Characteristic Switching-On and Passive Mode-Locking Times in a Quantum-Dash Fabry-Pérot Laser Diode

Ramón Maldonado-Basilio[1], Josué Parra-Cetina[1], Sylwester Latkowski[2], Nicola Calabretta[2], Pascal Landais[1]*, Senior *Member, IEEE*
[1] The RINCE Institute, School of Electronic Engineering, Dublin City University
Collins Avenue Extension, Glasnevin, Dublin 9, Ireland
[2] Eindhoven University of Technology, dept. Electrical Engineering, 5600MB Eindhoven, The Netherland
**Tel: (+353) 1700 8044, Fax: (+353) 1700 5508, e-mail: landaisp@eeng.dcu.ie*

ABSTRACT

In this paper, we present the experimental investigation of the switching-on and passive mode-locking times of a Fabry-Pérot quantum dash laser diode. Their values are 30ns and 8ns respectively. These times are measured in order to study the phenomenon of mode-locking in this device and its potential application for packet switching networks.

1. INTRODUCTION

The increasing demand for bandwidth driven mainly by internet traffic will require that future optical networks be dynamic and capable of handling high date rates exceeding 100 Gb/s. Optical packet switching has been envisaged as one of the solutions [1]. The guard times between the packets of few tens of nanoseconds are a major concern when considering packet switching at bit rates above 100 Gb/s. This implies that the clock recovery processing has to be functional within that range of time. Current clock recovery functionalities are produced by using phase-locked loop circuitry in which the transmitted data are synchronised to a local oscillator at the receiver end. However, the very high time resolution required for the short duration of the bit time slot results in a locking range in the order of microseconds, which makes this unsuitable for clock recovery functionality in data packet switching. While several compact semiconductor devices have been employed for clock recovery at bit rates beyond 160 Gb/s [2]-[3], packet based clock extraction with a very fast locking/unlocking time has only been demonstrated up to 40 Gb/s by using complex setups including several Mach-Zehnder interferometers along with semiconductor optical amplifiers (SOA) [4] and SOA- based ultra nonlinear interferometer [5]. In this work an experimental study of the switching-on and passive mode-locking times in a quantum-dash (QDash) Fabry-Pérot laser diode is presented. The proposed approach is based on an analysis of the instantaneous frequency of the ~40 GHz signal generated by the laser and measured at the output of a photodiode, after which, following a frequency down-conversion stage, the signal is recorded by a real-time oscilloscope. Experimental results show that the QDash laser diode is passively mode-locked in less than 8 ns after switching on the device. These results indicate that the QDash-PML-LD under investigation is a promising compact device for realizing packet based clock recovery.

2. PASSIVELY MODE-LOCKED QUANTUM-DASH LASER

The device under investigation is a 1-mm long, DC-biased, multimode QDash Fabry-Pérot laser diode [6]. The laser is a single-section device, without phase or saturable absorption sections. From Fig. 1(a), it is possible to observe that this passively mode-locked laser diode (PML-LD) presents a bias threshold current at 18 mA and provides an average power of 4.7 mW when collected by a pigtail-fiber, operating at 350 mA and temperature controlled at 25 ºC. Within the 3 dB optical spectral bandwidth, the QDash-PML-LD features more than 40 longitudinal modes from 1520 nm to 1532 nm, with an intermodal separation of 0.31 nm, corresponding to ~40 GHz free spectral range (FSR). Fig. 1(b), shows the optical power spectrum taken with a resolution of 0.02 nm.

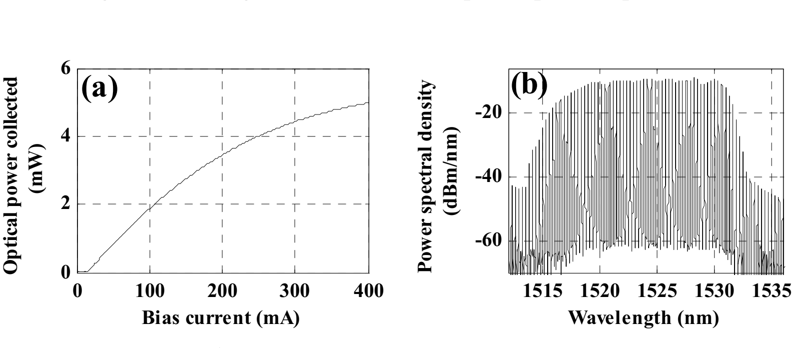

Figure 1: (a) Optical power collected versus bias current; (b) Optical power spectrum of the QDash-PML-LD.

