III-V-on-Silicon-Nitride Mode-Locked Laser with 2 pJ On-Chip Pulse Energy

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Abstract: We demonstrate a III-V-on-silicon-nitride electrically pumped mode-locked laser emitting at λ = 1.6 µm with an on-chip pulse energy of approximately 2 pJ, significantly higher than on III-V-on-Si and InP photonic integration platforms.

1. Introduction

Mode-locked lasers have applications in LIDAR [1], spectroscopic sensing [2], and optical communication [3], among others. Yet, many systems still rely on fiber or solid-state bulk lasers. On-chip solutions are desired to reduce the cost and footprint of these systems and enable their widespread use. Electrically pumped on-chip mode-locked lasers have been demonstrated in monolithic III-V and heterogeneous III-V-on-silicon platforms [4]. To realize low-noise, narrow-linewidth on-chip mode-locked lasers, one typically relies on the use of extended passive waveguide cavities. Heterogeneous III-V-on-silicon and monolithic InP-based extended-cavity mode-locked lasers have been reported, yet with limited on-chip pulse energies (≤ 0.6 pJ) [4]. Their performance in terms of pulse energy and noise is limited by two-photon and the associated free-carrier absorption, and the relatively high waveguide loss.

Here, we demonstrate a III-V-on-silicon-nitride electrically pumped mode-locked laser with an on-chip pulse energy of approximately 2 pJ emitting at λ = 1.6 µm. Silicon nitride (SiN) has negligible two-photon absorption at telecom wavelengths and waveguide losses as low as ~3 dB/m at 1550 nm have been demonstrated for 1.6 µm × 800 nm SiN waveguides fabricated on 200 mm Si wafers [5]. We use micro-transfer-printing to integrate the III-V active material with a SiN passive waveguide cavity. The reported mode-locked laser has a low repetition rate of 3 GHz and a narrow optical and RF linewidth of 1 MHz and 400 Hz, respectively.

2. Device design and fabrication

The mode-locked laser architecture is schematically depicted in Fig. 1. The III-V section consists of 2 gain sections (each 1.2 mm long) and a saturable absorber (60 µm long), electrically isolated from the gain sections. To obtain a low-loss, low-reflection transition from the active section to the passive SiN section, an intermediate amorphous silicon (a-Si) waveguide layer is used (with tapers), as in [6]. The loop mirror on the left, serving as the outcoupling mirror, has a transmission of 50 %, the right loop mirror has a transmission of 2 % (at λ = 1610 nm). The Fabry-Perot-type cavity has a total length of 48.3 mm, giving a repetition rate of 3 GHz for colliding-pulse mode-locking. Low-reflection grating couplers are used for chip-to-fiber coupling. The SiN and a-Si waveguide layers have a thickness of 395 nm and 400 nm, respectively, with 100 nm SiO_2 in between. The SiN waveguides have a width of 1100 nm and a waveguide loss of 0.16 dB/cm at λ = 1610 nm. The a-Si rib waveguide below the printed III-V device has a width of 2 µm (etch depth of 180 nm). The active region of the III-V material consists of 6 InAlGaAs quantum wells, similar to [7]. The simulated mode profile in the a-Si/III-V hybrid waveguide has a confinement factor of 3.4 % in the quantum wells.

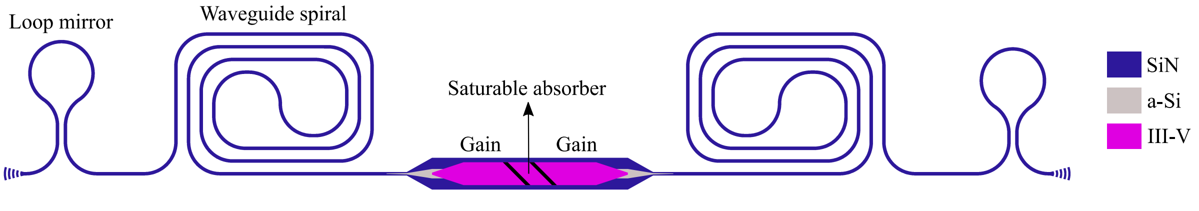

Fig. 1. Schematic illustration of the III-V-on-SiN mode-locked laser.

The SiN photonic integrated circuits (PICs), with a-Si waveguide layer, are fabricated on 200 mm wafers in imec's CMOS pilot line using 193 nm deep UV lithography. Low-pressure chemical vapor deposition (LPCVD) is used for the SiN waveguides. The III-V devices are processed on their native InP substrate before micro-transfer-printing, as in [7]. After micro-transfer-printing of the III-V devices on the SiN PICs, we proceed with a final metallization step to fabricate the contact pads. Micro-transfer-printing can be done in a massively parallel manner on a wafer-scale with submicron alignment accuracy, thereby providing a route to mass production.

