45 GHz self-pulsation with narrow linewidth in quantum dot Fabry-Perot semiconductor lasers at 1.5 μm

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Self-pulsation at 45 GHz repetition frequency has been demonstrated in 1.5 μm monolithic single-section quantum dot Fabry-Perot semiconductor lasers without saturable absorber. The mode-beating exhibits a narrow linewidth below 100 kHz, demonstrating high phase correlation between these modes. Such modelocked lasers open ways to low timing-jitter components for clock recovery or millimetre-wave generation in wireless transmission applications.

Introduction: Modelocked laser diodes (MLLDs) are of great interest for many applications in optical communications, since they allow high bit rate transmission through optical time-division multiplexing [1], the generation of millimetre-wave signals at high frequencies [2], and also all-optical clock recovery at 40 Gbit/s and beyond [3]. Nowadays, MLLDs based on quantum dots (QDs) are attracting great interest since they provide fast carrier dynamics and broad gain spectrum. Passive modelocking (PML) has already been reported at 1.3 μm using GaAs based QDs [4, 5]. However, high frequency PML at 1.5 μm using InP-based materials, already observed on Fabry-Perot type semiconductor lasers with either quantum wells or bulk type active layer [6, 7], has not yet been reported in QD lasers. In this Letter, we report for the first time experimental results on 45 GHz self-pulsation (SP) based on passively modelocked QD semiconductor lasers at 1.5 μm. We also show that the narrow linewidth of an SP signal exhibited by this laser, largely attributed to quantum dot properties, is very promising in terms of timing-jitter reduction for active modelocking (AML) applications.

Device structure and basic characteristics: The studied semiconductor lasers are made of a buried ridge structure, and contain an active layer based on QDs on InP substrate. The QD-based heterostructure was grown by GSMBE on an S-doped (100) InP wafer [8]. The active core consists of six layers of InAs QDs enclosed within 40 nm-thick barriers and two 40 nm-thick separate confinement heterostructure (SCH) layers. Both barriers and SCH are undoped and lattice-matched $Ga_{0.2}In_{0.8}As_{0.4}P_{0.6}$ layers ($\lambda_g = 1.17$ μm). Transmission electron microscopy of the active core has shown that our growth conditions lead to the formation of isotropic QDs. The typical height and diameter of QDs are 2.3 and 20 nm, respectively. The density of dots per QD layer is about 2×10^{10} cm^{-2} [8]. Both facets are cleaved, forming a Fabry-Perot (FP) cavity.

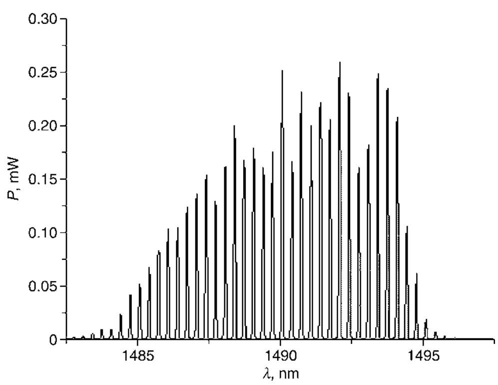

Fig. 1 *Optical spectrum of studied quantum dot Fabry-Perot laser, with spectral resolution 0.07 nm*

The studied FP laser has a cavity length of 950 μm. Fig. 1 shows a typical example of the optical spectrum of such a laser. One can observe that the central lasing wavelength is around 1490 nm. The mode-spacing is around 0.33 nm, corresponding to the 950 μm cavity length. The full width at half maximum is larger than 7 nm, suggesting the capability to obtain pulses with sub-picosecond half-width.

Passive modelocking: PML is investigated in these QD lasers at DC bias conditions. It is to be noted that these single-section lasers do not contain any saturable absorber. Fig. 2 shows an example of the beating spectrum observed at a DC biased current of 160 mA, with the resolution bandwidth of the electrical spectrum analyser (ESA) set to 10 kHz. One can observe an SP frequency close to 45 GHz, which coincides with the mode-spacing previously observed. A nearly Lorentzian lineshape is obtained, exhibiting a carrier-to-noise ratio greater than 30 dB and a 3 dB linewidth as narrow as 70 kHz. Such a narrow linewidth first suggests that the QD FP laser is passively modelocked, as in the case of bulk or quantum wells lasers. It is to be noted that, to the best of our knowledge, such a narrow linewidth has never been achieved with bulk or quantum wells lasers.

