Short Pulse Generation with 40 GHz Passively-Mode Locked Q-Dashed Fabry-Pérot Laser

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ABSTRACT

Generation of sub-picosecond pulses by a dc-biased passively mode-locked Fabry-Pérot laser is demonstrated. By using a tunable band-pass filter, it is observed that the width of the generated pulses decreases in direct proportion to the optical modes emitted by the laser. Furthermore, performing a passive compression by a piece of single mode fiber, we demonstrate the generation of 720 fs pulses by this type of mode-locked Fabry-Pérot laser.

Keywords: mode-locked lasers, quantum-dash semiconductor lasers, sub-picosecond pulse generation.

1. INTRODUCTION

Quantum-dot and quantum-dash mode-locked lasers (QD-MLL) have recently attracted much interest due to their potential applications for optical time-domain multiplexing, all-optical clock-recovery and all-optical waveform generation. Regarding the latter application, on one hand pulse generation has been demonstrated using two-section devices composed by an absorber and gain sections. Rafailov *et al.* [1] have studied the generation of 5 to 6.5 ps pulses at a repetition rate of 21 GHz. Xin and co-workers [2] have reported on 2 ps pulses at a repetition rate of 5 GHz. In these two studies, the devices under test exhibit an optical spectrum centred around 1200 nm, with a full-width at half maximum (FWHM) of 14 nm and 4.3 nm, respectively. On another hand, pulse generation has been also demonstrated using Fabry-Pérot (FP) QD-MLL lasers operating at 1550 nm. Gosset *et al.* [3] have reported 1.1 ps and 2 ps auto-correlated pulses at repetition rates of 134 GHz and 42 GHz, respectively. More recently, investigations on the characteristics of the QD-MLL structure, such as the confinement factor, have also been addressed in order to generate short pulses at 40 GHz with a minimum radio-frequency (RF) line-width [4]-[5].

The aim of our work is to perform a deeper experimental analysis on pulse generation by using a dc-biased passively mode-locked QD-FP laser. We analyse both the temporal pulse width and chirp of a 39.8 GHz signal generated by the QD-MLL. This study is performed in terms of the optical modes passing through a variable band-pass filter at the laser output. Furthermore, owing to the initial chirp exhibited by the generated pulses and the group velocity dispersion in a single mode fibre (SMF), pulses are passively compressed after its propagation through such a given piece of fibre. Thus, we experimentally demonstrate the generation of pulses as short as 720 fs by a dc-biased and passively mode-locked QD-FP.

2. EXPERIMENT

Our device under test is a 1.05 mm long, dc-biased, multi-mode Fabry-Pérot quantum-dash MLL. Further information on this type of device can be found in [5]. This device presents a bias threshold of 18 mA and a total collected power of 4 mW when operating at 400 mA and temperature controlled at 25 °C. Its optical spectrum exhibits around 31 longitudinal modes, 0.31 nm apart, giving an optical FWHM-bandwidth of 12 nm centred at 1526 nm. The average optical linewidth of each longitudinal mode is measured at 120 MHz.

The experimental setup is depicted in Fig. 1. The output of the FP QD-MLL is coupled to a 1 m long SMF followed by an isolator (ISO), a variable band-pass optical filter (BPF) and an Erbium doped fibre amplifier (EDFA). The ISO is placed at the laser output to suppress back-reflections, whilst the EDFA is used to enhance the power of the optical modes passing through the band-pass filter. In order to analyse pulse shape and chirp, the collected light from the EDFA is coupled to a FROG (Frequency-Resolved Optical Gating) system. Thus, the experiment is performed by measuring the temporal width of the optically-generated pulses in terms of the band-pass filter bandwidth. Due to the restrictions imposed by the central wavelength of the band-pass filter and the bandwidth of the EDFA, the filter was tuned at a central wavelength of 1530 nm and its bandwidth was set from 1 nm to 6 nm.

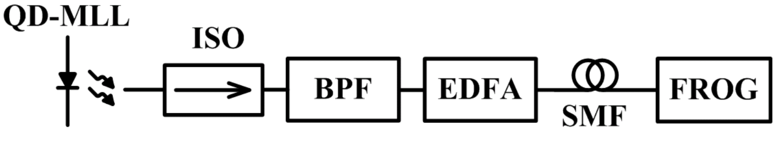

Fig. 1. Experimental setup utilized for characterizing the short pulses generated by the passively QD-MLL.

