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Influence of optical feedback on an optical pulse shape of a semiconductor laser

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Abstract. Gain-switched semiconductor lasers can produce pulses with naturally randomized phase, which makes them a convenient light source for quantum key distribution and random number generation. Nevertheless, semiconductor lasers are vulnerable to external optical feedback, a phenomenon, characterized by injection of a certain part of laser radiation into the laser's diode cavity. Although optical feedback may be used to decrease relaxation oscillations and chirp, it may have negative effect on laser pulses. Here, we study the influence of optical feedback on the pulse shape of a gain-switched laser.

Keywords: gain-switched laser, optical feedback, laser pulse interference

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Влияние оптической обратной связи на форму оптических импульсов полупроводникового лазера

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Аннотация. Полупроводниковые лазеры в режиме усиления способны излучать импульсы со случайной относительной фазой, что делает их надежным источником энтропии для квантового распределения ключа и генерации случайности. Тем не менее, полупроводниковые лазеры уязвимы перед влиянием оптической обратной связи – явления, характеризуемого инжекции определенной доли лазерного излучения обратно в полость лазерного диода. Хотя оптическая обратная связь может быть использована для подавления релаксационных колебаний и чирпа, она может иметь серьезный негативный эффект на лазерные импульсы. В этой работе мы изучаем влияние оптической обратной связи на форму импульса лазера в режиме переключения усиления.

Ключевые слова: лазер в режиме переключения усиления, оптическая обратная связь, интерференция лазерных импульсов

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Introduction

External optical feedback (EOF) is known to have positive effect on a pulsed laser, e.g., it can reduce frequency chirp [1] and suppress relaxation oscillations [2], which can be useful in telecommunications. It also finds applications in range and velocity measurements [3]. However, optical feedback often causes certain unwanted effects, e.g. chaos dynamics [4] or increase of turn-on delay jitter [5]. In general, influence of EOF is stronger on lasers operating in continuous mode, meanwhile modulated lasers might avoid being impacted by EOF in case feedback radiation comes into a laser's cavity between modulation pulses [6]. Nevertheless, under certain circumstances, modulated laser pulses can be significantly affected by EOF as well [7]. Thereby, laser modules are often equipped with an optical isolator to prevent unwanted feedback. In this work, we studied the influence of optical feedback on a shape of optical pulses in a gain-switched distributed feedback (DFB) semiconductor laser.

Materials and Methods

The fiber-optic experimental scheme used to demonstrate the effect of optical feedback on a laser signal is shown in Fig. 1. It consisted of a semiconductor 1550 nm DFB laser diode (model SWLD-1554.94-FC/PC-05-PM) controlled by a laser driver based on a Texas Instruments ONET1151L chip, and a ring mirror (a looped beam splitter). The optical variable delay line (VDL) was installed in front of the mirror to control the length of the external cavity.

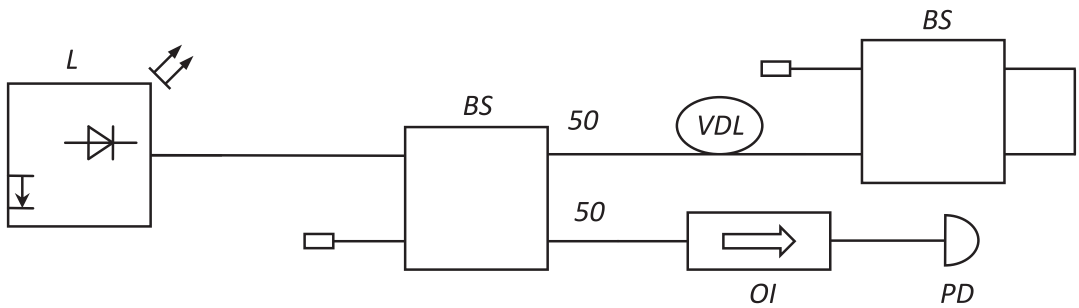

Fig. 1. The experimental scheme. *L* – laser module, *BS* – beam splitter, *OI* – optical isolator, *VDL* variable optical delay line, *PD* – photodetector

The experiment was conducted using a pulse train with pulses of duration 400 ps, pulse repetition rate of 1.25 GHz and average laser output power of 2.7 mW. During the experiment, we varied the delay line to change the length of the external resonator.

Results and Discussion

Figure 2 shows the waveforms of laser pulses at different VDL values. Each waveform in the figure is accompanied by a value of the delay introduced by the VDL in picoseconds modulo the pulse repetition period, where a 0 ps delay would mean that a reflected pulse completely overlaps a generated one. Hence, delay values describe a measure of time shifts of reflected pulses relative to generated ones. One can see that at positive delay values right parts of laser pulses are barely distorted, meanwhile first relaxation peaks are not changed at all. As we move on to the negative values, we can observe well-pronounced suppression of relaxation oscillations.

