European Conference on Integrated Optics (ECIO)
2026 © 2026 Optica Publishing Group

Low Repetition Rate III/V-on-SiN Mode-Locked Lasers through Micro-Transfer Printing

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Abstract: We demonstrate heterogeneously integrated mode-locked lasers using a two-step micro-transfer printing approach on a commercial SiN platform. We report stable mode-locked lasers operating with repetition rates of 1, 2.6 and 8.5 GHz.

1. Introduction

Integrated mode-locked lasers have been established as promising on-chip comb sources. Contrary to Kerr combs, mode-locked lasers are particularly interesting for low-noise and low repetition rate applications such as dual-comb spectroscopy [1]. The incorporation of heterogeneous integration has been crucial to enable miniaturization of these mode-locked lasers, by enabling the efficient integration of III/V amplifiers onto low-loss passive platforms such as Si, SiN and LN. In recent years, silicon nitride platforms have often been favored for their low propagation losses, wide transparency range and the absence of two-photon absorption. In combination with heterogeneous integration of III/V amplifiers, this has led to a number of demonstrations of continuous wave (CW) and mode-locked lasers [2–4]. An important hurdle for the integration of III/V on low-refractive index platforms such as silicon nitride, is the large index gap. Typically an intermediate layer is employed to bridge this gap, with previous demonstrations using amorphous silicon, crystalline silicon and polycrystalline silicon. The aforementioned demonstrations do however rely on expensive dedicated platforms, which is a downside when looking to further mature this technology. A versatile two-step micro-transfer printing approach was used in previous work on an in-house platform [5].

In this work, we show that this two-step integration approach can be transferred to a commercial SiN platform, and can be scaled to multiple devices on a single chip. We show mode-locked lasers with ring and Fabry-Perot topologies, with repetition rates of 1 GHz, 2.6 GHz and 8.5 GHz, in a first step towards scaling the development of integrated mode-locked lasers to a more mature level.

2. Design and Fabrication

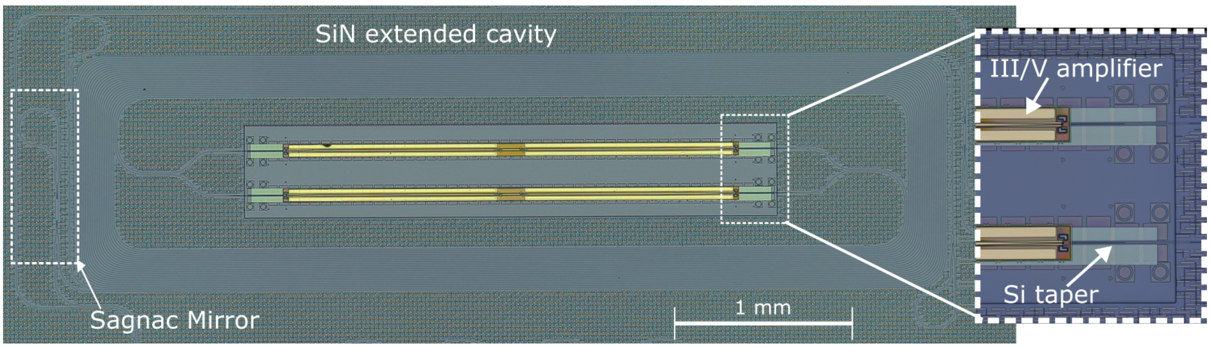

Fig. 1. Microscope image of the 1 GHz Fabry-Perot mode-locked laser, consisting of a long SiN extended cavity, Sagnac mirrors and a gain section with the transfer printed silicon interposer and III/V amplifier.

A design was made on the commercial SiN platform of Ligentec, containing a number of mode-locked laser designs with different topologies (ring, Fabry-Perot) and repetition rates ranging from 1 to 10 GHz. The different repetition rates are achieved by correctly designing the length of the extended cavities. Figure 1 shows a microscope image of a dual-comb source with a 1 GHz Fabry-Perot topology, in a compact 5.6 mm $\times$ 1.8 mm footprint.

