10 GHz Colliding Pulse Mode Locked Laser with Electrical and Optical Injection Synchronization

C. Ji, N. Chubun, R. G. Broeke, J. Cao, Y. Du, T. Tekin, S. J. B. Yoo
Department of Electrical and Computer Engineering, University of California, Davis, CA 95616, USA Email:cji@ece.ucdavis.edu
K.Y. Liou, J. R. Lothian, S. Vatanapradit, S.N.G. Chu, B. Patel,
W.S. Hobson, D.V. Tishinin, W. T. Tsang
Multiplex, Inc., 5000 Hadley Road, South Plainfield, New Jersey 07080 USA

Abstract: We report electrical and optical injection locking of an InP colliding pulse mode locked laser emitting synchronized, nearly transform-limited output pulses at 10.3 GHz, fabricated by active-passive integration and a single step regrowth process.

Semiconductor mode locked (ML) lasers operating at ~10 GHz have important applications for high-speed optical communications [1, 2]. However, long (> 4 mm) all-active mode locked lasers for achieving the 10 Gb/s and lower repetition-rate tend to suffer from strong pulse shaping effects with poor chirp and jitter performance[1]. These effects can be reduced by adopting shorter gain sections and integrated active-passive waveguides. Here we report, for the first time to our knowledge, the nearly transform-limited performance of a 8200 μm Buried Heterostructure (BH) colliding pulsed mode locked (CPM) laser with an integrated active-passive waveguide fabricated through a novel dry etching and single step regrowth process. This process is also compatible with future monolithic integration of multiple optical elements[3]. Two approaches for synchronization of the CPM laser output at 10.3 GHz, the electrical hybrid mode locking (HML)[4] and optical synchronous mode locking (OSML) [5] were also demonstrated.

The CPM laser process utilized a metal-organic vapor phase epitaxy (MOVPE) grown epi-structure on an InP substrate, consisting of a 2 μm thick *n-type* InP lower cladding layer, an undoped 0.5 μm thick InGaAsP waveguiding layer (1.15Q), and a six quantum well active region. The process began by depositing a 250 nm Plasma Enhanced Chemical Vapor Deposition (PECVD) SiO_2 layer patterned to mask the 2000 μm x 20 μm active section, while the MQWs were selectively removed in the passive sections by wet etching. After the SiO_2 mask removal, a thin (100 nm) undoped InP layer, a 2 μm thick p-type InP cladding layer, and a 100 nm thick highly doped p-type InGaAs contact layer were MOVPE regrown across the entire wafer. The 0.5 μm continuous waveguiding layer below the active region allows the waveguide mode to propagate through the active-passive interface with minimal coupling loss and back-reflection [3]. Next, the laser waveguide formation process included masking the ridge with patterned 250 nm PECVD SiO_2 layer, deep etching the ridge past the 1.15Q waveguiding layer with a methane-hydrogen based reactive ion etching (RIE) process without requiring precise etch depth control, and covering the waveguide sidewalls with a MOVPE regrown 2 μm thick Fe-doped InP layer. This waveguide process creates a BH structure in only a single regrowth step, while providing sidewall passivation and planarization. Subsequent processes included standard sample lapping, *p* and *n*-metalization and annealing. The *p*-InGaAs layer was also removed by wet etching across the 15 μm gap between the gain and saturable absorber (SA) sections for electrical isolation. Fig.1(a) shows the cross-sectional view of the BH ridge. Fig.1(b) shows the top view of the central portion of the CPM laser, with the active region consisting of two gain sections sandwiching the Saturable Absorber (SA). Symmetrical passive waveguides extends the laser cavity to the required length of 8200 μm.

For synchronization by HML, RF modulation was applied through a Ground-Signal-Ground microwave coplanar probe to the SA. The laser output was collected with a lensed fiber and routed to different instruments for characterization. For a 8200 μm long CPM laser, with 2000 μm long active region and a 45 μm long SA, synchronized nearly transform limited output was achieved with the gain sections forward biased at 152 mA, the SA reverse biased at –6.3V, and 19 dBm of RF modulation at 10.295 GHz. Fig. 2 shows the optical spectrum with 1.1 nm spectral width, and the autocorrelation trace measured through second harmonic generation (SHG). The autocorrelation trace was fitted to a sech^2 waveform, with an extracted 2.7 ps wide pulse and nearly transform limited time-bandwidth product of 0.368. The pulse width was a very sensitive function of the RF and DC biasing conditions and required careful optimization. Synchronization to the electrical clock was demonstrated by the stable CPM laser output trace on the 50 GHz sampling scope, triggered with the RF clock source, and strong linewidth narrowing of the CPM laser spectral peaks in the RF power spectrum.

