First demonstration of all-optical clock recovery at 40 GHz with standard-compliant jitter characteristics based on a quantum-dots self-pulsating semiconductor laser

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Abstract We demonstrate for the first time, thanks to a quantum-dots Fabry-Perot laser, the compliance of an all-optical 40 GHz clock recovery with ITU-T standards on time jitter removal for frequencies larger than 4 MHz.

Introduction
Self-pulsating (SP) semiconductor lasers based on bulk or quantum-wells structures have been extensively investigated for all-optical clock recovery. However, little information has been given on the jitter characteristics as compared with ITU-T standard for clock recovery. Nowadays, SP laser diodes based on quantum-dots are attracting great interests as they provide RF oscillators with fast carrier dynamics and also much better spectral purity [1,2]. In this paper, we report phase noise measurements on a 40 GHz clock recovery made on a self-pulsating quantum-dots Fabry-Perot laser. We demonstrate for the first time to our knowledge, that such a quantum-dots (QD) laser enables a high frequency jitter suppression that meets the ITU-T recommendation G825.1 requirements thanks to its intrinsic narrow free running spectral linewidth, as compared with lasers made on bulk or quantum wells.

Component and set-up descriptions
The SP laser under study is a Fabry-Perot (FP) semiconductor laser made of a buried ridge structure with a QD active layer on InP substrate (see [3] for details). The QD-FP laser is 1080 μm-long, has a central lasing wavelength around 1505 nm and self-pulsates around 39.4 GHz with a free running spectral linewidth of 50kHz.

We display in fig.1 the experimental set-up. A pattern generator is synchronized by an external 10GHz clock, the jitter of which is controlled by a white noise generator in the range 10kHz-1GHz, provided by an Eurotest jitter analyzer. It is used to modify the amount of jitter of the incoming data signal. The pattern generator provides a clock signal at 10 GHz and a pseudo random sequence (PRBS) at 10 Gbit/s that drive respectively a gain-switched laser ($\lambda_{\text{lasing}}=1552\text{nm}$) and a LiNbO$_3$ modulator. The modulated signal is then launched into an optical time division multiplexer (OTDM) that delivers the 40Gbit/s signal. We recall that such a multiplexer does not provide a pure PRBS signal. When no PRBS data drive the external modulator, OTDM delivers a clock that will be considered later on as the reference 40GHz clock (ref-ck). A polarisation controller is added due to the polarisation sensitivity of the QD active layer. The recovered clock signal is then amplified and filtered by a 5nm bandwidth optical filter before analysis.

QD-FP laser locking with unjittered OTDM signal
As first evaluation, we analysed the quality of the recovered clock with respect to the PRBS length of the incoming OTDM signal without jitter.

Fig. 2 Eye diagram of the incoming unjittered 2$^{21}$−1 OTDM signal (left) and the recovered clock (right).

We report in fig.2 a temporal trace recorded when using a 2$^{21}$−1 PRBS. As may be seen, we observe a high quality clock signal with high extinction ratio.
Fig. 3 shows PN curves recorded with a PRBS length varying from $2^7$-1 to $2^{31}$-1. As reference curve, the PN curve of ref-ck without jitter is also reported. Spurious spikes appearing on QD-FP laser PN curves for f>50MHz originate from PRBS contributions ($2^7$-1). QD-FP laser PN curves can be split up into 3 regions as described in [1,6]. In the frequency region below 60kHz (A), the noise is dominated by the injected signal and the clock recovery is fully transparent, i.e. there is no jitter filtering effect. Conversely, for f>4MHz (region C), we observe a clear demonstration of a jitter filtering effect with a 1/f² slope (-20 dB/decade); the noise is then determined by the QD-FP laser. The frequency range extending from 60 kHz to 4 MHz (region B) corresponds to the transition region where the noises from the incoming signal and the laser itself contribute both. The calculated rms jitter varies from 0.16 ps (ref-ck) to 0.198 ps (with OTDM $2^{31}$-1). Moreover, there is no difference on the laser PN curves whatever the ODTM PRBS length attesting the quality of the recovered clock.

**QD-FP laser locking with jittered OTDM signal**

The jitter removal can be more clearly demonstrated by injecting jittered signal into the QD-FP laser. Fig 4 gives the eye diagram of the incoming jittered $2^{31}$-1 OTDM signal (left) and the recovered clock (right), showing a drastic decrease of the time jitter.

**Jitter transfer function**

As another clear illustration of the jitter removal, we report for the first time to our knowledge the jitter transfer function (JTF) of an all-optical clock recovery. This curve in decibels is obtained in the presence of added noise by subtracting the PN curve of ref-ck to the QD-FP laser PN curve ($2^{31}$-1) of fig.5. As seen on fig.6, we obtain a very good agreement between the measured JTF and the JTF template expected from ITU-T recommendation G825.21. It is to be noticed that such a JTF can only be achieved with a QD laser thanks to its narrow free running spectral linewidth.

**Conclusions**

We show in this paper an all-optical clock recovery over 40Gbit/s signal based on a quantum dots Fabry-Perot self-pulsating laser. From phase noise measurements, we clearly demonstrate the high frequency jitter removal as expected from a clock recovery. In addition, we present for the first time to our knowledge a jitter transfer function measured on an all-optical device and its very good agreement with the ITU-T recommendation G825.1. Such a result constitutes a new step towards practical applications of SP lasers for all-optical clock recovery.

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**References**