All-Optical 40 Gb/s 3R Regeneration Assisted by Clock-Extraction Based on a Passively Mode-Locked Quantum-Dash Fabry-Pérot Laser

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Abstract *Experimental measurements on a quantum dash mode-locked Fabry-Pérot laser are presented. Its potential for clock recovery at 40 Gb/s in an all-optical 3R regeneration with an NRZ-to-RZ format conversion and wavelength offset of 23 nm is demonstrated.*

Introduction

Data regeneration operations as retiming, reshaping and reamplification (3R) are key functionalities in the development of all-optical transparent communication systems. The extraction of the clock signal from the incoming data in the optical domain at the receiver end is a natural step prior to or along with the implementation of such 3R functions. In this context, regeneration and all-optical clock recovery have been proposed for different data rates and formats by using a variety of schemes such as Mach-Zehnder interferometers (MZI)[1-2], electro-absorbers[3-4], semiconductor optical amplifiers (SOA)[5], and/or in combination with actively mode-locked distributed feedback or Fabry-Pérot (FP) lasers[6-7] and filtering techniques[8]. On the other hand, quantum-dash mode-locked (QDash-ML) FP semiconductor lasers have recently captured significant interest for their attractive applications in optical time-domain multiplexing systems as short pulse generators, wavelength tunable transmiters and frequency multipliers[9-11]. The aim of our work is twofold. Firstly an all-optical clock recovery function is implemented on a QDash-ML FP laser by injecting a non-return-to-zero (NRZ) pseudo random bit sequence (PRBS). In comparison with the input data, a reduction in timing jitter of the extracted clock is observed and analysed in terms of the wavelength of such a signal. Once the clock has been recovered, it is utilized for regenerating the PRBS data, featuring a NRZ-to-RZ format conversion. Measurements of the time evolution of the recovered clock and eye diagrams of the injected and regenerated PRBS data signal are reported.

Experiment

As depicted in Fig. 1, our experiment is organized in two stages. Firstly the clock signal is extracted from a 40 Gb/s (2^{31}-1)-long NRZ PRBS data sequence. Then the recovered clock is processed along with the data signal for implementing 3R regeneration function. The clock extraction operation is accomplished by using a 1 mm-long single-section QDash-ML FP semiconductor laser. A brief description of the QDash-based heterostructure, as well as features and dimensions of its active layer in order to achieve emission around 1550 nm have been given in [9,12]. A typical optical spectrum collected at the laser output without any injection is shown in Fig. 2a. At 350 mA it exhibits more than 30 longitudinal modes with 0.31 nm inter-modal separation, given an optical bandwidth of 12 nm centered at 1526 nm. Similarly, in Fig. 2b the beat-note at 40 GHz in free-running (FR) is depicted in dotted line, exhibiting a FWHM of 25 kHz[12]. When the laser is under optical injection, as it is the case to be exploited for clock recovery, the beat-note is synchronized to the injected signal and its linewidth is reduced to around 150 Hz, as shown in Fig. 2b (continuous line).

On the other hand, the eye diagram of the 40 Gb/s NRZ PRBS data signal at 1535.3 nm injected into the QDash-ML laser for clock extraction and the corresponding recovered clock are shown in Figs. 3a and 3b, respectively. Owing to the features of the utilized equipment for generating the PRBS bit sequence, such a signal presents a minimum timing jitter equal to 1.36 ps at 1533.5 nm. However, after its injection into the QDash-ML laser, the extracted clock presents a significative reduction of the timing jitter (0.55 ps). in comparison to that of the injected signal. As depicted in Fig. 4, this important feature is observed throughout the entire interval of the analyzed data signal wavelengths, which range from 1533.5 to 1553 nm. It is worth mentioning that in order to record these reported measurements, the optical sampling scope is triggered by the extracted optical clock after its distribution and conversion to an electrical signal.

