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► **To cite this version:**

Pierre Henry Hanzard, Maxwell Rowley, Antonio Cutrona, Sai Chu, Brent Little, et al.. Real-Time Study of Coexisting States in Laser Cavity Solitons. Integrated Photonics Research, Silicon and Nanophotonics 2021, Jun 2021, Washington, DC, United States. pp.IF1A.7, <10.1364/IPRSN.2021.IF1A.7>. <hal-03417995>

HAL Id: hal-03417995

<https://hal.science/hal-03417995v1>

Submitted on 17 Nov 2021

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Real-Time Study of Coexisting States in Laser Cavity Solitons

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Abstract: In this study, we demonstrate that two states can coexist in laser cavity soliton (LCS) microcombs. We present experimental evidence of the simultaneous presence of LCS and a background modulation using Dispersive Fourier Transform. © 2021 The Authors

1. Introduction

Laser Cavity-Solitons constitute a promising category of pulses for microcombs generation [1]. These self-localized waves show exceptional properties such as broad spectrum, high average power and remarkable mode efficiency compared to traditional micro-cavity based frequency combs. The LCS regime is created using a nonlinear Kerr micro-cavity nested in a fibre amplifying loop (Fig. 1(a)). The Kerr micro-cavity allows broadband generation whereas the fibre amplifying loop, including an EDFA, provides energy to the system. Compared with today's state-of-the-art systems, LCS microcombs provide a high robustness against perturbations and are easily controllable by tuning the cavity parameter, specifically the EDFA gain current and the cavity length. The study of LCS dynamics requires a very high temporal resolution in order to observe these femtosecond pulses, combined with a broad temporal range of measurement to observe their formation and study their interactions happening over hundreds of microseconds, which corresponds to the thermal and gain dynamics timescales. To observe these dynamics, suitable metrological tools must be implemented. Over the last ten years, several ultrafast metrology tools reaching this goal have been demonstrated in the ultrafast optics community, opening the research field of non-repetitive events [2]. These tools permitted the study of ultrafast laser start-up regimes such as the build-up of mode-locking [3], and allowed to observe different phenomena such as solitons collision-induced explosion in mode-locked lasers [4] and optical rogue waves [5].

2. Experimental results and discussions

In this experiment, the optical spectrum of the pulses is characterised using Dispersive Fourier Transform. This technique consists in applying chromatic dispersion to an optical pulse until reaching the so called far field condition, at which the pulse temporal profile is identical to its optical spectrum. However, the dispersion of the optical fibre induces a temporal stretch of the pulses, which can lead to pulses overlapping, causing information losses. This problem becomes more important when using high repetition-rate laser sources, for which the short temporal separation between pulses does not allow for the pulse to stretch enough. The LCS microcomb used in this experiment produces a 50GHz pulse train, and is thus not directly suitable for a DFT measurement. To overcome this problem, amplitude modulation is used to sample the emission rate of our laser at a lower repetition rate (Fig. 1(b)). The repetition rate is thus lowered to 33MHz, at which the pulses can temporally stretch without overlapping. However, the amplitude modulation used in this setup does not possess a resolution allowing to select single pulses. Bunches of 10 pulses are thus recorded and considered as a single average pulse, we call this method the few-pulses approximation. This approximation is justified by the fact that our study is focused over long timescales, for which the pulse-to-pulse variation is considered negligible.

Using this modulated-DFT setup, we have the ability to observe a signature of the radio-frequency response of the laser simultaneously with the DFT trace. Those measurements allow us to observe a set of laser states composed of the superposition of LCS with a continuous wave/Turing pattern state in real time. In our system, solitons and Turing patterns are identified by the locking of the laser lines of the red and blue detuned slope of the microcavity, respectively. These states can effectively coexist when the free-spectral range of the fibre laser cavity is in the order of the microcavity linewidth. When this condition is respected, a red and blue-detuned line can oscillate in the microcavity resonance together, allowing the coexistence of these nonlinear states. Their presence is confirmed when a radiofrequency beating equivalent to the free spectral range of the cavity is measured.

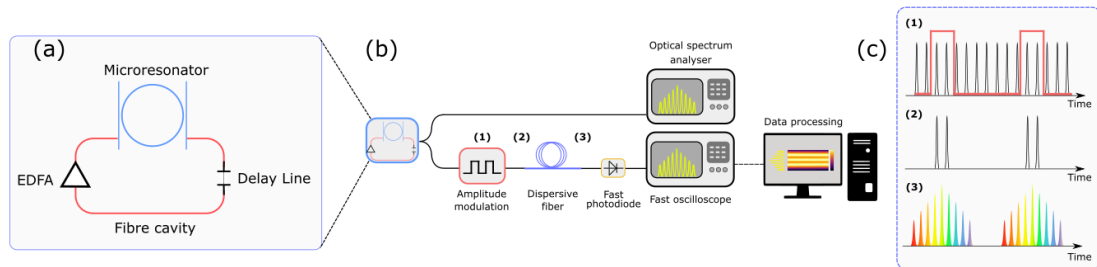


Figure 1. (a) LCS are generated using a micro-resonator nested in a fibre cavity. (b) Real-time diagnostic setup. Amplitude modulation is first used to reduce LCS repetition rate, allowing them to temporally stretch in a dispersion compensation fibre. The pulses are then recorded using a fast detection setup comprising a fast photodetector and oscilloscope.

This work concerns the dynamical study of those two superimposed states. Figure 2(b) illustrates a DFT measurement of the coexistence of a LCS with a continuous wave state. This measurement reveals the temporal buildup of the LCS, with the formation of a comb-like optical spectrum visible around 20 μs and centered at 1540 nm. On this measurement, a slow modulation matching the free-spectral range of the laser cavity can also be observed. This modulation results from the existence of a continuous wave state around 1540nm (visible in Figure 2(a)), appearing with the pulsed regime. The evolution of the modulation period over time demonstrates that the position of the laser lines within the microcavity is changing. More specifically, it shows that the frequency detuning between the two states is reducing until 150 μs , and then increasing until reaching 80MHz. In order to confirm the coexistence of these two states, laser-scanning-spectroscopy is used simultaneously with the measurement.

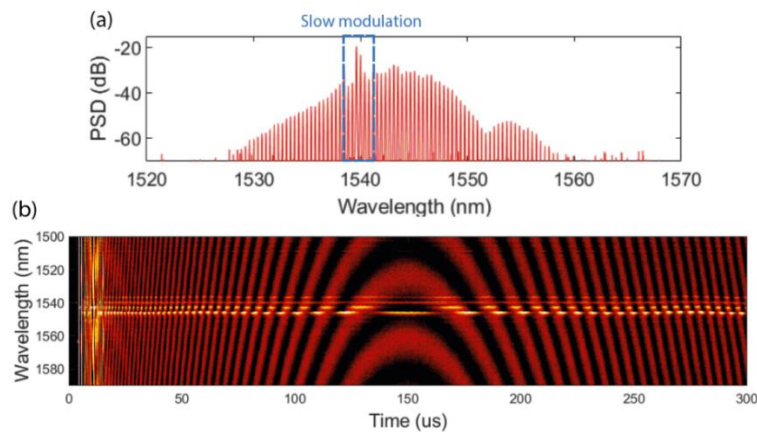


Figure 2 (a) Optical spectrum of the LCS. The spectral lines responsible for the slow modulation are circled in blue. (b) Start-up of the LCS regime (0-20 μs). The radio-frequency beating can be observed over hundreds of microseconds.

3. References

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