3. Characterization and conclusion

For the characterization the chip is placed on a temperature-controlled stage set to 16°C. The light is collected from the left grating coupler with a standard single-mode cleaved fiber. The results reported here are for a total gain current of 295 mA and a saturable absorber voltage of -2.5 V. Fig. 2(a) shows the RF spectrum observed on an electrical spectrum analyzer (ESA) when the light emitted by the laser is sent to a high-speed photodetector which is connected to the ESA. The clear peaks at 3 GHz and the higher harmonics are indicative of mode-locking. Fig. 2(b) shows the single-sideband phase noise measured at ~3 GHz. The red line corresponds to a Lorentzian line shape with a 400 Hz linewidth. Fig. 2(c) shows the optical spectrum. The individual comb lines cannot be resolved due to the 30 pm resolution of the optical spectrum analyzer. The optical linewidth is measured by heterodyning a 60 kHz laser with a line in the center of the spectrum. The heterodyne beat note linewidth is determined by taking the fast Fourier transform of a 1 µs time trace. A Lorentzian fit gives a linewidth of ~1 MHz (Fig. 2(d)). The measured fiber-coupled average optical power is -2.5 dBm, corresponding to 7.5 dBm on-chip (outside the laser cavity) and a pulse energy of ~2 pJ. Fig. 2(e) shows a pulse train recorded with a real-time oscilloscope. Optical autocorrelation measurements of pulses amplified by an L-band EDFA give a pulse width of 8 ps, assuming a sech^2 pulse (Fig. 2(f)).

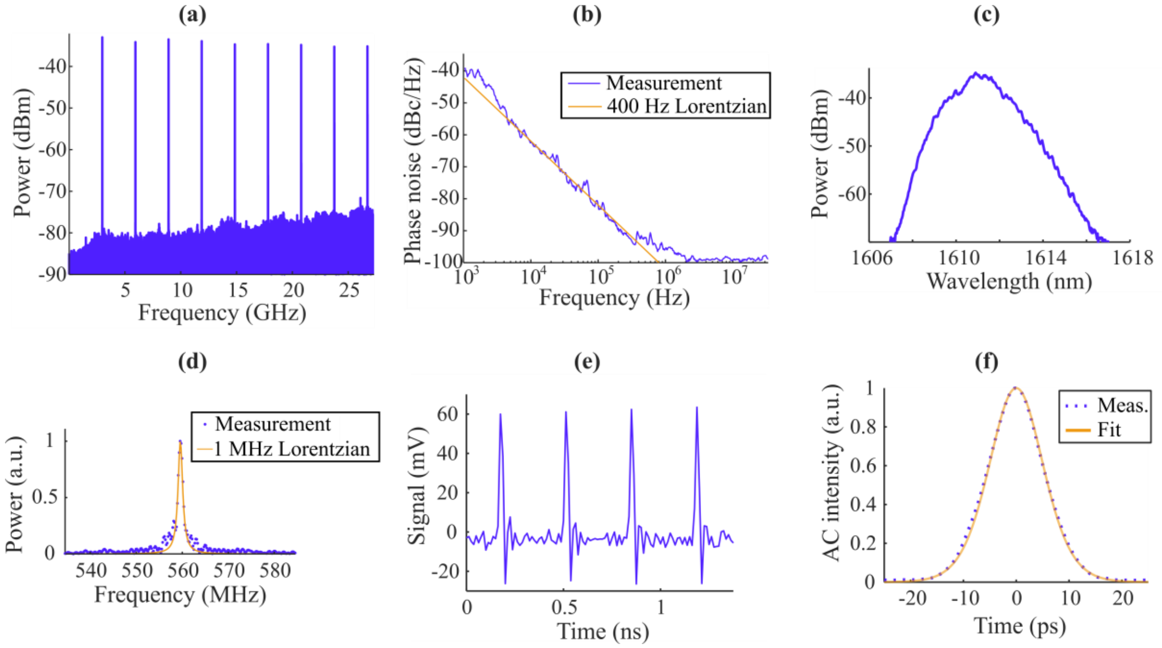

Fig. 2. (a) RF spectrum. (b) Single-sideband phase noise at the repetition frequency. (c) Optical spectrum (resolution of 30 pm). (d) Optical linewidth measurement. (e) Pulse train measured with real-time oscilloscope. (f) Optical autocorrelation measurement.

Our results open up new perspectives for the realization of high-pulse-energy, narrow-linewidth on-chip mode-locked lasers, which can be used for LIDAR, remote sensing, or even on-chip spectral broadening [8].

4. References

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