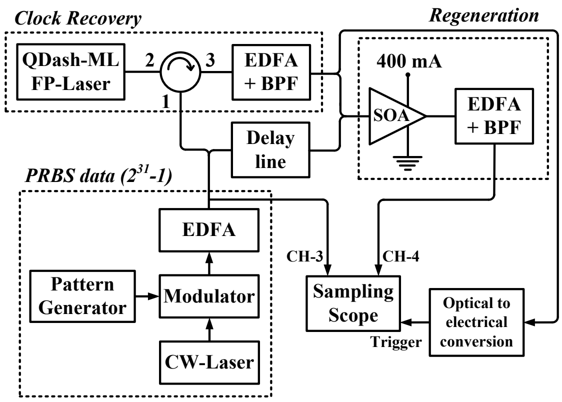

Fig. 1. Experimental setup utilized for clock-extraction and 3R regeneration on a 40 Gb/s NRZ PRBS data signal.

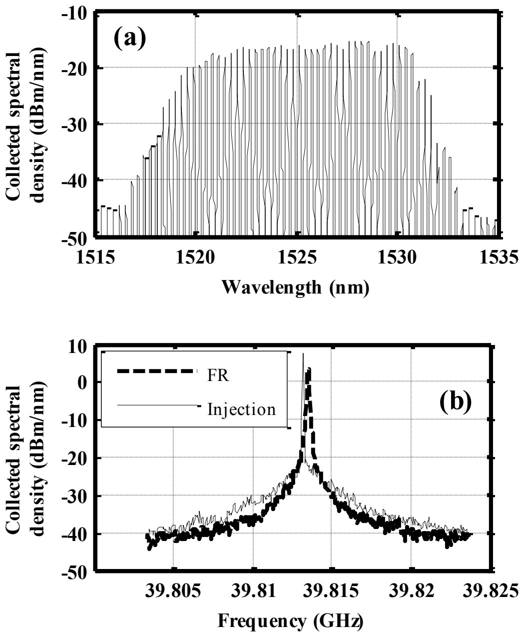

Fig. 2. a) Typical optical spectrum collected at the QDash-ML laser output. b) Beat-note at 40 GHz. Dotted line: in free running, continuous line: under injection.

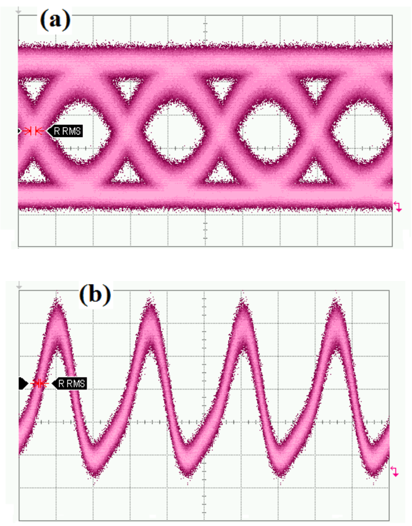

Fig. 3. a) Eye diagram of the 40 Gb/s NRZ PRBS data signal injected into the QDash MLL. b) Time evolution of the extracted clock. Horizontal and vertical scales are 10 ps/div and 500 μW/div, respectively.

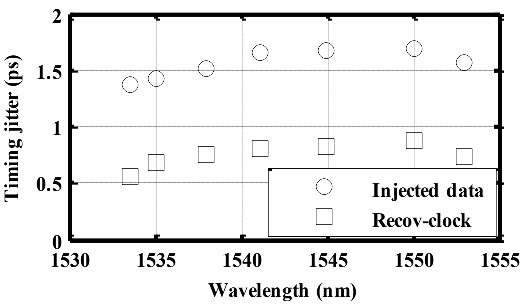

Fig. 4. Timing jitter improvement of the recovered clock in comparison to that of the injected data signal.

Regarding the 3R regeneration stage, both extracted optical clock and data signal are injected into a commercially available bulk semiconductor optical amplifier. The recovered clock is boosted by using an erbium dopped fibre amplifier (EDFA) and then passed through a 2 nm optical band-pass filter for reducing the excess of noise associated with the amplified spontaneous emission. The optical spectra of such signals at the SOA input are depicted in Fig. 5a. In our analyzed configuration, the regeneration function is achieved by using the cross-gain modulation mechanism inside the SOA. Indeed, as shown in Fig. 5a, the extracted clock power is larger than that of the data signal, allowing the saturation of the amplifier during its high state. In order to retrieve the regenerated data signal, an optical square-shape band-pass filter with a 1 nm bandwidth is utilized at the SOA output. In the case illustrated in Fig. 5b, the filter is set at 1535.7 nm central wavelength. No significant improvement in the regenerated data signal is observed when the band-pass filter is set at the blue-components, and a rather degradated signal is obtained when both red- and blue-components around the carrier are considered.

