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Integrated CMOS-compatible Q-Switched-Mode-Locked Laser at 1.9μm with On-Chip Artificial Saturable Absorber

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Abstract: We present a CMOS-compatible, Q-switched mode-locked integrated laser at 1.9μm with a compact footprint of 23.6×0.6×0.78mm, a Q-switched rate of 720kHz, a mode-locked rate of 1.2GHz, and pulse durations of 215fs.

OCIS codes: (140.4050) Mode-locked lasers; (140.3540) Q-switched lasers; (130.3120) Integrated optics devices.

1. Introduction

The field of integrated photonics has already revolutionized optical communications and is making rapid advances in signal processing, light detection and ranging, optical sensing, bio-medical diagnostics and imaging, and military-related applications. Large and complex radio-frequency and optical systems could be potentially replaced with compact, power-efficient, alignment-free, cost-effectively mass-produced integrated photonics components. An on-chip high repetition-rate mode-locked laser is a key enabler of many integrated photonics applications, such as all-optical sampling, on-chip frequency combs, low phase noise microwave oscillators, photonic analog-to-digital converters and others. In this work we present a compact CMOS-compatible Q-switched mode-locked laser (MLL), based on a silicon nitride on silicon platform and using Al_2O_3:Tm^{3+} as a gain material, with no off-chip elements other than the pump laser. This MLL, operating at 1.9μm, will seed a silicon-based supercontinuum device [1], which together with an on-chip silicon based frequency doubler [2] would allow for a fully on-chip 1f-2f frequency comb stabilization.

2. Laser Architecture

The mode-locked laser architecture is shown in Figure 1[a]. The laser consists of three gain section segments, which are connected using low loss compact photonic Euler bends. The gain material is a back-end-deposited Al_2O_3:Tm^{3+} 1.1μm-thick film. One large photonic trench is etched over the entire gain region of the laser, which allows the gain material to interact with the optical mode. The laser is pumped with a 1614nm externally coupled laser via an on-chip inverted taper and a pump/signal combiner. The mode-locking element is a Kerr-nonlinearity-based reflecting nonlinear interferometer, which provides higher reflection for higher signal powers [3].

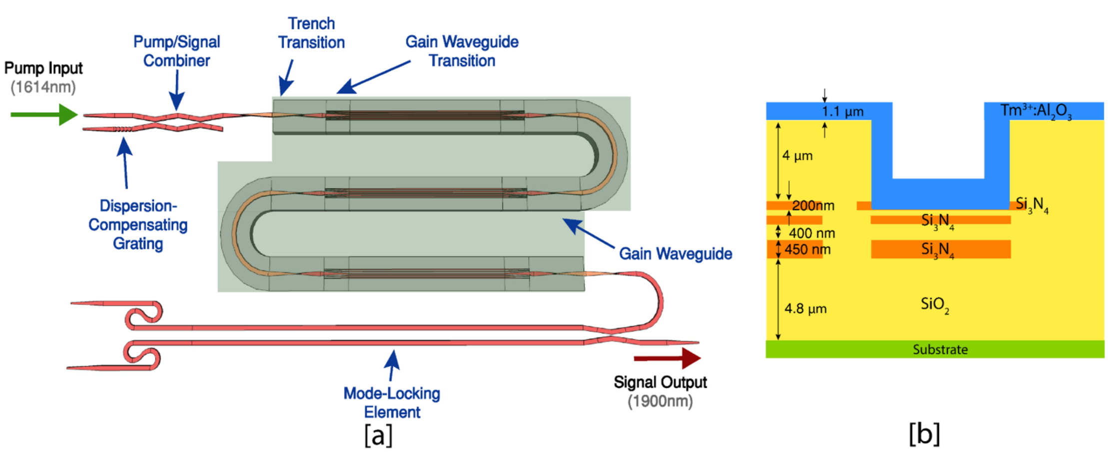

Fig. 1. [a] Mode-locked laser architecture; [b] Photonic layer stack.

An integrated wide-band (>100nm) grating serves both as a reflector and a dispersion-compensating element at the other end of the MLL cavity. The net dispersion of the laser is designed to be slightly anomalous in order to minimize the pulse duration. The MLLs were fabricated on 300mm wafers using the 65nm CMOS-compatible process at SUNY Poly Colleges of Nanoscale Science and Engineering, with the gain material being deposited at MIT's Microsystems Technology Laboratory. The photonic layer stack is shown in Figure 1[b]. The area of each MLL is 23.6mm×0.6mm.

3. Results

Figure 2[a] shows the optical spectrum of the MLL corresponding to 350mW of on-chip pump power and 4mW signal power. The broad spectrum indicates short pulse formation. The 3dB bandwidth of the spectrum is 17nm, corresponding to a 215 fs transform-limited pulses. The corresponding RF spectrum is shown in Figure 2[b] with a clear 1.2GHz mode spacing, corresponding to ∼13cm one-way MLL cavity length. Figure 2[c] shows time-domain data with Q-switched pulses at 720kHz. Figure 2[d] shows a close-up of one Q-switched pulse, where under the Q-switching envelope the individual cw-mode-locked pulses are visible with 0.8ns time spacing, corresponding to 1.2GHz fundamental MLL repetition rate.

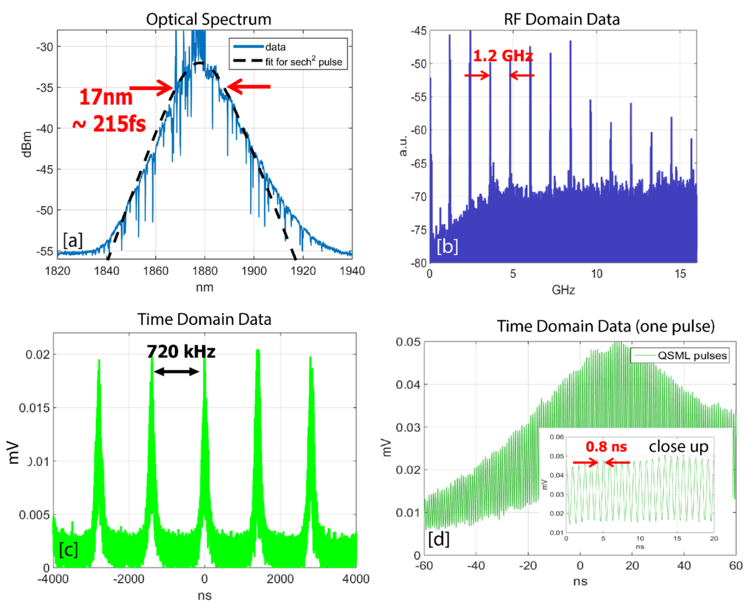

Fig. 2. [a] Optical spectrum of the MLL; [b] RF spectrum of the MLL; [c] Time-domain data showing Q-switching; [d] Close-up of time-domain data showing Q-switched mode-locking.

4. Conclusion

We have demonstrated an externally pumped CMOS-compatible fully integrated on-chip mode-locked laser at 1.9μm with a small footprint of 23.6mm×0.6mm×0.78mm. The laser has a broad spectrum corresponding to a transform-limited pulse duration of 215 fs, with a 1.2GHz fundamental repetition rate and a 720kHz Q-switching rate, which is a considerable improvement over previously demonstrated results [4]. Future lasers with more efficient artificial saturable absorbers and optimized cavity parameters have been designed in order to achieve a cw on-chip fundamentally mode-locked laser.

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