

III-V-on-Silicon 1-GHz Mode-Locked Lasers Towards Frequency-Comb Applications

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Abstract: Fundamental and technical noise sources in III-V-on-silicon mode-locked lasers are investigated and minimized. Their frequency stability is optimized to make them suited to applications such as dual-comb spectroscopy or dual-comb LIDAR. © 2020 The Author(s)

1. Introduction

Applications such as sensing and laser ranging (LIDAR) take advantage of narrow-linewidth continuous-wave lasers and optical frequency combs. Given the need for scalability of these products, a compact footprint and a method for high-volume low-cost fabrication are critically sought after [1]. Integrated photonics platforms based on silicon, silicon-nitride, and heterogeneous integration of these structure with III-V compound semiconductors show compelling capabilities to enable this new class of devices. Moreover, the stabilization of III-V-on-silicon continuous-wave (CW) lasers has shown great promise for the use of this platform in systems requiring high precision [2]. Although the specifications of laser systems based on these technologies do not compete with state-of-the-art devices for frequency metrology in the laboratory, finding the modalities for using them as ultra-miniaturized field sensors is an exciting endeavor. In recent times, III-V-on-silicon mode-locked lasers have improved their performance in terms of span, number of modes and optical line-width [3, 4]. By studying their noise sources, which have been poorly investigated so far, we aim at reaching new frontiers. Some of the numerous applications of frequency combs may become accessible to III-V-on-silicon mode-locked lasers, which would in turn unlock novel real-world applications.

We present an experimental set-up allowing us to investigate the noise mechanisms in near-infrared III-V-on-silicon mode-locked lasers of low-repetition frequency and identify the potential of these devices for frequency comb applications.

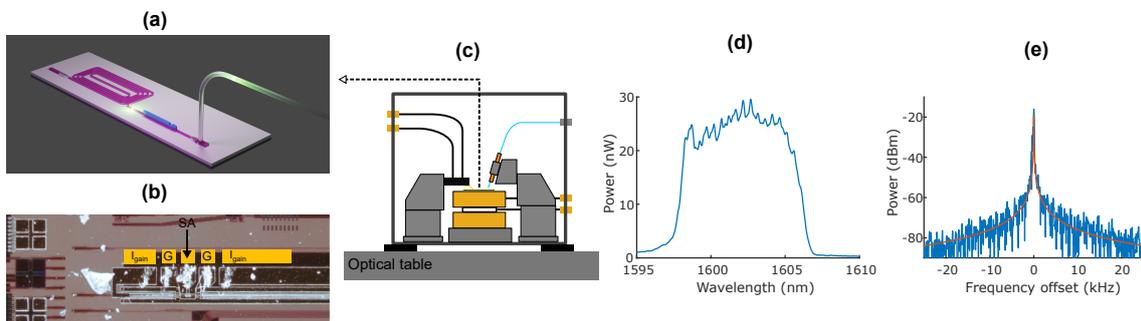


Fig. 1. Overview of the III-V-on-silicon mode-locked laser. (a) Artistic rendering of the mode-locked laser. (b) Micrograph of the gain section with the function of the different contacts indicated. (c) Schematic lay-out of the experimental set-up. (d) Optical spectrum on a linear scale. (e) An electrical spectrum containing the repetition-frequency signal with a 20-Hz FWHM Lorentzian fit.

2. Laser design

The III-V-on-silicon mode-locked laser investigated here has a repetition frequency of 1 GHz, making it suited for direct gas-phase sensing [4]. The III-V-on-silicon mode-locked laser has a passive low-loss (< 0.4 dB/cm) silicon waveguide cavity combined with a 6-quantum-well InP/InGaAsP amplifier waveguide that was die-to-wafer bonded on top of the passive silicon-on-insulator photonic circuit. The saturable absorber is defined in the gain waveguide by electrically isolating $40 \mu\text{m}$ of the gain waveguide and applying a reverse electrical bias to it. An artistic rendering of the device is shown in Fig. 1a and a micrograph of the gain section is shown in Fig. 1b.

3. Experimental results

To investigate the different noise mechanism influencing the laser behaviour, the chip is placed on a temperature controlled chuck inside a metallic enclosure on an optical table, as shown in Fig. 1c. The temperature stability is better than 1 mK for duration of 10 minutes, as shown in Fig. 2a. This excellent temperature stability allows us to identify different noise mechanisms that would otherwise be obscured by the influence of temperature fluctuations. Furthermore, the set-up is shielded from acoustic perturbations. The gain and saturable absorber are electrically contacted using a custom probe. The optical output of the laser, of an average power of $10 \mu\text{W}$, is coupled into a cleaved single mode fiber using an on-chip grating coupler and the resulting optical spectrum is shown in Fig. 1d. The repetition frequency is measured with an electrical spectrum analyzer to 1009608 kHz with a Lorentzian full-width at half-maximum (FWHM) of 20 Hz at 100-Hz resolution bandwidth (Fig. 1e), which is the narrowest RF line-width reported to date using a direct spectrum measurement.

We then measured the heterodyne signal obtained by beating, at 1604.00 nm, a line of the on-chip mode-locked laser with a CW laser of a free-running linewidth of 15 kHz at $100 \mu\text{s}$, detuned by 240 MHz. The resulting beat note, averaged over 100 ms, shows that the Gaussian broadening over this time span is less than 2 MHz (Fig. 1b). This result clearly shows the great potential of III-V-on-silicon mode-locked lasers as most semiconductor mode-locked lasers have an instantaneous line-width exceeding 10 MHz. Moreover, the long-term stability of the beat note was investigated using a frequency counter and demonstrates less than 10 MHz drift over a time span of 10 minutes. The corresponding Allan deviation of the fractional optical frequency stability is shown in Fig. 1c.

The long-term stability of the repetition-frequency signal, measured with a frequency counter shows a slow drift of less than 10 kHz over a period of 10 minutes and less than 1 kHz over the time period of a second. The Allan deviation of the fractional repetition frequency stability is shown in Fig. 1d.

This is the first demonstration of a III-V-on-silicon mode-locked laser stabilization analysis and the results show promising performance for frequency comb applications. Additional results will be presented at the conference.

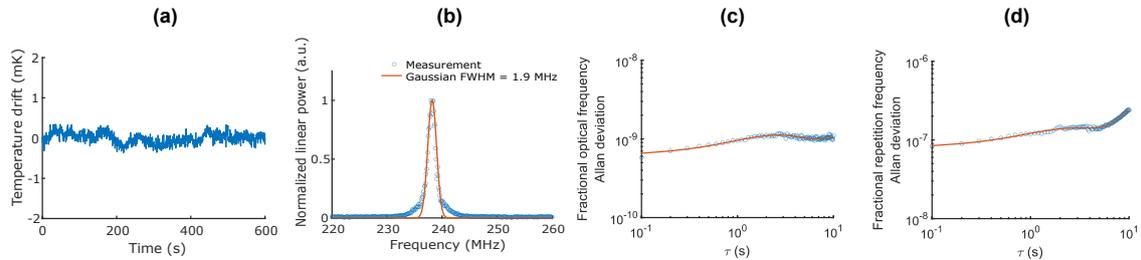


Fig. 2. Stability analysis of the III-V-on-silicon mode-locked laser. (a) Temperature of the chip measured with a thermistor as a function of time. (b) Electrical spectrum of a heterodyne beat note between a single comb line of the on-chip mode-locked laser and a reference CW laser. (c) The fractional optical frequency stability of a single comb line of the on-chip mode-locked laser. (d) The fractional repetition frequency stability of the mode-locked laser.

References

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