

Low Repetition Rate Mode-Locked Laser on a Commercial Foundry Low-Index Photonic Platform

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Abstract: We demonstrate a heterogeneously integrated III-V-on-silicon-nitride mode-locked laser with 710 MHz repetition rate. A versatile two-step micro-transfer printing approach is employed to enable low-loss integration on a commercial foundry low-index photonic platform.

1. Introduction

Integrated mode-locked lasers have gained a lot of interest in recent years, with potential applications in diverse fields such as metrology, light detection and ranging (LIDAR), telecommunication and spectroscopic sensing. Several demonstrations of mode-locked lasers using heterogeneous integration of III-V semiconductor optical amplifiers (SOA) on silicon nitride platforms have shown promising results to generate optical combs on a single photonic chip [1]. Silicon nitride platforms enable ultra-low losses and a wide transparency window, but the low refractive index introduces the need for an intermediate layer to allow for efficient evanescent coupling to III-V SOAs. Coupling structures using wafer bonding [2] or the deposition of intermediate layers [3] have been demonstrated, but both approaches require numerous fabrication steps and are not easily compatible with heterogeneous integration in a recess. The latter is however a crucial requirement for the use of commercial low-index photonic platforms, which usually have a thick top oxide cladding. Micro-transfer printing is a versatile technique used in a variety of heterogeneously integrated devices [4], and is used in this work for the integration of both the intermediate silicon coupling structure and the InP-based SOA. This two-step transfer printing approach can also easily be adapted for use on different target platforms and source materials. In this work it is used to demonstrate a low repetition rate mode-locked laser on the commercial foundry low-index platform of Ligentec SA.

2. Design and fabrication

The demonstrated mode-locked laser is fabricated on the commercially available silicon nitride platform of Ligentec SA. To bridge the large refractive index mismatch between the low-loss silicon nitride and the III-V SOA, an intermediate transition layer is introduced, to enable efficient evanescent coupling. In this work, we successfully employ a two-step micro-transfer printing strategy, in which both the intermediate layer and the III-V material are transferred onto the target sample in subsequent printing steps, as shown in Figs 1. (a) and (b). In [5], two approaches were proposed for the implementation of a silicon coupling structure serving as intermediate layer: transfer printing fully patterned silicon coupling structures and transferring silicon slab coupons which are patterned after printing on the target sample. In this work, we used the latter as it enabled higher lateral alignment accuracy at the cost of some additional processing steps on the target sample. After the two micro-transfer printing steps, the 1.3-mm long InP III-V amplifier was post-processed to isolate the saturable absorber, create vias to the n-contacts and to create the metal contacts, all using optical contact lithography, reactive ion etching and metal deposition (Fig 1. (c)). The demonstrated mode-locked laser is based on a Fabry-Pérot configuration consisting of the aforementioned silicon coupler and III-V amplifier in the center, with a 10-cm long SiN spiral waveguide and Sagnac reflector (designed to reflect 80%) on either side, schematically shown in Fig. 1. (d).

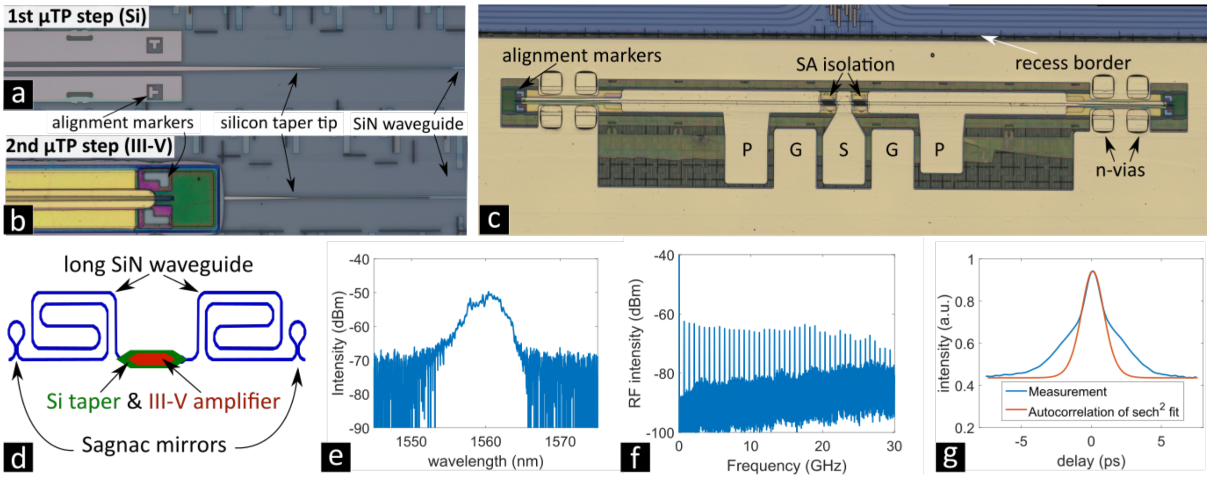

Fig. 1. a) Microscope image of the silicon coupler after the first micro-transfer printing (µTP) step. b) Microscope image of the InP-based SOA after the second micro-transfer printing (µTP) step. c) Microscope image of the finalized III-V amplifier with saturable absorber (SA) isolation, n-vias and metal contacts. d) Schematic representation of the Fabry-Pérot mode-locked laser. e) Measured optical spectrum with 10 dB bandwidth of 6.6 nm. f) Measured RF spectrum with 710 MHz line spacing. g) Autocorrelation measurement and $sech^2$ fit.

3. Measurements

The device was measured by probing the amplifier with a custom-designed PGSGP probe and biasing using two Keithley source measure units, one for the two amplifier sections connected in parallel and one for the saturable absorber. The temperature of the chip was kept constant at 16°C. The light is coupled out from one of the output facets into a lensed fiber, and subsequently split between a power meter (10%), optical spectrum analyzer (45%) and 40 GHz photodiode connected to an electrical spectrum analyzer (45%). Fundamental mode-locking was obtained for a driving current of 110 mA for the amplifiers, and a reverse bias of 3.8 V. The measured output power (at the power meter) for this operating point was -35 dBm, and an optical spectrum with a 10 dB bandwidth of 6.6 nm was obtained, consisting of over 1000 equally spaced optical lines, shown in Fig. 1. (e). Figure 1. (f) shows a relatively flat RF comb spectrum with a 710 MHz line spacing (corresponding to the 10-cm long extended cavity spiral waveguides) over a wide bandwidth. Due to the relatively low output power of the laser, two erbium-doped fiber amplifiers, with an optical filter in between, were required to obtain the autocorrelation measurement shown in Fig. 1. (g). The autocorrelation function of a $sech^2$ pulse was fitted to the data, showing a full width at half maximum of 2.18 ps for the deconvoluted pulse. This result is up there with the lowest repetition frequencies achieved for on-chip passive mode-locked lasers [3], but shows a considerably larger optical bandwidth and a significantly shorter pulse width, proving very promising for high-resolution spectroscopy applications.

4. Conclusion

We have demonstrated a heterogeneously integrated III-V-on-SiN mode-locked laser with a repetition rate of 710 MHz on a generic commercially available low-loss passive photonic platform, enabling very high resolution ideal for spectroscopic applications. The device was fabricated using a two-step micro-transfer printing approach to enable heterogeneous integration in a recess while limiting the required number of post-processing steps. Furthermore, the versatility of the fabrication methodology paves the way to build more advanced laser sources on various integrated photonic platforms, such as thin-film lithium niobate or silicon nitride.

References

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