The linewidth of the longitudinal modes have been measured with values between 10 MHz and 50 MHz using a heterodyning technique [7]. Despite being DC-biased, the laser exhibits a passive mode-locking behaviour, featuring a periodic variation of its output emission characterised by a pulse train at ~40 GHz repetition rate with pulse duration of 2.2 ps. Mode-locking in this type of lasers is attributed to the nonlinearities in the semiconductor active region, mainly sustained by four wave mixing processes [6]-[8]. The frequency of the RF beat-tone is determined by the laser FSR, featuring a FWHM of 25 kHz in free running conditions, which is smaller than the optical mode linewidth and demonstrates that the laser is passively mode-locked.

3. EXPERIMENTAL SETUP

The experimental setup to investigate the passive locking/unlocking time when the QDash-PML-LD is switching from the off to on state is depicted in Fig. 2(a). The modulating bias current is provided by a synthesized clock generator set at 40 kHz and duty cycle at 50%, with low and high current levels set at 0 and 100 mA, respectively as displayed in Fig. 2(b). This signal features a rise-time (from 10% to 90%) of ~8 ns. The selected frequency of the clock generator allows an efficient use of the real-time scope in terms of its internal buffer size and sampling rate, whereas it is sufficient to observe the dynamic behaviour of the tested device. Moreover, the selection of the bias current upper level relies on the operating conditions of the PML-LD at which the QDash-PML-LD synchronizes to an externally injected signal [9]-[10]. The optical power emitted from the laser is collected through a lensed fibre and passed through an optical isolator (ISO) to avoid back reflections and the ~40 GHz beat-tone signal is detected on a fast (50 GHz) photo-detector (PD) followed by an RF-amplifier. Taking into account the features of the real-time oscilloscope used in this experiment (10 GHz frequency bandwidth and 40 GS/s sampling rate), the beat-tone signal of interest is frequency down-converted (FDC) to ~1 GHz by using an RF-mixer and a local oscillator (LO) at ~39 GHz.

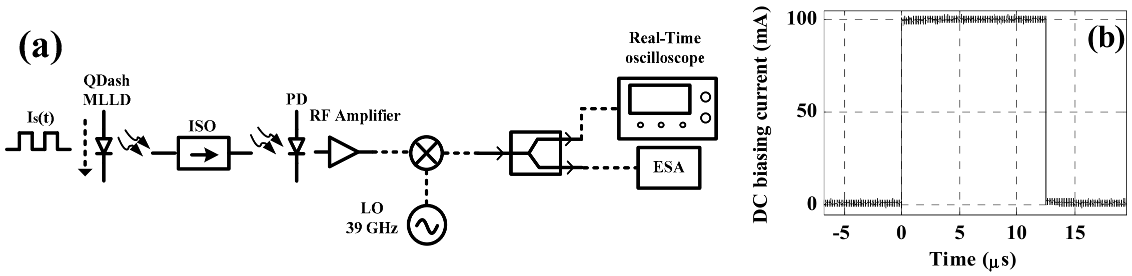

Figure 2: (a) Experimental setup. Continuous (—) and dashed (---) lines denote optical and electrical links, respectively: (b) Modulating bias current of 40 kHz from synthesized clock generator.

4. RESULTS

Firstly, we study the free-running (neither external optical injection nor electrical modulation is applied to the laser) operation of the QDash-PML-LD biased at 100 mA. Fig. 3(a) shows the FDC beat-tone measured with the real-time oscilloscope. A stable frequency component of ~1 GHz is observed in this signal, as depicted in the zoom in trace of Fig. 3(b) and with the help of an electrical spectrum analyzer (ESA), set at a resolution of 30 kHz and a span of 5 MHz, in Fig. 3(c). Moreover, the linewidth of the down-converted signal is ~25 kHz.

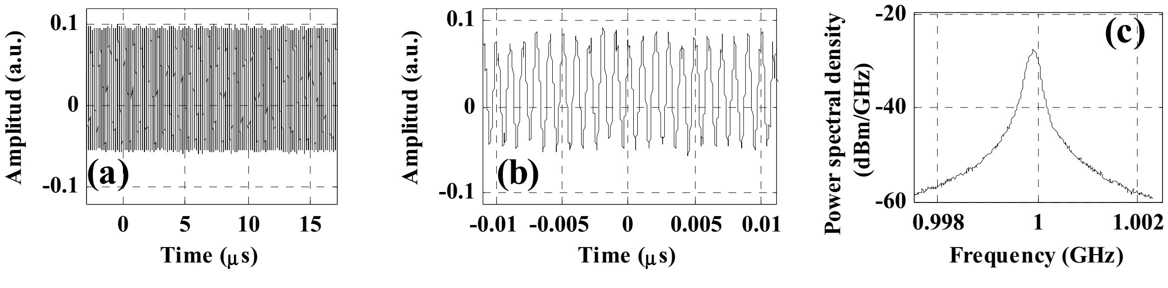

Figure 3. Frequency down-converted beat-tone in constant current conditions. (a)-(b) Measured with real-time oscilloscope. (c) Measured with electrical spectrum analyzer set at a resolution of 30 kHz and span of 5 MHz.

