

Optical Clock Recovery Operation of a Colliding-Pulse Mode-Locked Laser Diode with Integrated Active-Passive Waveguides

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Abstract: We investigate the optical clock recovery operation of a colliding-pulse mode-locked laser with integrated active-passive waveguides. Nearly transformed-limited 10 GHz recovered clock signal was demonstrated with low timing jitter and error free performance.

Optical clock recovery [1, 2] is an important function for realizing all-optical communication systems, allowing the extraction and regeneration of a clear optical clock train from a degraded data-stream and subsequent 3R regeneration. Semiconductor mode locked lasers offers a compact solution for this application, and has been previously demonstrated in high bit rate applications[2]. In this paper, we report the investigation of optical clock recovery at 10 GHz using a colliding-pulsed mode-locked (CPM) laser with integrated active-passive waveguides for the first time.

Fig. 1 shows the fabricated buried heterostructure (BH) 10 GHz CPM laser with a 2000 μm long active section, monolithically integrated on either side with passive waveguides to form the 8200 μm long laser cavity [3]. The 45 μm saturable absorber (SA) situated at the center of the laser cavity allows two identical pulses to circulate symmetrically within the cavity and collide at the SA, generating two pulses per round-trip time. In this CPM configuration the SA experiences deeper saturation compared to conventional mode locked (ML) lasers, resulting in more stable mode locking and more efficient pulse shaping [4]. The active passive integration approach with shorter gain sections minimizes timing jitter, and the pulse chirping effects associated with short pulse passing through the gain material [3]. At the same time this process is also compatible with monolithic integration with other optical components[5].

Under 143 mA DC current injection to the gain sections and -5.8V bias to the SA, the CPM laser passively mode locks with RF frequency of 10.3 GHz, emitting nearly transformed limited 4.7 ps wide pulses with a time-bandwidth product of 0.47 at 1555.7 nm. In this optical clock recovery experiment, a pseudo-random-bit-sequence (PRBS) return to zero (RZ) data stream was generated by modulating the output pulse train from a commercial (Pritel) fiber ML laser. A RF synthesizer clock source drives both the fiber laser and the PRBS pattern generator operating at 10.3 GHz. The fiber laser emitted transform limited 2.7 ps wide pulses at 1558 nm. Fig. 2 shows the optical spectra of the fiber laser and the passively mode locked CPM laser. The fiber laser output signal, after PRBS data modulation, then coupled into the CPM laser through an optical circulator and a lensed fiber. The optical circulator also extracted the CPM laser output through the same lensed fiber, which then routed the output signal to different instruments for time and frequency domain characterizations.

Fig. 3 (a) shows the digital sampling scope trace (triggered with the RF synthesizer) of a PRBS 2^7-1 data stream injected into the CPM laser. Fig 3(b) shows the corresponding CPM laser output at -10 dBm coupled optical power, demonstrating that a stable 10.3 GHz optical clock has been extracted by the CPM laser, and synchronized to the RF synthesizer. The optical spectrum and pulse width of the CPM recovered clock signal remained unchanged from the passive mode-locking condition. The timing jitter of the clock signal can be estimated by integrating the RF spectral noise power at the 10.3 GHz carrier frequency. Fig. 4 compares the single side band (SSB) phase noise spectra at 10.3 GHz for the recovered clock and the Pritel fiber laser output. Integrating from 20k to 80 MHz, the timing jitter of the CPM extracted clock was 0.57 ps, while the corresponding timing jitter for the Fiber output was 0.17 ps.

We further evaluate the clock recovery signal quality through bit-error-rate (BER) measurements. First the BER of the PRBS data signal was measured, by directly triggering the BER-Tester (BERT) module with the RF synthesizer clock signal. For comparison, BER measurements were then repeated on the same data signal, but this time with the

BERT triggered using the CPM recovered optical clock, which was converted into electrical signal through a 10 Gb/s optical receiver. Fig. 5 shows the resulting BER curves. No power penalty was observed triggering the BER-Tester using the CPM recovered clock signal compared to the electrical synthesizer triggering case. Also in both cases we obtained error free operation detecting up to 10^{12} bits.

In conclusion, we successfully demonstrated optical clock recovery operation at 10 GHz in a CPM laser with integrated active-passive waveguides. The CPM laser generated nearly transformed limited clock signal, which functioned error free with no power penalty compared to the original synthesizer clock. This shows that the CPM laser can operate as a compact 10 GHz clock recovery element, potentially integrated as part of a monolithic multi-functional photonic chip in future all-optical communication systems.

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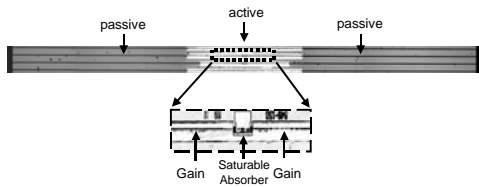


Fig. 1 (a) Top view of the 10 GHz CPM laser with integrated active-passive sections. (inset) showing higher magnification view of the SA region.

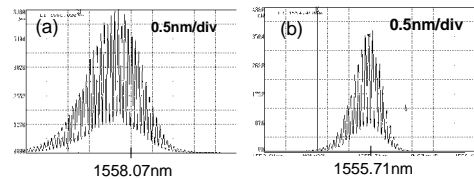


Fig. 2 Optical spectra of (a) fiber mode locked laser. (b) 10 GHz CPM laser under passive mode locking.

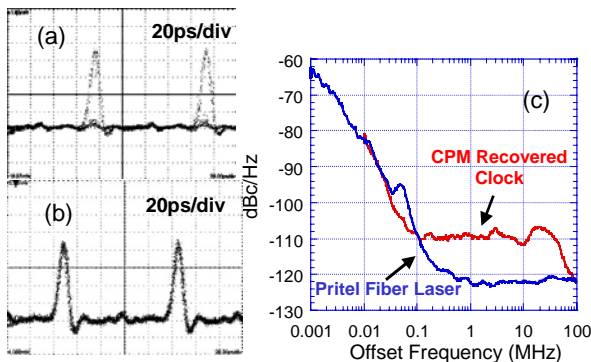


Fig. 3. 50 GHz sampling scope traces of (a) PRBS (2^7-1) data signal (b) CPM laser recovered clock. (c) SSB phase noise spectra of the fiber laser output and the recovered clock from the CPM laser.

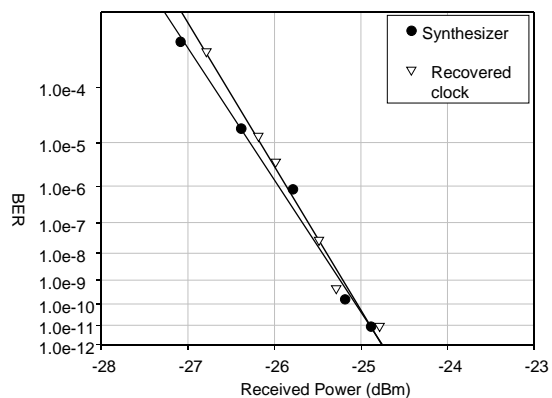


Fig. 4 BER curves of the PRBS data stream with the BER-Tester triggered respectively with the RF synthesizer and the recovered clock from the CPM laser.