Ultralow 192 Hz RF linewidth optoelectronic oscillator based on the optical feedback of mode-locked laser diodes

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Abstract: We present an ultralow RF linewidth (192 Hz) and subpicosecond phase noise (260 fs) using a passively mode-locked quantum-well laser with feedback via a dual optical fiber loop.
OCIS codes: (060.2340) Fiber optics components; (060.5060) Phase modulation; (140.5960) Semiconductor lasers; (230.5590) Quantum-well devices; (320.7090) Ultrafast lasers.

1. Introduction

Optical self seeding feedback techniques can be used to improve the noise characteristics of passively mode-locked laser diodes (MLLD) [1, 2]. External cavities such as fiber optic cables can increase the phase memory of the MLLD and subsequently improve the timing jitter [3]. In this work, an improved optical feedback architecture is proposed using a dual optical fiber loop delay as a cavity extension of the mode-locked laser. A composite cavity is included for suppressing supermode noise artifacts presented due to harmonic mode-locking effects [4]. Using this configuration, we achieve a RF linewidth of as little as 192 Hz, which is the lowest reported linewidth of any high frequency (>1 GHz) passively mode-locked laser to date, making it promising for the development of low cost, high frequency optoelectronic oscillators.

2. Experimental configuration

The experimental setup for the dual optical feedback loop is shown in figure 1. The MLLD was a 20 GHz two-section MLLD, fabricated on a three quantum-well AlGaInAs/InP epitaxial structure [5]. The output of the laser was coupled into a lensed fiber which was fed through a circulator to minimize back reflections. A 3 dB fiber coupler was then used to split the output into two paths, one towards an optical delay line, and the other towards a dispersion shifted erbium doped fiber amplifier (DS-EDFA) followed by a length of dispersion shifted fiber (DSF) before being recombined via a second 3 dB coupler. The signal was then fed into an optical attenuator before being coupled back into the SA end of the MLLD cavity with the TE polarization maximized. The additional output port of the 3 dB coupler was used for subsequent spectral analysis. The total length of the composite cavity (inner fiber loop) was ~22 m, and the outer fiber loop was ~66 m, of which ~48 m was dispersion shifted via the EDFA, attenuator, and an additional length of DSF, resulting in a total dispersion of approximately 200 fs/nm.

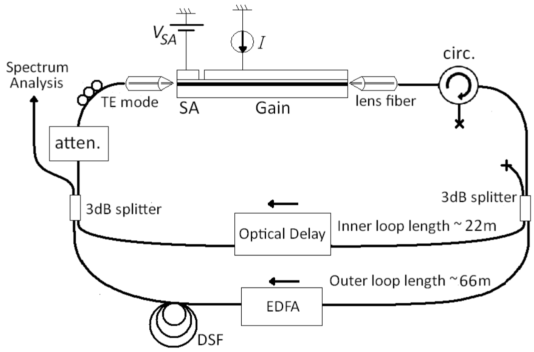

Fig. 1. Experimental configuration of the dual loop optoelectronic oscillator. (SA: saturable absorber, circ.: optical circulator, DSF: dispersion shifted fiber, atten.: optical attenuator).

3. Results

The laser was passively mode-locked when the gain section was forward biased with 83 mA and the SA section was reverse biased with 2.9 V. Figure 2(a) shows the RF spectrum of the output of the dual optical feedback loop with an uncorrelated composite cavity length, (i.e. the modes associated with the inner loop were not aligned to the modes of the outer loop). When the composite cavity length was optimized using the variable optical delay line,

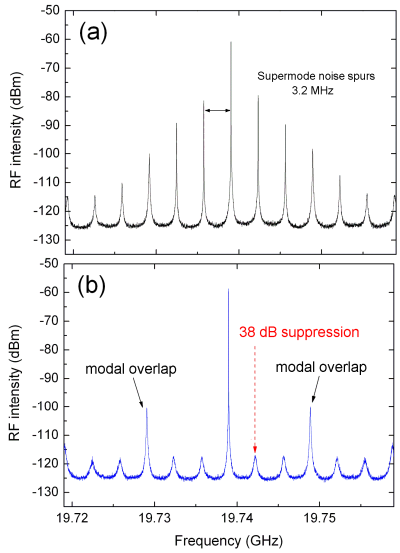

Fig. 2. (a) Uncorrelated composite cavity length resulting in large supermode noise resonances, and (b) optimized composite cavity length resulting in supermode noise suppression.