Secondly, the current applied to the QDash-PML-LD is modulated by a clock signal at 40 kHz as showed in Fig. 2(b). The time domain trace of the FDC beat-tone taken with the real-time scope is shown in Fig. 4(a). Analyzing the emitted power of the QDash-PML-LD (visualized in these plots as the envelope of the beat-tone), it does not exhibit an instantaneous response with the current supplied, particularly after the threshold current (Ith) has been reached. By zooming in the trace a switch on time τ_0 of around 30 ns is observed, as showed in Fig. 4(b). This recorded data containing the down-converted beat-tones is analyzed with the implementation of a fast-Fourier-transform (FFT) in time-windows or frames of 10 ns size. The selected window sets a resolution of ~80 MHz for the calculation of the instantaneous frequency of the down-converted beat-tone signal. The instantaneous frequency exhibited by the recorded FDC beat-tones is showed in Figs. 4(c) and 4(d). The red and blue traces represent the frequency of the beat-tone when the QDash-PML-LD is constantly DC biased at 100 mA and with the 40 kHz modulated current, respectively. By maintaining the same frame size and as a consequence the same resolution, the FFT analysis is performed four times within a time span of 60 ns. This approach would allow 6 frames only, but we time shift each frame by 2.5 ns. The first analysis is carried for a time frame [0 ns, 10 ns], the second analysis from [2.5 ns, 12.5 ns], the third [5 ns, 15 ns] and so on and so forth. As a result, we achieved 24 values of the frequency between 0 ns and 60 ns. The results of this analysis show that the frequency of the down converted beat-tones stabilizes to a constant value of ~1 GHz only after a response time τ_1 of ~38 ns. As this is showed in Fig. 4(d).This means that the passive mode-locking process taking place in the QDash-PML-LD occurs ~8 ns after the switch on time. These results obtained with this method of analysis are complementary to the ones obtained in [11], where a single analysis along the recorded data was performed and the information in each frame allowed an uncertainty of at least 10 ns from frame to frame, as demonstrated when the results are compared.

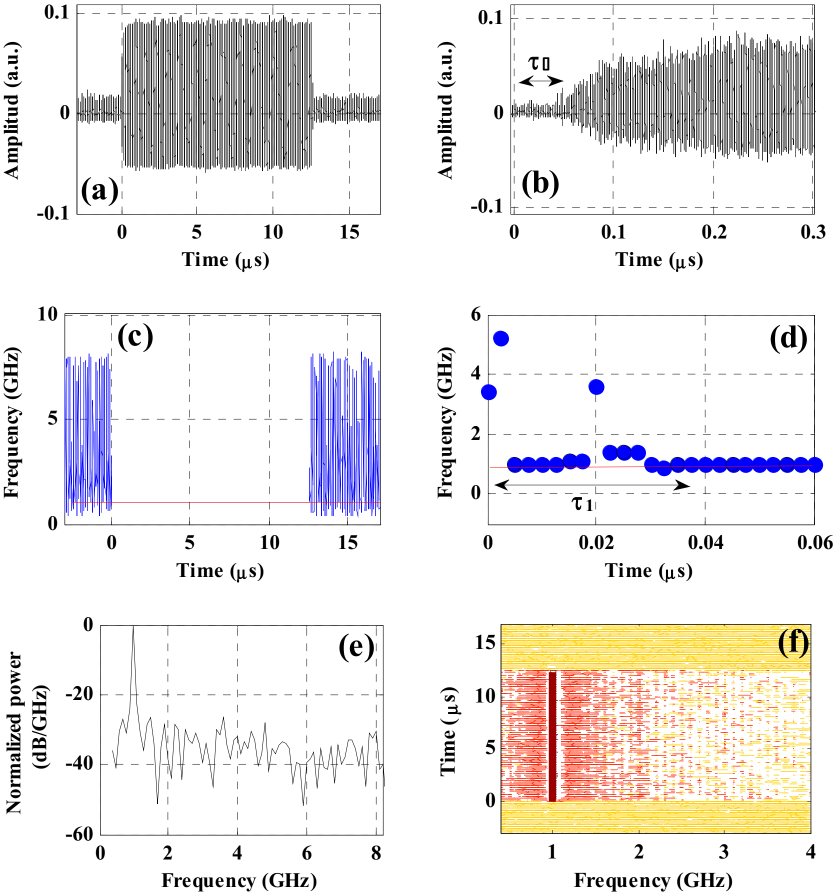

Figure 4. (a)-(b) Time domain of the FDC beat-tone signal after applying the modulating bias current. (c)-(d) Instantaneous frequency of the recorded beat-tone both in constant current (red) and after current modulation (blue). (e) Power spectrum of the one of the 10 ns time-windows analysed with a FFT, when the instantaneous frequency is stabilized at ~1 GHz. (f) Spectrogram of the FDC beat-tone signal analyzed on the entire 20 µs recorded data, the darker the colour areas the more spectral power of the recorded signal.