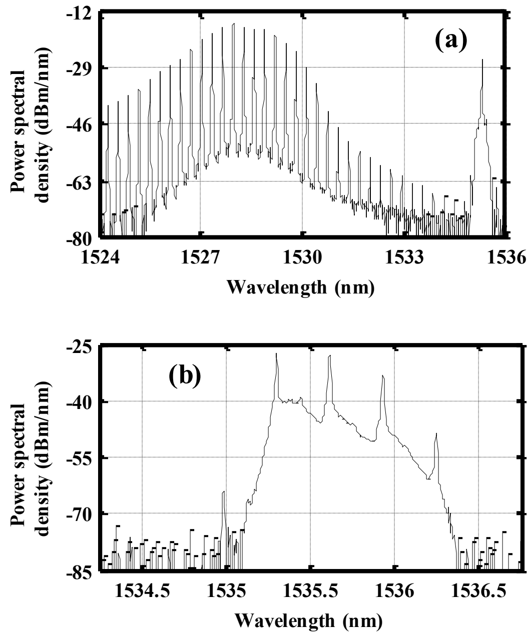

Fig. 5. a) Optical spectrum of the recovered clock and data signal at the SOA input. b) Data signal at the SOA output after passing through the band-pass filter.

The quality of the regenerated data signal is analyzed through its eye diagram recorded after the optical band-pass filter. As depicted in Fig. 6 for a data signal at 1535.3 nm, a format conversion from NRZ to return-to-zero (RZ) is accomplished after the regeneration stage. Moreover, a minimum signal-to-noise ratio (SNR) of 4.5 in the recovered signal is obtained for an input SNR of 6.2. It is worth mentioning that, as in the reported eye diagrams of Fig. 3, in this case the sampling scope is also triggered by the extracted clock (optical signal) after its conversion to an electrical signal. This is the main source of degradation in the output signal. However, it resembles a realistic scenario where the clock pulses are extracted from the incoming data signal at the receiver end. A more extensive set of experimental results are presented in Fig. 7 for a carrier wavelength of data signal ranging from 1533.5 to 1553 nm. As it is observed, the SNR of the regenerated signal follows a similar trend to that of the extracted clock (see Fig. 4) even though a corresponding degradation is observed. Indeed, a larger SNR degradation is observed as the data signal wavelength approaches the main frequency components of the recovered clock.

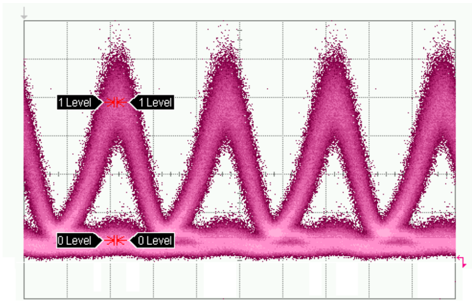

Fig. 6. Eye diagram of the regenerated RZ PRBS data signal at 1535.3 nm. Horizontal and vertical scales are 10 ps/div and 500 µW/div, respectively.

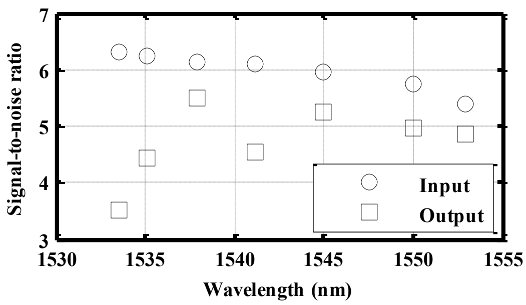

Fig. 7. Signal to noise ratio of the data signal at the input and output of the 3R regenerator as a function of the carrier wavelength.

Conclusions

In this work, an all optical clock recovery function at 40 Gb/s based on a QDash-ML FP laser with a wavelength detuning between the clock and the data stream of 23 nm is demonstrated. The measured timing jitter of the recovered clock ranges from 0.55 to 0.87 ps. The 40 Gb/s recovered clock has been exploited in an all-optical 3R regeneration function based on a commercial SOA. The SNR of the 3R regenerated data signal ranges from 3.53 to 5.24 for an SNR input data ranging from 5.4 to 6.3.

Acknowledgements

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