0-7803-9217-5/05/$20.00©2005 IEEE

In another identically-fabricated device, OSML through optical injection was achieved through injection of 3 ps transform limited pulses from a commercial fiber ML laser (Pritel) at the CPM frequency (10.29 GHz) and 1557 nm. The injection signal was coupled into the CPM laser using a lensed fiber setup including an optical circulator for isolation and signal extraction. Output synchronization effect was observed for coupled optical power as low as –20 dBm. Fig. 3(a) shows the sampling scope trace triggered with the Pritel laser clock signal under passive ML, exhibiting no phase correlation, and Fig 3(b) with –10 dBm optical injection. The clean and stable trace in Fig. 3(b) indicated that synchronization to the Pritel injection signal was achieved. Fig. 4 shows the corresponding overlay RF power spectra centered at 10.29 GHz under the passive mode locking and –10 dBm optical injection conditions. The sharp spectral line and the strong suppression of the sideband noise level under optical injection, in contrast to the passive mode locking condition, confirmed the timing jitter reduction associated with OSML synchronization. The timing jitter can be evaluated by integrating the noise power in the single-sideband (SSB) phase noise spectra centered at the CPM frequency, in the range of 20k-80MHz [1]. The resulting rms timing jitter was 0.28 ps for the HML case and 0.6 ps for the OSML case at –10 dBm, while the Pritel laser signal had a rms jitter of 0.17 ps.

In conclusion, we have demonstrated nearly transform limited CPM operation at 10.3 GHz, with active-passive integrated waveguide for chirp and jitter reduction. The BH waveguide was formed in a simple dry etching and single step MOVPE regrowth process. The laser output was synchronized to an external clock source under both the HML and OSML conditions.

References:

[1] K. Yvind, D. Larsson, L. J. Christiansen, J. Mork, J. M. Hvam, and J. Hanberg, "High-performance 10 GHz all-active monolithic modelocked semiconductor lasers," *Electronics Letters*, vol. 40, pp. 735-7, 2004.

[2] H. Fan, C. Wu, M. El-Aasser, N. K. Dutta, U. Koren, and A. B. Piccirilli, "Colliding pulse mode-locked laser," *IEEE Photonics Technology Letters*, vol. 12, pp. 972-3, 2000.

[3] C. Ji, R. G. Broeke, Y. Du, C. Jing, N. Chubun, P. Bjeletich, F. Olsson, S. Lourdudoss, R. Welty, C. Reinhardt, P. L. Stephan, and S. J. B. Yoo, "Monolithically integrated InP-based photonic chip development for O-CDMA systems," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 11, pp. 66-77, 2005.

[4] T. Hoshida, H. F. Liu, M. Tsuchiya, Y. Ogawa, and T. Kamiya, "Subharmonic hybrid mode-locking of a monolithic semiconductor laser," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 2, pp. 514-22, 1996.

[5] S. Arahira and Y. Ogawa, "480-GHz subharmonic synchronous mode locking in a short-cavity colliding-pulse mode-locked laser diode," *IEEE Photonics Technology Letters*, vol. 14, pp. 537-9, 2002.

(This work was supported in part by DARPA and SPAWAR under agreement number N66001-02-1-8937.)

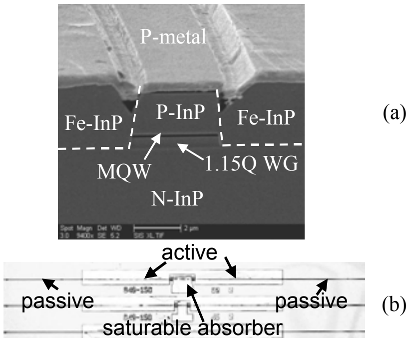
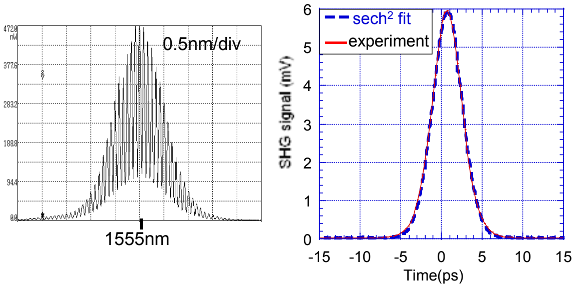


Fig. 1 (a) SEM cross-sectional view of the BH waveguide. (b) Top view showing the central gain and SA sections of the CPM laser.



(a) (b)

Fig. 2(a) Optical spectrum and (b) autocorrelation trace under electrical HML fitted to a sech^2 waveform.

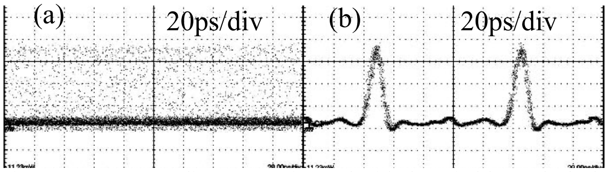


Fig. 3. 50 GHz sampling scope triggered with the Pritel laser clock showing optical CPM laser output (a) under passive ML (b) with Pritel optical injection.

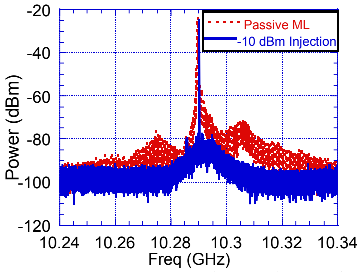


Fig. 4 RF power spectra under passive mode-locking and OSML conditions with –10 dBm injected optical power.