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It is worth mentioning that owing to the initial chirp exhibited by the generated pulses and the group velocity dispersion effect, a piece of SMF (450 m maximum length) lying in between the EDFA and FROG was added in order to compensate for the initial pulse chirp and therefore to perform a passive pulse compression. Thus, all the measurements were acquired by using, besides the 1m-SMF patch cord interconnecting the EDFA output and the FROG input, a piece of a given length SMF.

3. RESULTS

For filter bandwidths of 2 nm and 6 nm, the retrieved pulse shape and chirp from the FROG system (before their propagation through the SMF) are depicted in Fig. 2. Pulses have a FWHM-width of 3.6 ps and 2.6 ps, respectively. Furthermore, at the FWHM-leading and -trailing edges, pulses exhibit a negative chirp ranging from +18 GHz to -30 GHz, and from +30 GHz to -170 GHz, respectively. In order to compensate for this initial chirp, a passive pulse compression approach based on group velocity dispersion in a SMF was implemented [6]. To this aim, a piece of SMF with a given length (450 m maximum) lying in between the EDFA and FROG system is considered.

The retrieved pulses after their propagation through this piece of SMF are depicted in Fig. 3. Despite the initial chirp is not completely cancelled out, compressed pulses are obtained after their propagation through the SMF. Particularly, for a filter bandwidth of 2 nm, a positive chirp is obtained after pulse propagation, ranging from -25 GHz to 8 GHz. Conversely, for a filter bandwidth of 6 nm, the chirp is reduced to a value of -7 GHz at the FWHM-leading edge of the compressed pulse. At these conditions (2 nm and 6 nm filter bandwidth), there were obtained pulse widths of 2.1 ps and 1.25 ps, respectively. This provides pulse compression ratios approximately equal to 2. It should be noticed that chirp compensation and passive pulse compression can be further improved by using a piece of SMF with an optimum length [6]. For uncompressed pulses of 6 ps to 2 ps obtained at the output of the QD-MLL, we estimate SMF optimum lengths ranging from 50 m to 500 m, respectively.

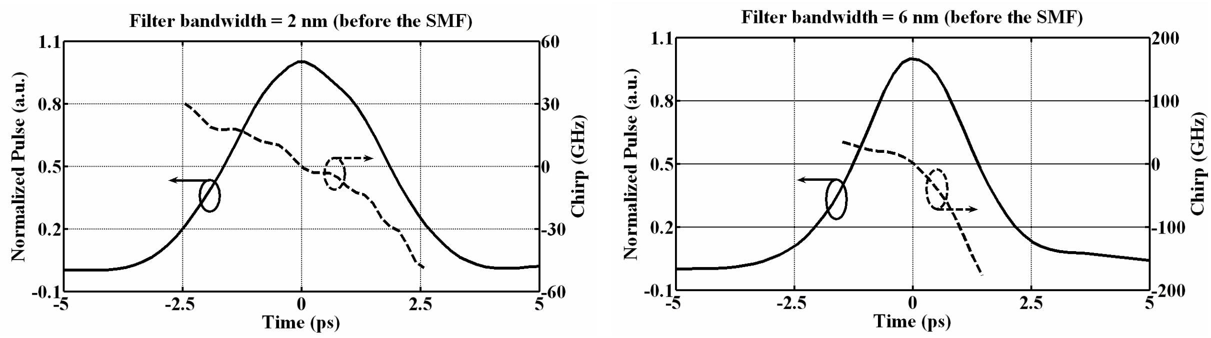

Fig. 2. Retrieved pulses (before their propagation through the SMF) from the QD-MLL for a filter bandwidth of 2 nm (left) and 6 nm (right).

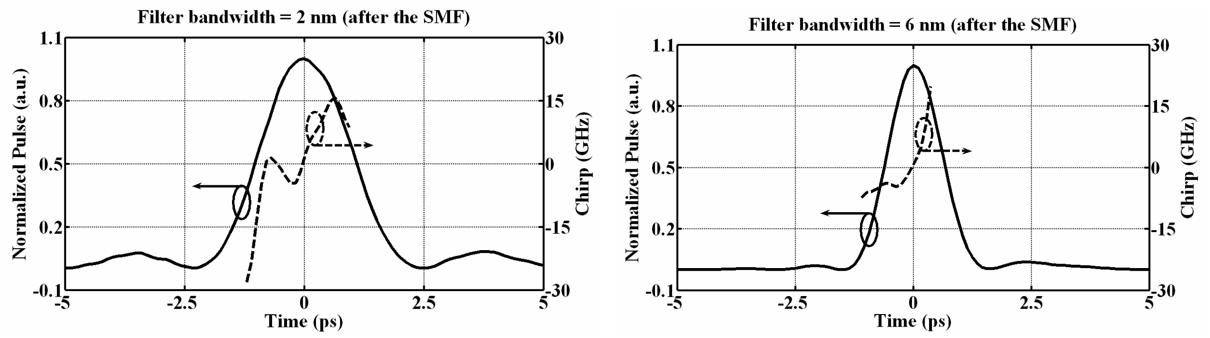

Fig. 3. Retrieved pulses (after their propagation through the SMF) from the QD-MLL for a filter bandwidth of 2 nm (left) and 6 nm (right).

