Active and passive mode-locking in buried ridge mode-locked quantum dots Fabry-Perot semiconductor lasers

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Abstract *Both passive and active mode-locking have been demonstrated in single-section quantum dots Fabry-Perot semiconductor lasers without saturable absorber, generating pulses at 28 GHz repetition frequency with one picosecond pulse width.*

Introduction

Mode-locked sources are of a number of applications in optical communication. In particular, mode-locked lasers generating short pulses allow achieving very high bit rate, for example, 160 Gbit/s, by optical time-division-multiplexing [1]. Passive mode-locked lasers can be used for all-optical clock recovery at 40 Gbit/s and beyond [2]. Mode-locked lasers based on quantum dot (QD) are of particular interest as they provide fast carrier dynamics and broad gain spectrum [3]. However, passive mode-locking, already observed on Fabry-Perot type semiconductor lasers with quantum well or bulk type active layer [2,4-5], has not yet been reported in QD lasers. In this paper, we will report on, for the first time, results on short pulse generation, based on passively mode-locked QD semiconductor lasers at 1.5 µm. We will also show that the active mode-locking can further improve the quality of the generated pulses both in shape and in terms of time jitter

Device structure and basic characteristics

The studied semiconductor lasers are made of a buried ridge structure (BRS), and contain an active layer based on quantum dots on InP substrate. The QD-based heterostructure was grown by GSMBE on an S-doped (100) InP wafer [6]. The active core consists of 6 layers of InAs QDs enclosed within 40nm-thick barriers and two 40nm-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 (λ_g=1.17µm). 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 2.3nm and 20nm, respectively. The density of dots per QD layer is about 2_10^{10} cm^{-2} . Both facets are cleaved, forming a Fabry-Perot (FP) cavity.

The studied FP lasers have a cavity length of 1500 µm, with a lasing threshold of 55 mA. Figure 1 shows a typical example of the optical spectrum of such a laser. One can observe that the central lasing wavelength is around 1500 nm. The mode-spacing is around 0.25 nm, corresponding to the 1500 µm cavity length. The full width at half maximum (FWHM) of the lasing spectrum is measured to be 5 nm.

Passive mode-locking

Passive mode-locking 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. Figure 2 shows the beating spectrum observed at a DC biased current of 105 mA, by lighting a 50 GHz bandwidth photodiode followed by an electrical spectrum analyser (ESA). A nearly lorentzian lineshape is obtained, with a 3 dB linewidth as narrow as 50 kHz. Such a narrow linewidth suggests that the QD FP laser is passively mode-locked, as in the case of bulk or quantum well lasers.

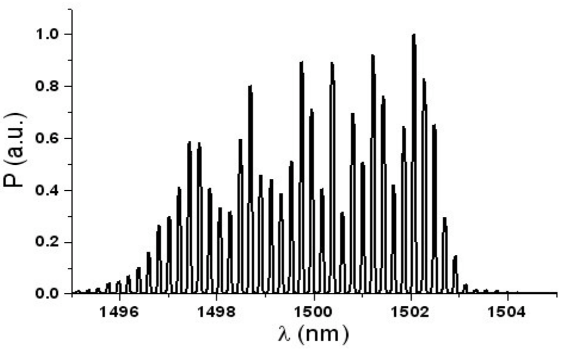


Figure 1 Optical spectrum of the studied quantum dot Fabry-Perot laser

To verify the passive mode-locking, a tunable band pass filter is used to select only one FP mode. Then the mode's spectral linewidth is measured by 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. 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 [7].