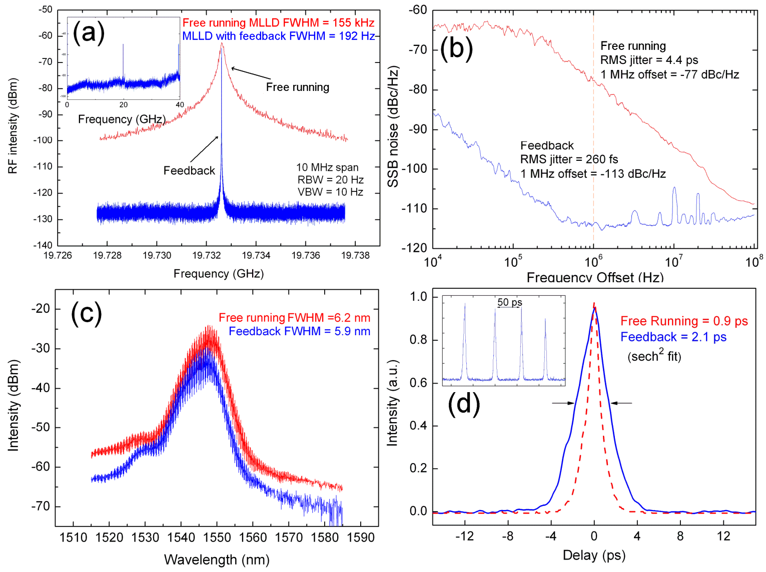

Fig. 3. Comparisons of free running MLLD performance and dual loop feedback performance in (a) the RF spectrum, (b) SSB phase noise, (c) optical spectrum, and (d) second harmonic generation (SHG) autocorrelation.

such that the length corresponded to an overlap of every third mode of the fundamental fiber cavity loop (i.e. ~22 m) the peak power of the supermodes were reduced to less than -100 dBm (figure 2(b)). A comparison of the RF spectrum of the MLLD with (blue trace) and without (red trace) feedback is shown in figure 3(a). The 3 dB linewidth of the free running MLLD was 155 kHz with a single-side-band (SSB) phase noise of -77 dBc/Hz at a 1 MHz offset (figure 3(b) – red trace). The corresponding RMS timing was 4.4 ps (integrated from 20 kHz – 8 MHz). The linewidth of the MLLD with feedback (operating under the same conditions as when free-running) was as little as 192 Hz, with a SSB phase noise of -113 dBc/Hz at an offset of 1 MHz, and an integrated RMS jitter of 260 fs. A comparison of the optical spectrum and pulse width are shown in figures 3(c) and (d), respectively. The 3 dB spectral bandwidth of the free running MLLD was 6.2 nm, and the pulse width was 0.9 ps. Due to chromatic dispersion in the fiber (other than the dispersion shifted fiber), the 3 dB bandwidth at the output of the optical feedback loop was 5.9 ps, and the pulse width was 2.1 ps. The pulses in both instances were free from *Q*-switching instabilities and pedestal modulation. The average output power of the MLLD coupled into a fiber was 1 dBm while free running. With an optimized feedback intensity of -26 dBm (assuming a lensed fiber coupling efficiency of 50 % [5]) controlled via the attenuator, the output power of the dual fiber loop oscillator was -8.5 dBm.

4. Conclusions

To summarize, a dual optical feedback loop for MLLDs has been proposed for generating ultralow linewidths and subpicosecond phase noise. Using this method we have acquired an extremely low RF linewidth of 192 Hz and a low RMS jitter of 260 fs (integrated from 20 kHz – 80 MHz) using a 20 GHz quantum-well based MLLD. The reported RF linewidth is the narrowest reported to date of any high frequency passive MLLD operating above 1 GHz, making this system promising for the development of compact, high frequency, low cost and low noise OEOs.

5. References

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