Low Phase Noise Hybrid Silicon Mode Locked Laser Using On-Chip Coherent Photon Seeding

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Abstract: We demonstrate 6dB improvement in phase noise of a mode-locked semiconductor laser using coherent photon seeding, achieving a record linewidth of 29kHz. The complete photonic-circuit including the feedback cavity is integrated on a single chip.
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1. Introduction

Mode locked laser diodes (MLLD) are compact, efficient and low cost sources to generating short picosecond optical pulse trains at very high repetition rates, in the tens of GHz. The rms timing jitter of the generated optical pulses/ microwave frequency can be <1ps [1], surpassing the state of the art jitter performance provided by CMOS/SiGe technology [2]. These pulses can therefore be used in a multitude of applications such as optical time division multiplexing (OTDM), all optical signal processing and microwave/millimeter wave transmission. However, the adoption of these sources is currently limited by the cost and complexity that surround the MLLD. All the MLLD demonstrations use cleaved facet mirrors, which are not ideally suited for on-chip photonic integration. The better performing MLLD are based on quantum dot (QD) materials which need molecular beam epitaxy and therefore increase the cost of individual lasers.

The low optical confinement factor in the QD material is often quoted as the primary responsibility of reduced timing jitter, because of reduced amplified spontaneous emission [3]. The hybrid silicon technology [4] inherently allows the manipulation of the confinement factor in the quantum well (QW) active material by means of changing the silicon waveguide width underneath. Additionally, the technology also allows for complete integration of silicon photonic/electronic circuitry along with optical gain/loss elements. In this text we show the integration of a 1.3µm QW based colliding pulse mode-locked laser that is stabilized using a ~4cm on-chip feedback cavity to generate record performance in microwave linewidth for QW MLLD.

2. Device design and results

Fig. 1 shows the schematic and a photographic image of the photonic circuit. The laser comprises a colliding pulse mode-locked laser (8.68GHz cavity) formed by two loop mirror reflectors on either side of a 1200µm long gain section and a centrally placed 40µm saturable absorber. One of the outputs to this laser is sent to a ~4cm (10× cavity length) long silicon delay line followed by a 560µm long semiconductor optical amplifier (SOA), a thermal tuner section and a 100% loop mirror reflector. The other output is angled and terminated at the polished facet for diagnostics. The loop mirror reflectivity of the diagnostic output port is 10% and the loop mirror connecting the mode-locking cavity to the external cavity is 55%. All measurements were performed at 20°C.

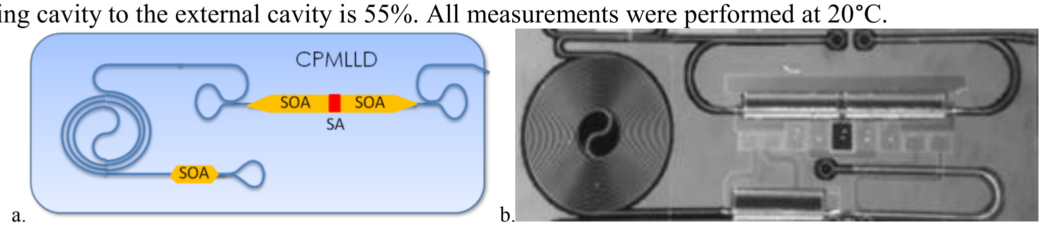

Fig. 1 (a) Schematic of the MLLD, showing the silicon waveguides (dark blue lines) along with integrated gain (orange) and loss (red) elements. SOA-semiconductor optical amplifier, SA-saturable absorber, CPMLLD-colliding pulse MLLD. (b) Image of the chip.

The laser output observed when biased in passive colliding pulse operation is shown in Fig. 2. The SOA current and the absorber voltage are 75mA and -0.4V respectively. The RF spectrum shows colliding pulse operation at 17.36GHz and more than 50dB suppression of the 8.68GHz tone. The photodiode bandwidth and responsivity are 50GHz and 0.23 respectively. The 3dB linewidth of the fundamental (17.36GHz) is 44kHz when the feedback cavity SOA (FC-SOA) is turned off by reverse biasing at -2.5V. The pulsewidth is 7.7ps and is transform limited.