The long extended cavity is formed in the low-loss SiN waveguides with a length designed to achieve the 1 GHz repetition rate. The cavity mirrors are formed by two Sagnac mirrors. Centrally placed in the cavity is the gain section, for which a two-step micro-transfer printing approach is employed. In the first step an unpatterned silicon coupon is printed, and waveguides and tapers are subsequently patterned with electron beam lithography and etched in an inductively coupled plasma etcher. In the second step, the 2.5 mm-long III/V multi-quantum well amplifiers are printed on top of these silicon coupons. These amplifiers already contain an electrically isolated section which can be reversed biased to serve as the saturable absorber. A final metallization step (not shown in the figure) is used to facilitate easier electrical contacting. The output waveguides are routed to edge couplers at the side of the chip, for efficient coupling to lensed fibers.

3. Experimental Results

Characterization of the mode-locked lasers was done using a dedicated probe, driven by two Keithley source measure units, while the chip is kept thermally stable at a fixed temperature using a thermoelectric cooler. The light captured using the lensed fibers is then analyzed using an optical spectrum analyzer and a photodetector connected to an electrical spectrum analyzer. Several mode-locked laser devices were characterized on this chip, of which we report three with repetition rates of 986 MHz, 2.65 GHz and 8.58 GHz. The respective optical and RF spectra are shown in Figure 2. All devices show clear optical comb spectra centered at c-band wavelengths, with optical 10 dB bandwidths reaching up to 15 nm and RF spectra with large signal-to-noise ratios, indicating stable mode-locking operation.

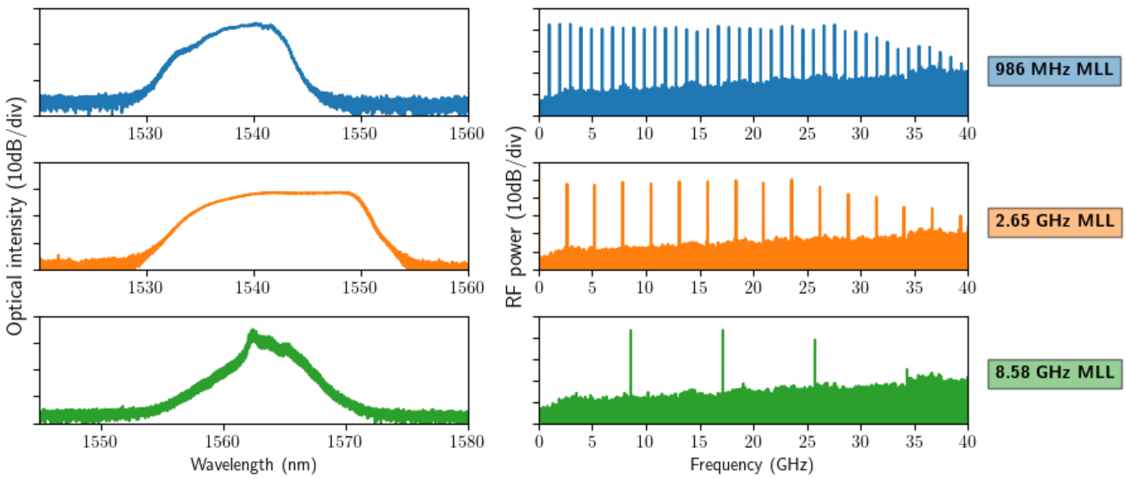

Fig. 2. **(left)** Optical spectra and **(right)** RF spectra of three mode-locked lasers with respective repetition rates of 986 MHz, 2.65 GHz and 8.58 GHz.

4. Conclusion and Outlook

We successfully transfer the versatile two-step micro-transfer printing approach to a commercial SiN platform. We report on several mode-locked lasers with repetition rates varying from 1 GHz to 8.6 GHz. This is a first step towards a more scalable integration approach for such low repetition rate mode-locked lasers.

Future work will look into further fabrication and characterization of these devices, with the aim of getting relevant data on the yield and reliability of these chips. Furthermore, this approach will be transferred from a sample-scale process to a wafer-scale process, to mature this technology even further.

Acknowledgments

This work was supported by the European Innovation Council (EIC) through the Molokai project (Grant no. 101159440)

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