Scalable Butt-Coupled Integration of 800 nm Lasers on Silicon Nitride using Micro-Transfer Printing

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Abstract: We demonstrate micro-transfer printed 800 nm GaAs-based lasers on a SiN platform using a scalable butt-coupling method. We show continuous-wave lasers with 4 mW output power and passive mode-locking with a 519 Hz radio-frequency linewidth.

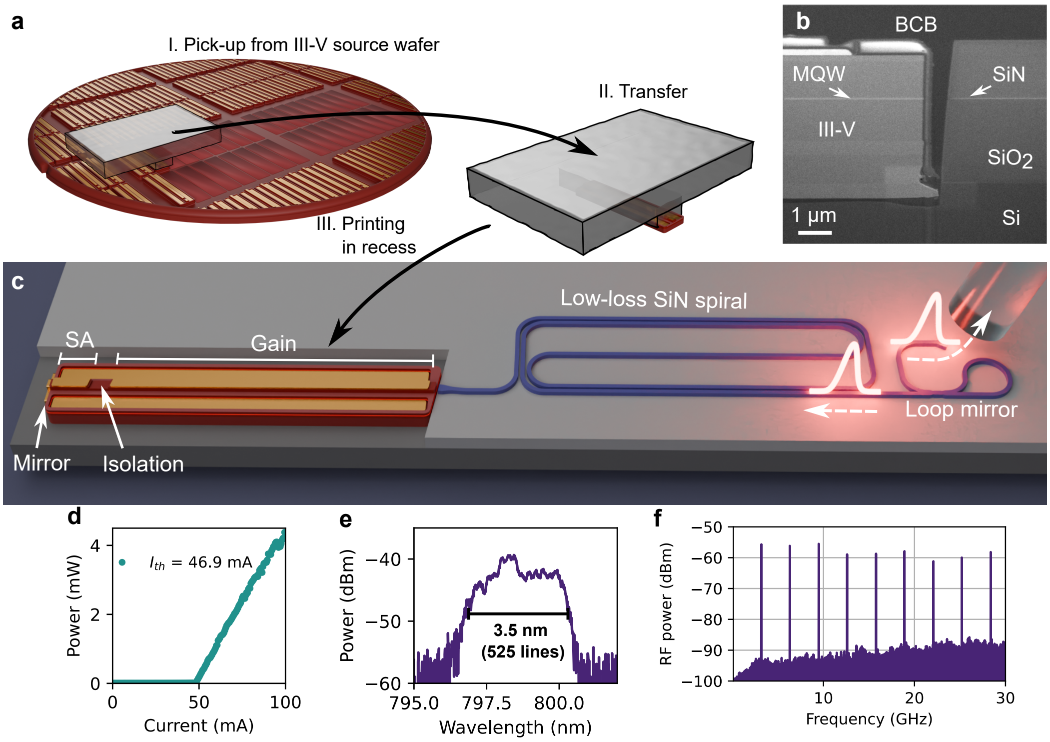

Fig. 1. (a) Micro-transfer printing process. (b) Focused ion beam (FIB) cross-section of the butt coupled integration. (c) Schematic of an integrated extended-cavity mode-locked laser. (d) Continuous-wave (CW) light-current curve of a 9.2 GHz extended-cavity laser. (e) Optical spectrum of a 3.2 GHz mode-locked laser driven at 85 mA gain current and -1.3 V SA bias. (f) Radio-frequency (RF) comb of the same mode-locked laser measured with a radio bandwidth of 100 kHz. Adapted from [1].

1. Introduction

The integration of (near-)visible light sources on silicon photonics waveguide platforms is critical for scalable production of photonic integrated circuits (PICs) for applications in quantum computing, optical clocks, and augmented reality [2]. While silicon nitride (SiN) waveguides offer an excellent low-loss, broad-transparency window for near-infrared and visible wavelengths, the efficient and scalable integration of III-V gain materials at shorter wavelengths approaching the visible spectrum remains a key challenge. The coupling mechanism primarily used at telecommunication and data communication wavelengths, evanescent coupling using silicon tapers, is not feasible at shorter wavelengths due to material absorption. This means light must be butt-coupled from the III-V source. A mature technique to achieve this is chip-to-chip coupling [3], which is inherently limited in scalability. Alternatively, wafer bonding can be used to integrate III-V on SiN in a scalable manner [4, 5]. However this requires complex coupling structures, since the III-V waveguides cannot be integrated planar with the SiN waveguides.

To overcome these limitations, we demonstrate the heterogeneous integration of 800 nm laser sources on the 200 mm silicon nitride platform of imec using micro-transfer printing (MTP) [6]. We leverage the flexibility of micro-transfer printing to directly butt-couple the III-V sources to the silicon nitride waveguide by placing them in a recess etched down to the silicon substrate, vertically aligning the III-V and SiN waveguide modes. This provides a mechanically robust, broadband optical interface with superior thermal management, enabling complex and high-power laser systems which can be integrated at the wafer scale.

2. Results

GaAs-based laser coupons were fabricated with shallow-etched ridge waveguides, electrical contacts, and plasma etched facets. The facets were passivated and the rear facet was coated with a gold highly-reflective layer. To facilitate mode-locking, a small part of the gain section of the laser was electrically isolated from the rest, which can be biased separately to act as a saturable absorber to facilitate mode-locking. The coupons were subsequently micro-transfer printed by picking them up from the III-V source wafer using an elastomer stamp, as seen in Fig 1a, and printing them in an etched recess. A FIB cross-section of the coupling region is shown in Fig 1b.

With this technique, extended-cavity lasers were fabricated consisting of a reflective semiconductor optical amplifier (RSOA) butt-coupled to a SiN cavity, which includes a low-loss spiral and a Sagnac loop mirror as the output coupler (Fig. 1c). By forward-biasing both SOA sections, we achieve CW operation with more than 4 mW waveguide-coupled power, as seen in Fig. 1d.

By reverse-biasing the saturable absorber, we achieve passive mode-locking. The spectrum of the optimal mode-locking point of a 3.2 GHz free-spectral range (FSR) laser is shown in Fig. 1e, showing flat, broad spectrum spanning 3.5 nm or 1.7 THz (525 comb lines). The laser output is measured on a 25 GHz bandwidth photodiode and the resulting RF spectrum is shown in Fig. 1f, showing narrow, equidistant peaks with an extinction ratio exceeding 50 dB. Phase noise measurements of the fundamental tone reveal a Lorentzian RF linewidth of just 519 Hz, indicating excellent passive stability of the comb. This excellent passive stability, combined with the scalability of the MTP process, establishes this platform as a viable route for manufacturing high-performance, fully integrated laser systems at near-visible wavelengths.

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