A 20 GHz colliding pulse mode-locked heterogeneous InP-silicon laser

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Abstract: We demonstrate a colliding pulse mode-locked laser based on heterogeneous InP-silicon platform, working in the passive mode locking regime with a 20 GHz repetition rate. The laser outputs nearly transform limited pulses with record narrow pulse width of 1.37 ps on the silicon platform.

OCIS codes: (140.4050) Mode-locked lasers; (140.5960) Semiconductor lasers; (250.5300) Photonic integrated circuits.

1. Introduction

Mode-locked lasers (MLLs) are important for applications in a variety of fields, including high speed communication, optical sampling, arbitrary waveform generation and bio-imaging [1]. Compared to their bulk counterparts, monolithically integrated semiconductor MLLs take advantage of the footprint, cost, energy efficiency, and possibility for massive production. Silicon photonics employs a large number of compact and complex components, enabled by low loss silicon waveguides with a large confinement factor, leveraging the low-cost manufacturing infrastructure of the mature CMOS electronics industry [2]. It is desirable to integrate MLLs into silicon photonic integrated circuits and have data generated and processed on chip.

Several mode-locked laser schemes employing different heterogeneous integration methods have been demonstrated previously [3, 4]. In this paper, we report a 20 GHz colliding pulse mode-locked (CPM) heterogeneous silicon laser employing direct wafer bonding [5]. The laser outputs nearly transform limited pulses with record narrow pulse width of 1.37 ps on the heterogeneous silicon platform.

2. Laser design and performance

A schematic diagram of the designed CPM laser is shown in Fig. 1. The laser is fabricated using direct wafer bonding of III-V quantum well gain material to a SOI substrate. This is used to create a heterogeneous waveguide in which the optical mode overlaps partially with electrically pumped AlGaInAs quantum wells and partially with a Si rib waveguide. The total cavity length is around 4 mm, which is comprised of a 2 mm heterogeneous waveguide section, forming the gain section of the mode-locked laser, and the two passive waveguide sections, leading to a fundamental mode locking frequency of ~ 10 GHz. Lateral tapers are used to transform the oscillating optical mode back and forth from gain section into passive silicon ridge waveguide section and vice versa. The saturable absorber (SA), 60-μm in length, is formed by etching trenches in the top contact, and is placed in the center of the cavity in a colliding pulse configuration to allow harmonic mode locking operation at 20 GHz. The laser mirrors are formed by Sagnac loop mirrors, which use an adiabatic spline curve to reduce the footprint of the mirrors, facilitating integration with other on-chip components as well as avoiding cavity length uncertainty caused by cleaved facets [6]. More information on the fabrication and design of the amplifier, laser epitaxial material, and heterogeneous transition can be found in [5].

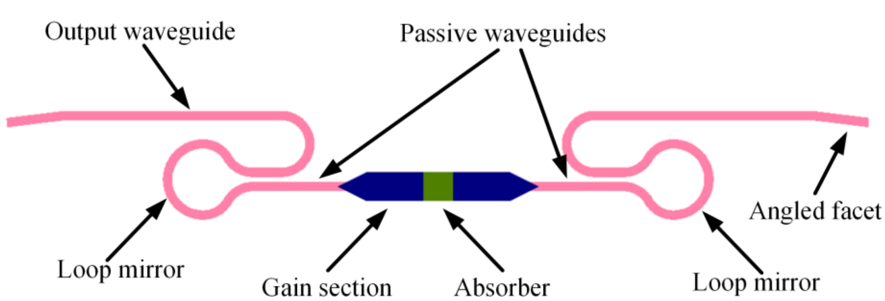

Fig. 1 A schematic diagram of the fabricated heterogeneous silicon colliding pulse mode locked laser.

