Timing Jitter and All-Optical Clock Recovery Based on a Quantum-Dash Fabry-Pérot Semiconductor Laser

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ABSTRACT

An experimental analysis of the timing jitter associated with sub-picosecond pulses produced from a quantum dash passively mode-locked Fabry-Pérot laser is produced. Moreover, application as an all-optical clock recovery function for a 40Gb/s data rates with non-return-to-zero (NRZ) modulation format is demonstrated using this laser.

1. INTRODUCTION

Short optical pulse generation by a passively mode locked (PML) quantum-dash (QDash) based Fabry-Pérot (FP) laser diode (LD) has been demonstrated recently. A single section device with dc-bias current applied operate in a passive mode-locking regime, resulting in the formation of picosecond pulses with a 40 GHz repetition rate [1]. Reduction of the pulse duration below picosecond level has been achieved, after the introduction of a simple passive compression scheme, based on anomalous group velocity dispersion in a standard optical fibre [1],[2]. Despite these interesting results, there was no jitter evaluation performed, which is an important parameter when the device is to be considered as a clock or a pulse source.

The main objectives of this paper are two-folded. In the first part of the paper experimental measurements of the timing jitter of this passively mode-locked QDash-LD are carried out and in the second part to demonstrate an all-optical clock recovery function achieved by this laser with a NRZ 40Gb/s pseudo random data stream.

2. EXPERIMENT I – Timing Jitter

The experimental setup used to characterise the passively mode-locked QDash-LD is presented in Fig. 1. We investigate the time and the spectral (optical and RF) domains of this laser emission.

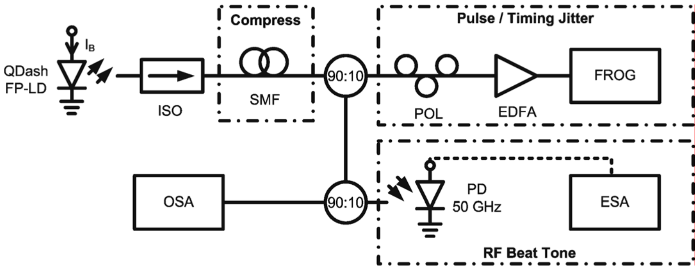

Figure 1. Experimental setup to characterise the output of the QDash-FP-LD under passive mode-locking operation. The studied laser is temperature controlled at 25 ºC and DC-biased.

Laser under test is a 1.05 mm-long, Fabry-Pérot device, with an active region composed of quantum-dash layers similar to the one presented in [3]. The QDash-FP-LD is temperature stabilised at 25 ºC, dc-biased and operates in multi-mode regime with a signature of strong passive mode-locking mechanisms as it will be determined. It features a bias threshold of 18 mA. The output of the LD is coupled into an optical fibre at an average power of 4 mW when operating at a bias of 400 mA, and continues to an optical isolator (ISO), preventing potential feedback to the tested device from other elements of the setup. Similar to the previously presented work, a simple compression scheme based on a single mode fibre (SMF) is employed to take an advantage of reduced pulse duration [1]. Optical spectrum recorded with an optical spectrum analyser (OSA) exhibits around 31 longitudinal modes, 0.31 nm apart, giving an optical full width at half maximum (FWHM) bandwidth of 12 nm centred at 1526 nm, as presented in Fig. 2a. The optical linewidth corresponding to each of the longitudinal modes varies between 10 and 50 MHz, depending of the mode wavelength and applied level of the bias current [4]. The optical signal is analysed in the electrical domain by a 50 GHz photodetector and a 60 GHz electrical spectrum analyser (ESA) providing 1 kHz of radio and video bandwidth at 1 MHz span. The RF peak is recorded at a frequency of 39.77 GHz. This frequency corresponds to the free spectral range between the optical modes present at the output of the LD. It features a linewidth of 25 kHz, measured at FWHM of a Lorentzian curve fitted to the experimental data, as can be seen in Fig. 2b. When this RF beat tone linewidth is compared with the summary optical linewidth of contributing optical modes, the relation $\Delta_{RF} \ll \sum\Delta_{OPT}$ is satisfied, which demonstrates the passive mode-locking of such a dc-biased laser. As a result of the locking of the longitudinal spectrum, a very short optical pulse-train occurs with a 39.8 GHz repetition rate. A sample of these pulses has been captured using a frequency resolved optical gating (FROG) system as shown in Fig. 2c. The pulse is characterised by a 720 fs width after compression by 450 m long standard single mode fibre.

