Synchronization of InP Colliding Pulse Mode Locked Laser by Electrical Subharmonic Modulation

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Abstract: This paper reports on self-aligned fabrication and successful operation of InP colliding pulse mode locked lasers using bisbenzocyclobutene (BCB) films for planarization with reduced parasitics. Measurements showed nearly transformed-limited output at 28.2 GHz repetition under electrical subharmonic hybrid mode locking.

Semiconductor mode locked lasers are important ultra-compact sources for short optical pulse generation, leading to applications in optical communications including optical time-division-multiplexed (OTDM) transmission systems, ultrafast data processing [1], and integrated photonic microsystems. Hybrid mode locking schemes involving either electrical modulation [1-3] or optical injection [4] from external master mode-locked-lasers are attractive for supporting synchronized low-jitter applications. In particular, subharmonic hybrid mode locking techniques allow reduced bandwidth requirements on the external drive sources [3-4].

We fabricated a colliding pulsed mode locked laser (CPM) through a very simple self-aligned wet etching process applied to an InP-InGaAsP wafer. The CPM laser includes a saturable absorber (SA) placed in the middle of the laser cavity. Two counter-propagating laser pulses collide directly at the saturable absorber, which is driven deeper into absorption saturation for more stable and effective pulse-shaping for generating ultra-short pulses without self-pulsing commonly seen in regular mode locked lasers [1-2,4]. The MOCVD grown InP-InGaAsP wafer consisted of a 2 um thick lower InP n-cladding layer, a 0.5 um thick waveguiding core layer (1.15Q), a 6QW active region, a 2 um thick upper InP p-cladding layer, and a 0.1 um thick $In_{0.53}Ga_{0.47}As$ p-type contact layer. PECVD deposition of a 0.25 um thick SiO_2 followed by its patterning of stripe in the reverse mesa direction allowed fabrication of a ridge waveguide by a wet etching process that stopped selectively at the top of the 6QW active region. Subsequent spinning of a 3 um thick bisbenzocyclobutene (BCB) polymer layer, baking, and its planar etching process allowed exposure of the top of the waveguide ridge planarized by the remaining BCB film. A *p*-type metallization, a liftoff process, a backside *n*-type metallization, and a rapid thermal annealing completed the fabrication of the CPM laser. Fig. 1. shows a cross-section SEM image of the fabricated device. No critical lithography alignment step was required to contact the narrow waveguide. The 2 um thick BCB film below the SA metal pads also reduced the pad capacitance to < 0.1 pF, allowing efficient microwave modulations without parasitic roll-offs.

We characterized electrical subharmonic hybrid mode locking (SHML) of a 3000 um long CPM laser consisting of two 1410 um long gain sections separated by a 150 um long SA section and a 15 um gap between the gain and SA sections. The ridge was 3 um wide. With the SA forward biased, the CPM laser achieved CW lasing at threshold current 100 mA, and the SHML experiment was conducted with SA reverse biased at -3V and the gain section biased at 177 mA total current injected. A 14.1GHz microwave modulation signal at 23 dBm was applied to the SA section through a bias-T and a Ground-Signal-Ground microwave coplanar probe. Fig. 2 shows the microwave power spectrum the CPM laser optical output collected by a lensed fiber and O/E converted by a 40 GHz PIN detector connected to the microwave power spectrum analyzer. A single sharp spectral peak at 28.2 GHz, the natural CPM frequency of the laser can be observed. The linewidth of the spectral peak was 100 kHz, limited by the resolution bandwidth of the spectrum analyzer. This narrow linewidth supported the fact that the pulsed output had minimal jitter in good synchronization with the external microwave source. The amplitude modulation [3] due to the drive signal at 14.1GHz was more than -22dB down compared to the CPM mode locking signal. Fig. 4 shows the autocorrelation trace of the pulsed output generated through the second harmonic generation (SHG) in a 0.5 mm thick LiNO3 crystal. The autocorrelation scan confirmed in the time domain that CPM operation was indeed taking place at 28.2GHz with stable and narrow pulse trains. Approximating a Gaussian pulse shape, the curve fit parameters estimate a pulse width of 2.8 ps from the autocorrelation scan, which is slightly longer than the pulse transit time through the 150 um long SA section (2.1 ps). Fig. 4 shows the corresponding optical spectrum. The optical spectral FWHM was 1.2 nm centered at 1.6 um. The resulting time bandwidth product is 0.394, indicating that the CPM output pulses were nearly transform limited. Reference [1] observed reductions in the pulse widths as the SA width decreased. Further experiments on CPM lasers with shorter SAs are in progress.

In conclusion, we observed synchronized CPM output at 28.2 GHz under second order electrical subharmonic hybrid mode locking at 14.1GHz with nearly transform limited output pulses for the first time to our best knowledge. The simple fabrication technique combined with the lower frequency microwave requirements makes the InP CPM laser a very attractive candidate for a compact, stable, and synchronized ultrashort pulse source in photonic systems.