Moreover, a trace of the frequency power spectrum of one of the frames analysed at a time corresponding from 5.0035 µs to 5.0135 µs in the 20 µs recorded data is displayed in Fig. 4(e), along with a spectrogram (see Fig. 4(f)) corresponding to all the recorded data for all frames considered in the analysis. Both figures corroborate the frequency stabilization at ~1 GHz of the FDC beat-tone signal.

5. CONCLUSIONS

An experimental setup to investigate and to measure the switching-on time and the passive mode-locking time in a QDash-PML laser diode was presented. The analysis of the down converted beat-tone data recorded with the real-time oscilloscope showed that in free running operation, the laser switches on in a time of around 30 ns.

A further analysis based on the instantaneous frequency demonstrated that the frequency of the down converted beat-tones stabilizes to a constant value of ~1 GHz after a response time of 38 ns. This result stands for a net time of 8 ns to reach a stable passive mode-locking condition in the QDash-PML-LD once it is switched on. These results indicate that the QDash PML-LD under investigation is able to operate within a part of an optical packet network where the guard times between the data packets are in the order of few tens of nanoseconds (clock recovery), and also it proves its capability and reliability to be turned off for long periods of time in absence of data traffic and to be turned on again while staying functional, contributing on this manner to save energy in the packet receiver system.

REFERENCES

[1] D.J. Blumenthal: Optical packet switching, in *Proc. ECOC 2004*, Stockholm, Sweden, pp. 830-833.

[2] E. Tangdionga, *et al.*: SOA-based clock recovery and demultiplexing in a lab trial of 640-Gb/s OTDM transmission over 50-km fibre link, in *ECOC 2007, Postdeadline paper, P.D. 1.2*.

[3] V. Roncin, *et al.*: Multidata rate system performance of a 40-GHz all optical clock recovery based on a quantum-dot Fabry-Pérot laser, *Photon. Technol. Lett.,* vol. 19. pp. 1409-1411, Oct. 2007.

[4] D. Petrantonakis, *et al.*: A 40 Gb/s 3R burst-mode receiver with a 4 integrated MZI switches, in *Proc. OFC 2006,* March 2006*. Paper PDP25.*

[5] E. Kehayas, *et al.*: 40 Gb/s all-optical packet clock recovery with ultrafast lock-in time and low inter-packet guardbands, *Opt. Express*, vol. 13.pp. 475-480, Jan. 2005.

[6] S. Latkowski, *et al.*: Sub-picosecond pulse generation by 40 GHz passively mode-locked quantum-dash 1-mm-long Fabry-Pérot laser diode, *Opt. Express.*, vol. 17. pp. 19166-19172, Oct. 2009.

[7] R. Maldonado-Basilio, *et al.*: Timing jitter, optical, and mode-beating linewidths analysis on subpicosecond optical pulses generated by a quantum-dash passively modelocked*, Opt. lett.*, vol. 35. pp. 1184-1186, Apr. 2010.

[8] G.-H. Duan, *et al.*: High performance InP-based quantum dash semiconductor mode-locked lasers for optical communications, *Bell Labs. Technol. J.*, vol. 14. pp. 63-84, Autumn 2009.

[9] R. Maldonado-Basilio, *et al.*: 40 GHz mode-beating with 8 Hz linewidth and 64 fs timing jitter from a synchronized mode-locked quantum-dash laser diode, *Opt. Lett.*, vol. 36. pp. 3142-3144, Aug. 2011.

[10] J. Parra-Cetina, *et al.*: Wavelength tunability of all-optical clock-recovery based on quantum-dash mode-locked laser diode under injection of a 40-Gb/s NRZ data stream, *Photon. Technol. Lett.,* vol. 23. pp. 531-533, May. 2011.

[11] R. Maldonado-Basilio, *et al.*: Mode-locking dynamics in a quantum dash Fabry-Pérot laser diode for packet based clock recovery*,* in *Proc. OFC 2012*, Mar. 2012, paper JTh2A.14.