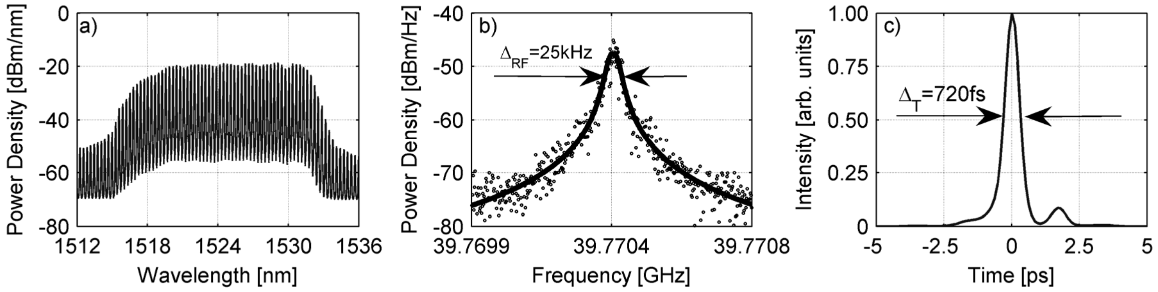

Figure 2. Signals produced by PML QD-FP-LD with bias applied at 350 mA: (a) optical spectrum recorded (b) RF beat tone produced on fast photodiode (c) sub-picosecond pulse retrieved with FROG system.

The FROG system is further utilised for the measurement of the timing jitter associated with the generated optical pulse stream. A shift of the optical delay by 25 ps with respect to the 'zero delay' position used for auto-correlation (AC) related data, allows recording of spectrograms corresponding to cross-correlation (CC) components, resulting from two consecutive pulses. Spectrally integrated spectrograms provide the AC and the CC traces produced by the investigated pulse-stream, FWHM durations of both traces are found as τ_{AC} and τ_{CC} respectively. The timing jitter can be calculated with the following formula [5]:

$$\sigma = \frac{\Delta_T}{\tau_{AC}} \sqrt{\tau_{CC}^{\ 2} - \tau_{AC}^{\ 2}} \ , \tag{1}$$

where Δ_T is FWHM pulse duration, and σ is the timing jitter associated with the generated pulse-train. Both the pulse duration and timing jitter evolutions with respect to bias level applied to the tested QDash-FP-LD are presented in Fig. 3.

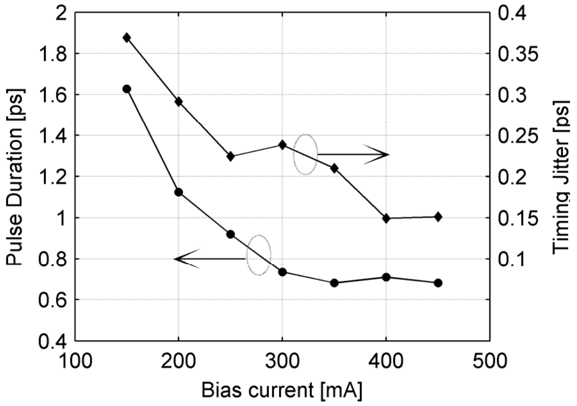

Figure 3. Pulse duration (●) and timing jitter (♦) measured for bias current range from 150 to 450 mA.

Pulse durations ranging between 1.7 ps and 720 fs can be observed with decreasing trend when the bias current increases. The timing jitter follows a similar trend with values from 370 downward to 150 fs. This trend in both the pulse duration and timing jitter may be attributed to the increased intensity of nonlinear inter-modal interactions in the active region of the laser diode. These nonlinearities result in a stronger four-wave mixing effect, which is a contributing mechanism to the passive mode-locking in single section laser structures [6]. The improved mode-locking leads to reduction of the phase-noise (timing jitter) and pulse duration.

3. Experiment II – All-Optical Clock Recovery

In Fig. 4, a scheme used to investigate the response of the PML QDash-FP-LD under injection of the optical data-stream is presented. The setup consists of four main sections. In the first block a (2^{23}-1) long NRZ 40 Gb/s pseudo random bit sequence (PRBS) from a pulse pattern generator (PPG) is applied onto the optical carrier at 1550 nm from CW laser source via a Mach-Zehnder modulator, and amplified with an EDFA 1. 10% of the optical data-stream power is directed to the detection block, while remaining power is injected into the QDash-FP-Laser via an optical circulator. The signal is preconditioned with a polarisation controller (POL) and a variable optical attenuator (VOA). The laser is DC-biased at 102 mA and temperature stabilised at 25 °C. The signal at the third port of the circulator is amplified with EDFA 2 and filtered with a tuneable optical bandpass filter (OBPF). The filter has a Gaussian profile, with a bandwidth of 2 nm, and its central wavelength is set at 1530 nm in order to spectrally isolate the output of the QDash-FP laser – optical clock - from the injected data. The optical clock signal is then converted to the electrical domain by a 50 GHz photo-detector (PD) and 40 GHz RF amplifier (RF AMP). The electrical clock directed to the detection stage is analysed with the ESA and used as trigger for a digital sampling oscilloscope (SCOPE) featuring an 80 GHz bandwidth optical-input. In order to optimize polarisation controllers and filtering, the OSA is used to monitor both optical signals: the data and the recovered clock.