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

References:

[1] Y. K. Chen, M. C. Wu, "Monolithic colliding pulse mode-locked quantum well laser," IEEE J. Quantum Electron., vol. 28, pp. 2176-2185, Oct. 1992.

[2] H. K. Lee, V. Loyo-Maldonado, B. C. Qiu, K. L. Lee, C. Chu, S. Pinches, I. G. Thayne, A. C. Bryce, J. H. Marsh, "Efficient direct locking of colliding pulse mode-locked lasers on semi-insulating substrate at 1.5um," IEEE Photon. Technol. Lett., vol 14., pp1049-1051, Aug. 2002.

[3] T. Hoshida, H. F. Liu, M. Tsuchiya, Y. Ogawa, T. Kamiya, "Subharmonic hybrid mode-locking of a monolithic semiconductor laser," IEEE J. Select. Topics Quantum Electron., vol 2., pp514-522, Sept. 1996.

[4] S. Arahira, Y. Ogawa, "480-GHz subharmonic synchronous mode locking in a short-cavity colliding-pulse mode-locked laser diode," IEEE Photon. Technol. Lett., vol 14., pp537-539, April, 2002.

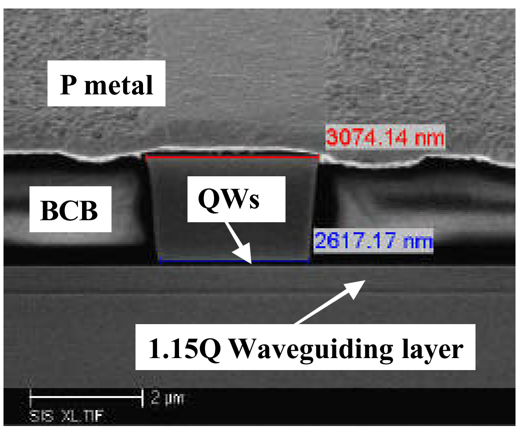

Fig. 1. Cross-sectional view of the fabricated ridge waveguide CPM laser with BCB planarization.

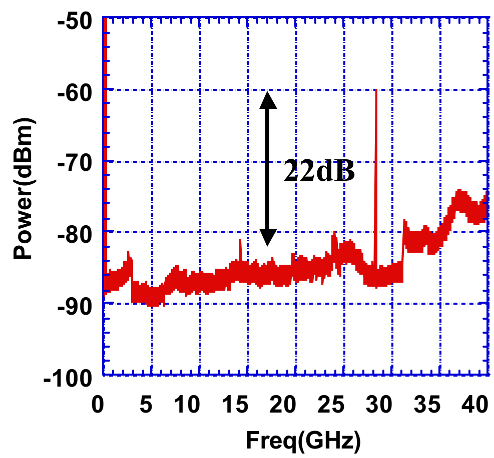

Fig. 2. Microwave power spectrum of a 3000 um CPM laser under subharmonic hybrid mode locking. AM modulation suppression is >22dB.

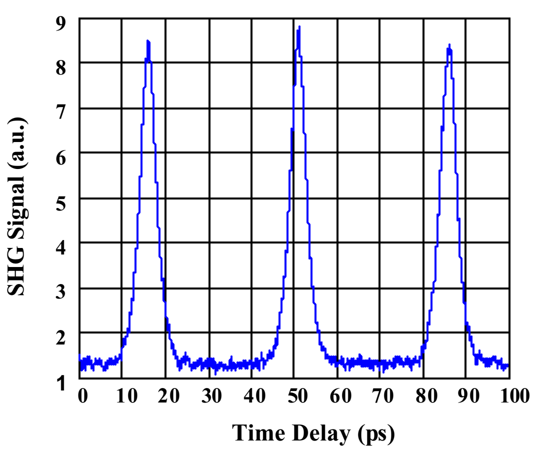

Fig. 3. Autocorrelation trace showing 28.2 GHz CPM operation of a 3000 um CPM laser under second order SHML.

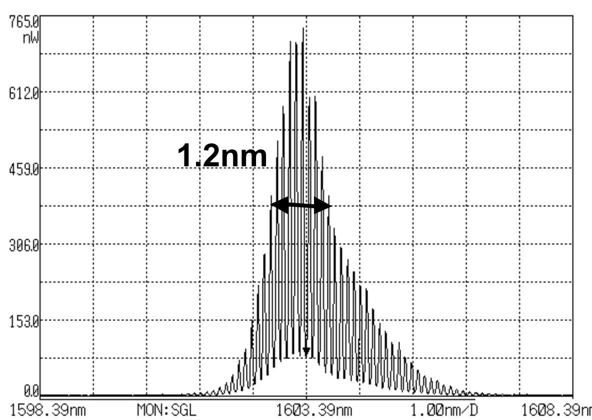

Fig. 4. Optical spectrum of 3000 um CPM laser under second order SHML.