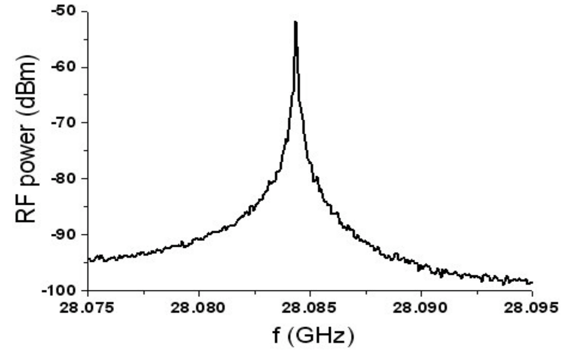
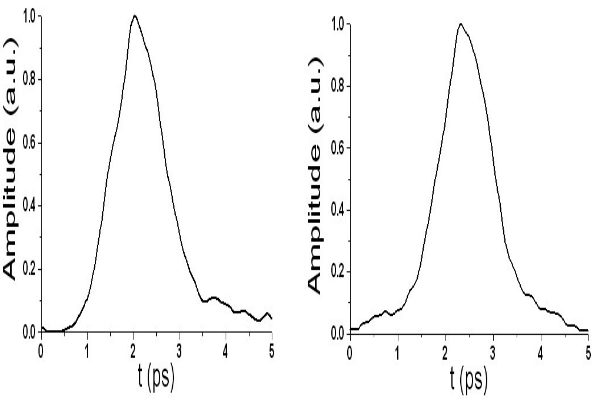


Fig. 2 Mode beating spectrum of the passively locked FP quantum dot laser observed using a high speed photodiode and an ESA.

The pulse shape of the QD FP laser is then measured by using an auto-correlator. Figure 3(a) shows the recorded auto-correlation trace. Asuming a gaussian shape, the deconvoluted pulse width $\Delta\tau$ is estimated to be 1.0 ps. As the spectral linewidth $\Delta\nu$ is 667 GHz ($\Delta\lambda \approx 5$ nm), leading to a product $\Delta\tau.\Delta\nu$ of 0.67. Taking into account the fact that the pulse shape and the envelope of the optical spectrum are not gaussian, such a low value indicates that these pulses are nearly Fourier-transform limited.



(a) (b)

Fig. 3 Measured auto-correlation trace of the QD FP laser, (a) passively mode-locked, (b) actively mode-locked.

Active mode-locking by optical or electrical modulation

Passive mode-loked lasers can generate pulses, but these pulses contain quite large time jitter as the spectral linewidth of mode-beating is still quite large compared to the actively mode-locked lasers. Two types of active mode-locking have been investigated: optical locking by injecting an intensity modulated signal, and electrical locking by modulating the injection current, both at 28.085 GHz. Both types of locking produce similar results in terms of the pulse characteristics. Figure 4 shows the mode beating spectrum of the locked lasers by electrical modulation at 28.085 GHz. One can observe that the spectral linewidth is drastically reduced to a value corresponding to the resolution bandwidth of the ESA. Such a linewidth reduction leads to a much reduced time jitter compared to the purely passively locked case.

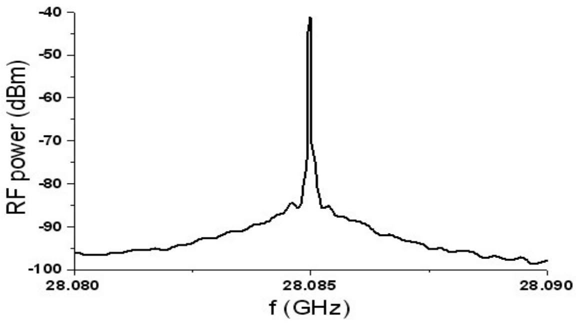


Fig. 4 Mode beating spectrum of the actively locked FP quantum dot laser observed using a high speed photodiode and an ESA.

Figure 3(b) shows the pulse shape of the electrically locked lasers. One can see that the active mode-locking does not change the pulse width, but lead to a more regular pulse shape.

Conclusions

Both passive and active mode-locking have been demonstrated in QD FP semiconductor lasers. Mode-locking produces pulses at 28 GHz repetition frequency with one picosecond pulse width. Active-mode-locking using optical or electrical modulation allows to reduce significantly the phase noise of the beating signal, leading to reduced time jitter. These promising results, largely attributed to quantum dots properties, open ways to design high performance sources for high bit-rate optical communication and for all-optical clock recovery.

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