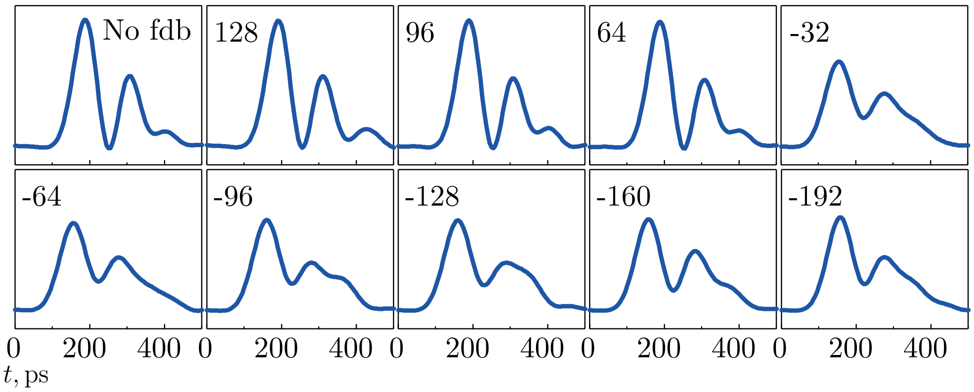

Fig. 2. Experimental laser pulse shapes at various optical feedback delay

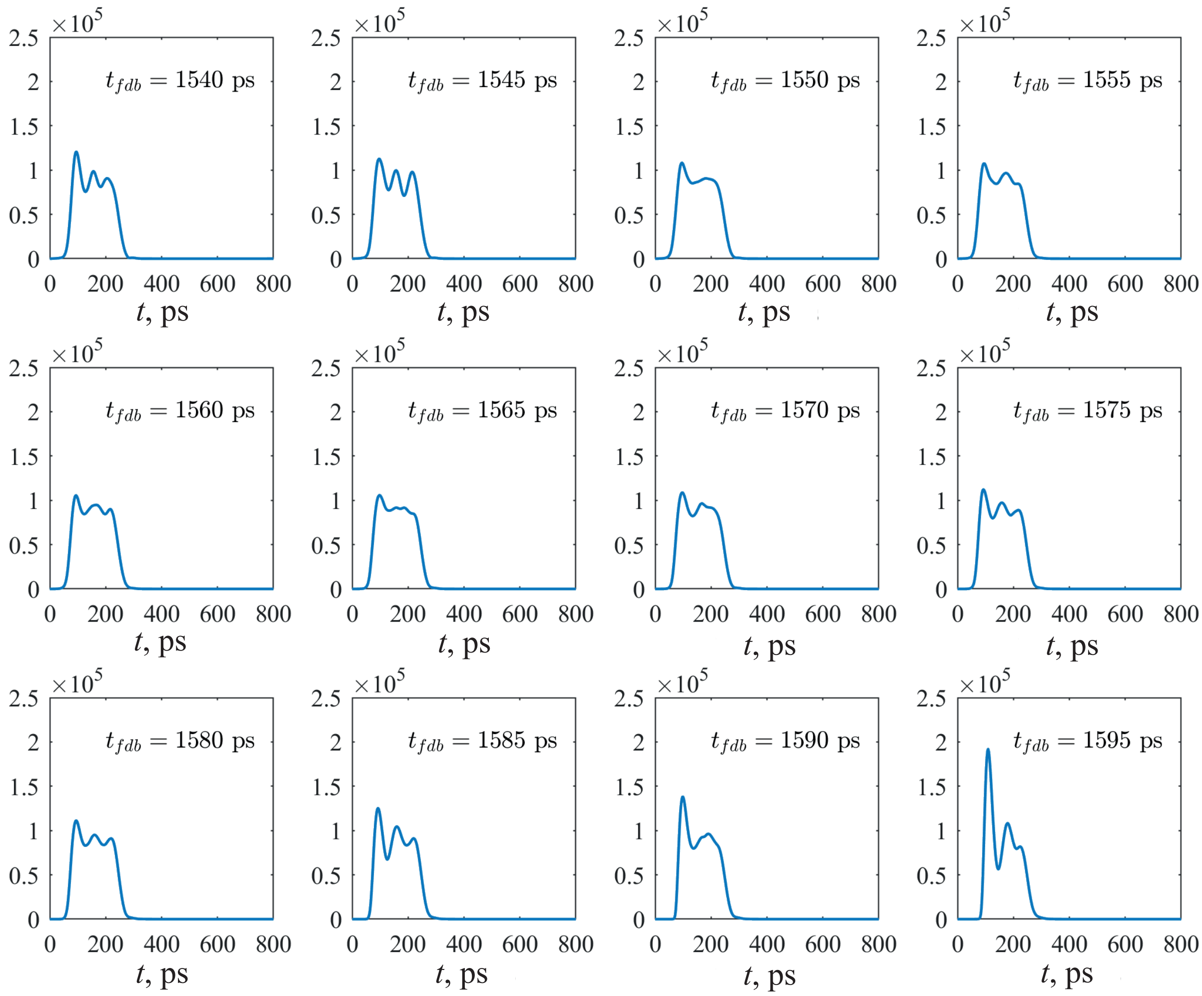

Fig. 3. Simulations of laser pulse shapes at various optical feedback delay

Figure 3 represents the results of computer simulations of a semiconductor laser diode with optical feedback, conducted with the commonly used rate equation model [8]. Simulation parameters are presented in Table. Simulations show that the influence of optical feedback on the waveform of laser pulses strongly depends on the arrival time of the reflected pulse. In particular, suppression of relaxation oscillations is more pronounced when the onset of lasing occurs under the quasi-stationary part of the reflected pulse, i.e. when the reflected pulse returns into the resonator earlier that the new pulse appears.

Table

Simulation parameters

Parameters	Values
Bias current I_b, mA	6.0
Carrier lifetime τ_e, ns	1.0
Pulse width ω, ns	0.4
Central optical frequency ω_0, THz	193.548
Pulse repetition rate f_p, GHz	1.25
Confinement factor Γ	0.12
Threshold carrier number N_{th}	5.5·10e7
Transparency carrier number N_{tr}	4·10e7
Spontaneous emission factor C_{sp}	10e-5
Quantum differential output ϵ	0.3
Henry factor α	5
Feedback coupling factor κ_{fdb}, GHz	5

Conclusion

We performed an experimental and theoretical analysis to study the influence of optical feedback on an optical pulse shape of a gain-switched laser. It was shown that laser radiation reflected into the semiconductor laser diode's cavity may significantly change the pulse waveform at certain delay values, which is presented by our simulations, which are in a good agreement with the experimental results.

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