Performing an approach similar to that previously described, the width of the retrieved pulses from the FROG system is depicted in Fig. 4 in terms of the filter bandwidth before and after its propagation through a piece of a given SMF lying in between the EDFA and the FROG system. It is important to mention that the pulse width was also retrieved for an unfiltered optical spectrum, where the full optical bandwidth (12 nm) of the device was injected into the FROG system. From these experimental results it is observed that the width of the generated pulses decreases as the filter bandwidth increases. The wider pulse (~6 ps) is obtained when the filter suppresses most of the optical modes (1 nm filter bandwidth), passing through only three longitudinal modes. Conversely, the narrower pulse (720 fs) was obtained with an unfiltered signal (full bandwidth) and after its propagation through the 450 m SMF.

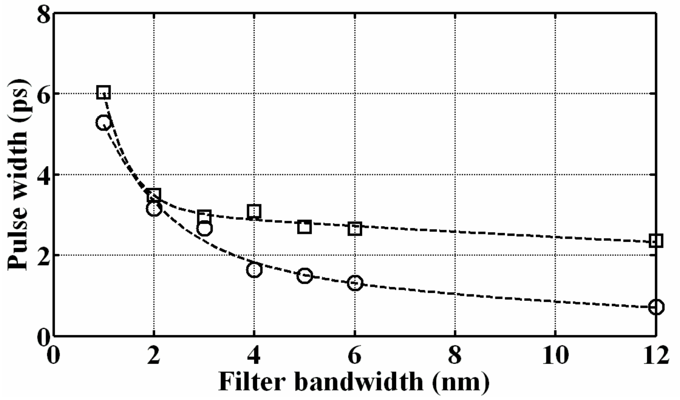

Fig. 4. Pulse width in terms of the filter bandwidth before (squares) and after (circles) its propagation through a piece of SMF (QD-MLL is dc-biased at 350 mA).

A final experimental analysis has been carried out by measuring the width of the optically-generated pulses in terms of the bias current of the QD-MLL. In this case, filter bandwidths of 3 nm, 6 nm and 12 nm (no filter) have been considered. As it can be observed from Fig. 5, the shorter pulses are obtained when the optical signal has not been filtered and it propagates through the given length SMF. Moreover, pulse width is reduced in nearly 1 ps as the bias current is increased from 100 mA to 450 mA.

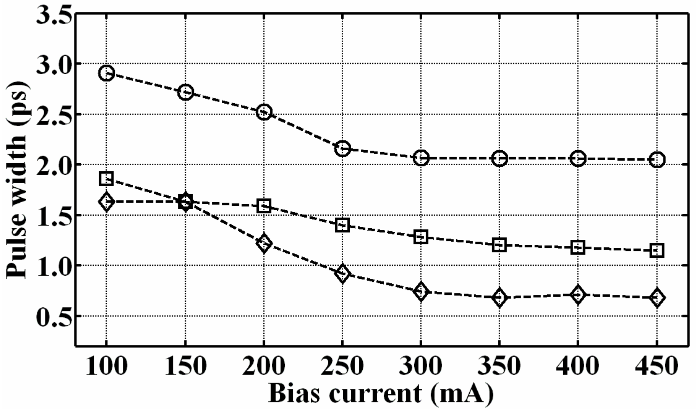

Fig. 5. Pulse width in terms of the QD-MLL dc-bias current for different filter bandwidths: 3 nm (○), *6 nm* (□) *and unfiltered pulses* (◊).

4. CONCLUSIONS

Pulse generation in the sub-picosecond regime and at a repetition rate of 39.8 GHz has been experimentally demonstrated by using a dc-biased passively mode-locked QD-FP. From these results, it can be envisaged the generation of even shorter pulses by using QD-FP lasers exhibiting a wider optical spectrum. Similarly, by designing QD-FP lasers with a specific free spectral range, sub-picosecond pulse generation can be obtained at repetition rates ranging from 40 GHz, 80 GHz, 160 GHz and above.

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