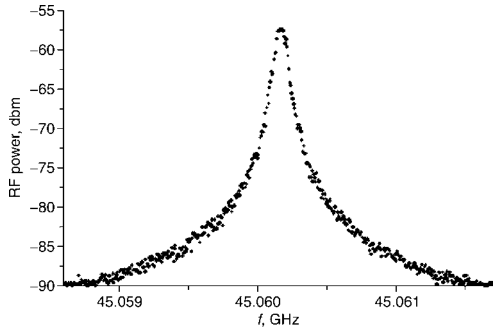

Fig. 2 *Mode-beating spectrum of passively locked FP quantum dot laser observed using high-speed photodiode and ESA*

To verify the PML, a tunable bandpass filter is used to select only one FP mode. Then the mode's spectral linewidth is measured using a self-homodyne technique. The measurement shows that the linewidth of these modes is of the order of 50 MHz. There is thus a very large linewidth reduction, indicating that there is a strong correlation between the phases of these modes [7]. It is believed that the strong phase correlation is due to the enhanced four-wave-mixing in this QD structure, due to the short lifetime of the electrons at the excited state in the conduction band [9].

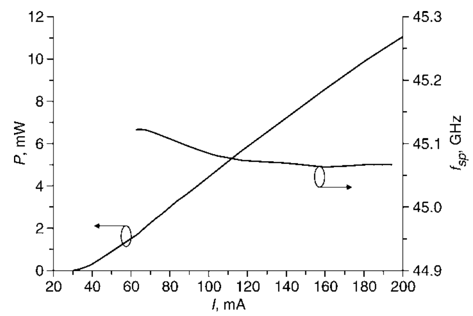

Fig. 3 *Output power and SP frequency evolution against injected current for studied quantum dot Fabry-Perot laser*

The output light against current characteristics of the FP laser were measured under continuous-wave operation at a fixed temperature of 20°C. Fig. 3 shows the evolution of the output power and the SP frequency against injected current by lighting successively a powermeter and a 50 GHz bandwidth photodiode followed by an ESA. One can observe from the output power curve that the threshold current of this laser is 30 mA. On the SP frequency curve, one can first observe that the evolution of the SP frequency is continuous and almost constant over the whole range of injected current. In addition, PML begins at a low injected current of 65 mA, which is only two times the threshold current, showing the early occurrence of nonlinear effects in such a component [10].

Active modelocking with low timing-jitter: AML can be achieved either by injecting an optically intensity modulated signal, or by modulating the injection current. Both types of AML produce RF spectrum with the same characteristics: a narrow central spike corresponding to the spectral noise contribution of the injected signal, and a broader noise band at the base of the central spike corresponding to the spectral noise contribution of the MLLD. The width of the latter contribution, which determines the resulting timing-jitter of the output signal, is related to the spectral linewidth of the free-running MLLD. The broader the free spectral linewidth, the larger the noise contribution.

Fig. 4 shows an example of RF spectrum obtained for optical AML at 45.06 GHz with the studied FP laser. The FP laser is locked with an optical clock signal generated by a frequency synthesiser and a Mach-Zehnder modulator. The measured locking bandwidth is about 1.5 MHz. The RF spectrum shows a sharp peak at 45.06 GHz, with a spectral linewidth determined by the chosen resolution bandwidth (3 kHz), and a carrier-to-noise ratio greater than 40 dB. The noise band at the base of the peak indicates that the laser is not perfectly locked, and is responsible for high-frequency timing-jitter of the output signal. The high-frequency timing-jitter has been evaluated from this RF spectrum, following the method in [11], and assuming a low amplitude noise. The high-frequency timing-jitter is estimated to be as low as 82 fs, indicating that the intrinsic amount of noise due to the free-running MLLD is very small owing to the low spectral linewidth of the QD FP laser.

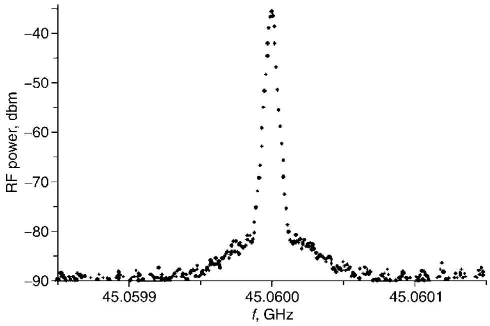

Fig. 4 *Mode-beating spectrum of actively locked FP quantum dot laser observed using high-speed photodiode and ESA*

Conclusions: PML at very high frequency has been demonstrated in 1.5 µm QD FP semiconductor lasers. The narrow linewidth exhibited by such component has never been achieved with bulk or quantum well FP lasers. Such a narrow linewidth enables the achievement of low timing-jitter in actively modelocked lasers. These promising results, largely attributed to QD properties, open ways to design high performance short pulse sources and low timing-jitter components for high-bit-rate optical communications.

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