The CPM laser was tested on a copper heat sink with a fixed stage temperature of 20 ℃ using a thermoelectric cooler. The optical output was coupled to a lensed single mode fiber. After passing through an isolator and an EDFA, the signal was split and led to an optical spectrum analyzer for spectrum analyzing, a second-harmonic generation (SHG) autocorrelator for time domain analysis, and an electrical spectrum analyzer with a 50-GHz photodiode for microwave spectrum measurement, respectively. Fig. 2 shows the fiber coupled light-current curve of the tested chip with different SA reverse bias voltage (with a fiber coupling loss of ~ 12 dB). The lasing threshold current increases from 35 mA to 47 mA as the reverse bias voltage increases due to the increase of absorption loss in the SA section. By optimizing the gain section current and SA section reverse voltage (I_{gain} = 84.44 mA, V_{SA} = -4.19 V), we demonstrate the shortest pulse width reported on a silicon platform. Fig. 3 shows the corresponding optical spectrum, which has a full width half maximum (FWHM) of 2.79 nm. The electrical spectrum shown in Fig. 4 over a 50 GHz span exhibits a sharp RF peak at the second harmonic mode locking frequency of 20 GHz, with the signal to noise floor ratio larger than 50 dB, indicating excellent mode locking quality. Fig. 5 presents the autocorrelation trace of the narrowest pulse. The deconvolved pulse width is 1.37 ps if a Gaussian pulse shape is assumed, which results in a nearly transform-limited time bandwidth product value of 0.46 when paired with the FWHM of the optical spectrum. The excellent performance makes this CPM laser a promising candidate for on-chip integration.

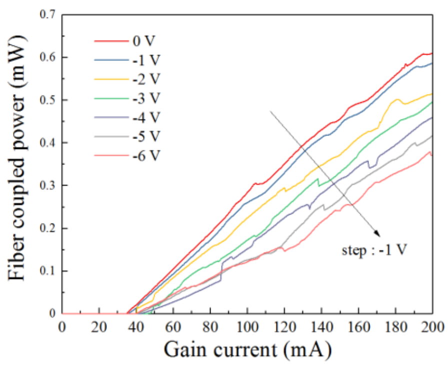

Fig. 2 Fiber coupled L-I curve of the tested CPM laser with different SA reverse bias voltage.

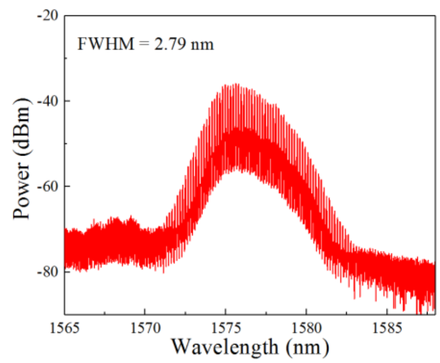

Fig. 3 Optical spectrum of the narrowest pulse point (I_{gain} = 84.44 mA, V_{SA} = - 4.19 V).

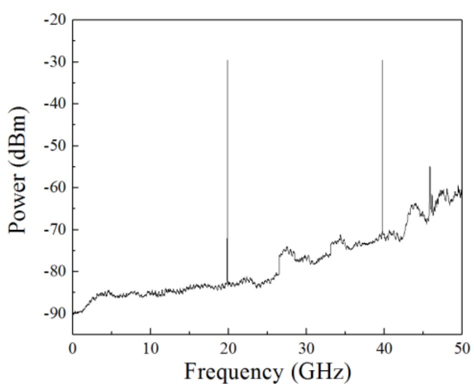

Fig. 4 RF spectrum in a 50 GHz span view. (I_{gain} = 84.44 mA, V_{SA} = - 4.19 V).

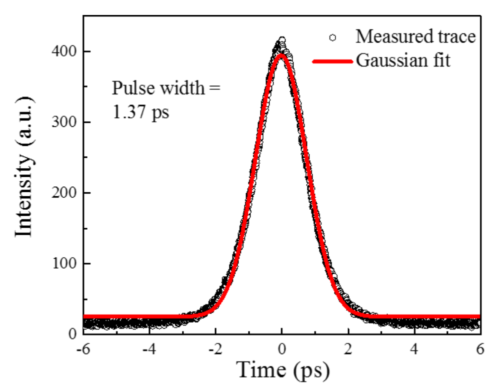

Fig. 5 Autocorrelation trace of the narrowest pulse point (I_{gain} = 84.44 mA, V_{SA} = - 4.19 V).

3. Acknowledgment

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