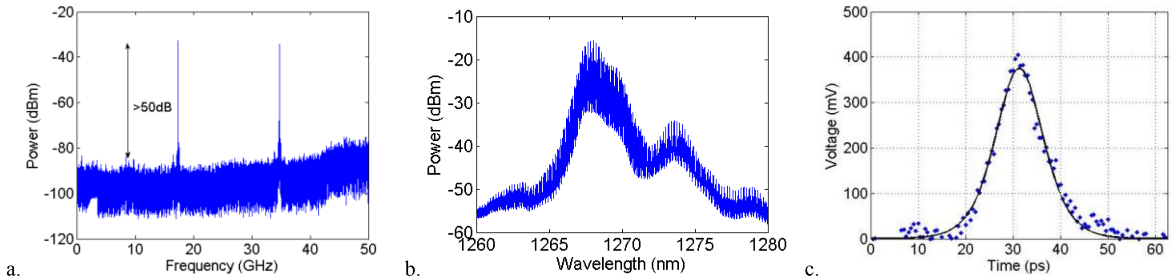

Fig. 2 (a) RF spectrum (resolution 3MHz) (b) optical spectrum (resolution 0.02nm) and (c) autocorrelation trace of the colliding pulse mode-locked laser without feedback. Fig. 2(c) also shows the $sech^2$ fit (black) to data.

By sweeping the current on the FC-SOA and the tuner current we observed an improvement in RF linewidth down to 29kHz. Table 1 is a record of the 3dB, 10dB and 20dB linewidths, with and without feedback. The SOA current was 2.5mA (weak feedback regime) and the tuner current was 7mA. The phase noise comparison with and without the external cavity is shown in Fig. 3. The improvement from the feedback cavity is limited by two effects. First, the optical bandwidth of the laser is limited due to a co-propagating higher order group of optical modes in the gain section, and the noise reduction is proportional to this bandwidth [5]. Second, the ASE from the external SOA is not filtered before it is fed back; therefore, increasing the FC-SOA current broadens the linewidth again. We do not observe any changes in pulsewidth due to feedback.

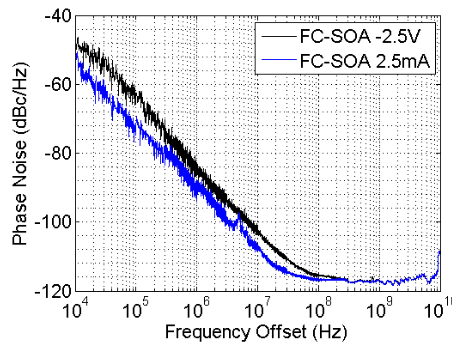

Fig. 3 Phase noise of the 17.364GHz signal with (blue) and without (black) on-chip feedback.

Table 1. Summary of linewidth improvement by using the on-chip feedback cavity.

Linewidth	3dB	10dB	20dB
Without feedback	44kHz	103kHz	292kHz
With feedback	29kHz	60kHz	159kHz

3. Conclusions

In conclusion, we demonstrated a fully integrated QW mode-locked laser under colliding pulse operation that was stabilized using an integrated feedback cavity. The feedback cavity narrows the RF linewidth of the fundamental to 29kHz, which is a record for an integrated mode locked laser. Further improvements through cavity design to increase optical bandwidth and filtering the feedback signal can show larger improvements in phase noise.

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4. References

[1] M. Thompson, A. Rae, R. Penty, I. White, A. Kovsh, S. Mikhrin, D. Livshits, and I. Krestnikov, "Absorber Length Optimisation for Sub-Picosecond Pulse Generation and Ultra-Low Jitter Performance in Passively Mode-Locked 1.3µm Quantum-Dot Laser Diodes," in Optical Fiber Communication Conference and Exposition and The National Fiber Optic Engineers Conference, Technical Digest (CD) (Optical Society of America, 2006), paper OThG3.

[2] P. W. Juodawlkis, J. C. Twichell, G. E. Betts, J. J. Hargreaves, R. D. Younger, J. L. Wasserman, F. J. O'Donnell, K. G. Ray, R. C. Williamson, "Optically sampled analog-to-digital converters," MTT, **49,** 1840–1853 (2001).

[3] J. –P Tourrenc, S. O'Donoghue, M. T. Todaro, S. P. Hegarty, M. B. Flynn, G. Huyet, J. G. McInerney, L. O'Faolain, T. F. Krauss, "Cross-Correlation Timing Jitter Measurement of High Power Passively Mode-Locked Two-Section Quantum-Dot Lasers," PTL , **18**, 2317-2319 (2006).

[4] M. J. R. Heck, J. F. Bauters, M. L. Davenport, J. K. Doylend, S. Jain, G. Kurczveil, S. Srinivasan, Y. Tang, J. E. Bowers, "Hybrid Silicon Photonic Integrated Circuit Technology," JSTQE ,**19**, 6100117 (2013).

[5] L. A. Jiang, K. S. Abedin, M. E. Grein, and E. P. Ippen, "Timing jitter reduction in modelocked semiconductor lasers with photon seeding," APL, **80**, 1707-1709 (2002).