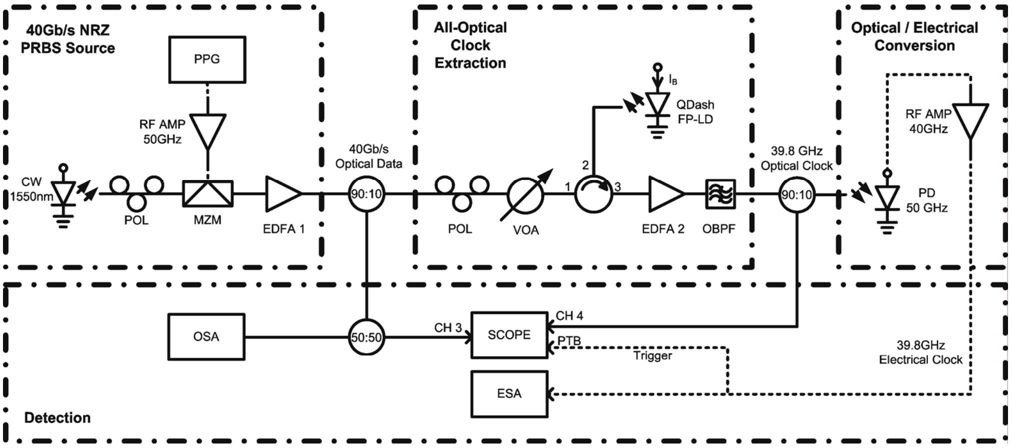

Figure 4. Experimental setup used for the clock extraction from 40Gb/s NRZ PRBS bit-stream using all-optical means. It consists of four main sections: 40Gb/s optical source, all-optical clock extraction, optical to electrical conversion, and signal detection.

RF spectra recorded from free running laser in PML condition, when there was no external modulated signal injection is depicted in Fig. 5. In the same figure the RF peak is plotted, when the 40Gb/s NRZ PRBS data-stream is injected into the tested laser. The data is spectrally shifted by 20 nm from the clock signal. The RF peak undergoes a reduction in terms of the FWHM linewidth down to 150 Hz, the limit of the ESA resolution. The waveform corresponding to the recovered clock signal is shown in Fig. 5b, while optical data triggered by this clock in Fig. 5c.

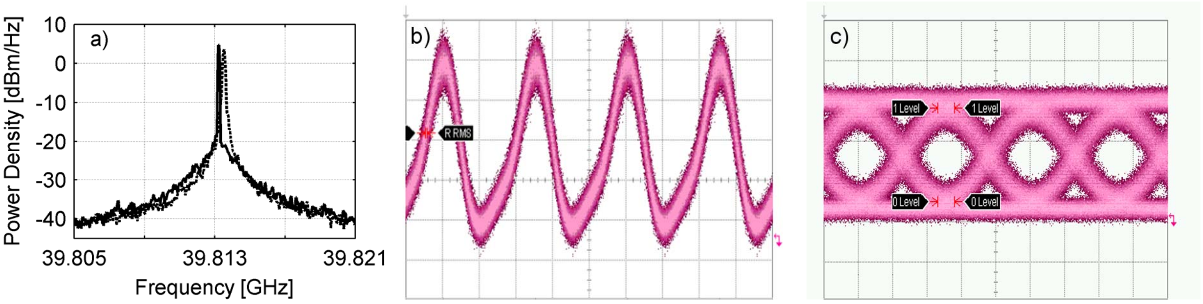

Figure 5: (a) RF signals recorded with ESA corresponding to free running QDash-FP-LD (dashed) and when the laser is subject to an injection of the external optical modulated signal. (b) Waveform corresponding to the optical clock at the output of the clock recovery block (time scale: 10 ps/div Y-scale: 0.3 mW/div). (c) 40 Gb/s NRZ eye-diagram obtained with extracted clock used as a trigger (time scale: 10 ps/div; Y-scale: 0.5 mW/div).

It should be noted that the sampling oscilloscope is fitted with precision time-base module, which offers a minimal timing jitter of 200 fs. This value is in order of the timing jitter associated with the tested device under PML conditions, as presented in former experiment. Furthermore, large contributions to the jitter observed with the scope originate from components used in optical to electrical conversion. As a result timing jitter is measured at 551 fs with this setup. The eye-diagram of optical data triggered with recovered clock is also penalized, however it is characterised by a 9 dB extinction ratio and a 5.76 Q-factor which leads to an estimated bit error rate of 4E-9 [7].

4. CONCLUSIONS

The timing jitter accompanying sub-picosecond optical pulses emitted at 39.8 GHz by a passively mode-locked QDash-FP-LD was experimentally investigated. An approach based on a comparison of the intensity auto- and cross-correlations was used. Both the AC and CC traces were obtained from the FROG system, with accordingly adjusted optical delay line. The measured values of timing jitter were as low as 150 fs and demonstrate significant phase-noise reduction due to nonlinear effects inside the laser cavity. Moreover, when such a laser was under optical injection of a NRZ data-stream, it was able to synchronize its free running frequency to the bit-rate of the incoming signal. The data can be separated spectrally from the clock signal by tens of nanometers. The above experiments demonstrate that the QDash-FP-LD can provide a stable optical clock signal at very high frequencies but also can be used as an all-optical clock-extraction function.

ACKNOWLEDGEMENTS

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