400 nm silicon is micro-transfer printed and patterned using electron beam lithography and reactive ion etching (RIE) to achieve the narrow tip required due to enable adiabatic coupling between the layers.

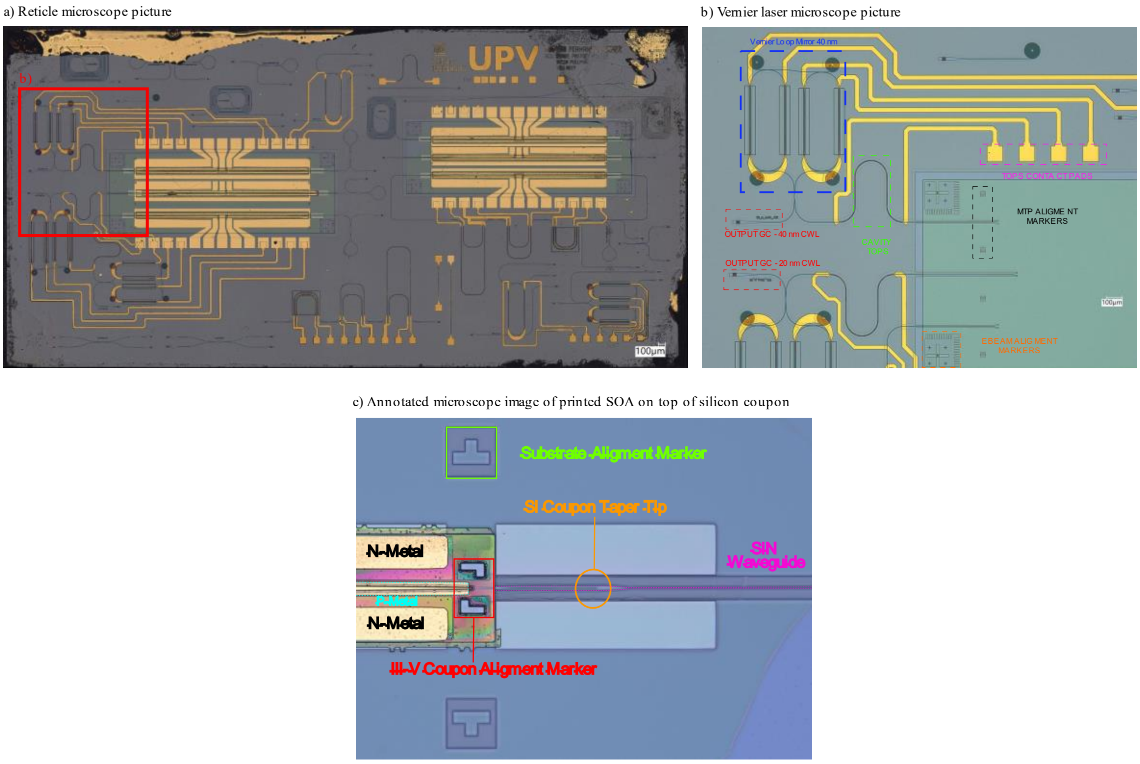

Figure 3. Fabricated chip overview. a) Reticle microscope picture b) Vernier laser microscope picture c)Annotated microscope image of printed SOA on top of silicon coupon.

Before the printing the SOA, another layer of BCB is spin coated and then the amplifier is aligned onto the silicon coupon underneath. Finally a bi-layer of 1000 nm of gold and 40 nm of titanium for the SOA and laser cavity thermo-optic phase shifters (TOPS) contact pads is deposited through sputtering and lift-off.

Device Characterization

By performing a voltage sweep on the individual rings in the Vernier configuration, the lasing mode can be shifted over a total tunable range of 34 nm as shown in Figure 4b. The maximum Side Mode Suppression Ratio (SMSR) was be computed at the gain peak (around 1540 nm).

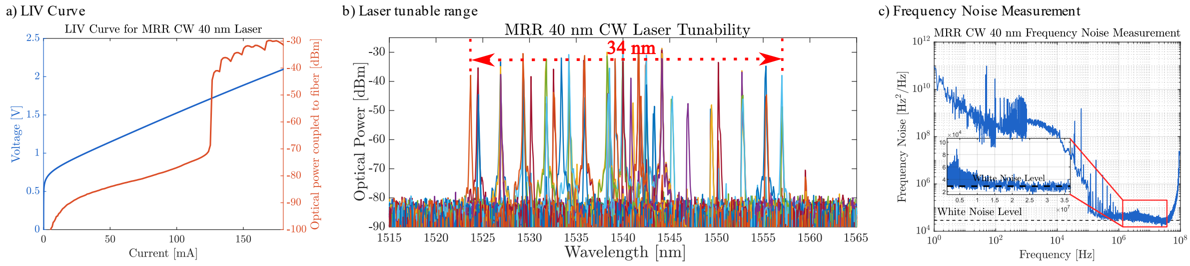

Figure 4. Laser Characterization results. a) LIV curve b) Laser tunable range c) Frequency Noise.

By analyzing the frequency noise at higher frequencies where the measurement is relatively free from technical noise from electronics, vibrations, and other environmental factors [2]. The white noise level in Figure 4c corresponds to a modified Schawlow-Townes linewidth of $\pi S_F(f) = 90$ kHz.

Conclusion

This work is the result of a strong collaboration between UPV Photonics Research Labs and UGent Photonic Research Group, marking the first demonstration of a heterogeneously integrated external cavity laser on the VLC-CNM silicon nitride platform. This initial demonstration, achieved using a two-step micro-transfer printing technique, showcased tunable ranges of 34 nm around a 1540 nm wavelength. Despite the higher linewidths of 90 kHz attributed to platform losses and grating coupler designs, this work establishes a critical foundation for future advancements in integrated photonics. VLC Photonics' customers stand to benefit greatly from these developments as the platform continues to advance with new designs and improvements.

Acknowledgment

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References

[1] Cisco, "Cisco Annual Internet Report (2018-2023) White Paper," 2020.

[2] M. A. Tran, "Narrow linewidth tunable semiconductor lasers using Si/III-V heterogeneous integration," *APL Photonics*, vol. 4, Nov 2019.