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GENERATION OF HIGH AMPLITUDES PULSES WITH EXCITABLE DFB LASERS AND AN INTEGRATED DISPERSIVE REFLECTOR

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Abstract. This paper is devoted to investigation of pulse generation by a distributed feedback (DFB) laser with an integrated passive dispersive reflector. This configuration is treated in the framework of the simple rate equation model for dimensionless carrier and photon numbers. The two functions describe the influence of reflector on the laser dynamics. The theoretical results show that under certain condition the laser is operating in excitable regime suitable for pulse generation. We have identified the appropriate values of parameters for pulse generation. We apply small perturbation to the system in order to generate periodic pulses. Finally, the influence of these parameters on shape of pulses is investigated.

Keywords: *DFB laser, passive dispersive reflector, excitability, pulse generation.*

Rezumat. Această lucrare este dedicată investigării generării impulsurilor de către un laser cu feedback distribuit (DFB) cu un reflector dispersiv pasiv integrat. Această configurație este tratată în cadrul unui model de ecuații simple pentru purtători adimensionali și numărul de fotoni. Cele două funcții descriu influența reflectorului asupra dinamicii laserului. Rezultatele teoretice arată că, în anumite condiții, laserul funcționează în regim excitabil adecvat pentru generarea de impulsuri. Am identificat valorile adecvate ale parametrilor pentru generarea impulsurilor. Aplicăm mici perturbări sistemului pentru a genera impulsuri periodice. În final, este investigată influența acestor parametri asupra formei impulsurilor.

Cuvinte cheie: *laser DFB; reflector dispersiv pasiv; excitabilitate; generarea impulsului.*

Introduction

Over the last years it was observed an increased interest in excitable optoelectronic devices and in particular for excitable semiconductor lasers [1]. Excitability has been investigated both theoretically and experimentally. This can be defined as a dynamic property of the system underlying the responses. When a system is in rest state, it can admit two different responses to a perturbation. These two responses will depend on the size of the perturbations compared to a given threshold. In the first case, the perturbation is smaller than a given threshold. In this situation the system generates a linear response that is proportional to the perturbation and is of small amplitude. For an external perturbation greater than that of threshold, the system's answer will be an excitable spike. The amplitude of response (spike) is independent of any other attributes of the perturbation. We mention that after the response, in both cases, the system returns to its initial rest state.

The interest in excitable systems comes to photonics from chemistry and biology, with a variety of applications such as reaction-diffusion systems, cardiac tissue, and neural modeling [2]. Excitability is also of interest for optical systems. Some specific laser systems were shown to be excitable: a semiconductor laser with optical feedback [3 - 6], with injected signals [7 - 9]. In [5], the authors reported experimental evidence of coherence resonance in an optical system. It was shown that when the noise is adding in a laser diode with optical feedback the regularity of the excitable pulses increases up to an optimal value of the noise strength. One can observe that both phase and amplitude fluctuations of the pulses are very important for the dynamics of the system. For generalize the indicator of coherence it was introduced the common entropy of the two variables mentioned above and it was shown the mechanism of destruction of the excitable orbit after the resonance.

In [8] the dynamics of a quantum dot semiconductor laser operating under optical injection was experimentally analyze. Following the experiment, the appearance of single- and double-pulse excitability at one boundary of the locking region it was observed. In [9] the authors analyzed the response of an injection-locked semiconductor laser to different external perturbations. They demonstrated the existence of a perturbation threshold beyond which the response of the system is independent of the strength of the stimulation and, thus, demonstrated its excitable character. It was shown that optically perturbing such an excitable system via the control of the phase of the injection beam can be useful for optical pulse generation. Also, excitability was demonstrated in a Q-switched fiber ring laser with graphene as a saturable absorber [10]. In [11] with the aim to show the system's response to external perturbation, the authors presented excitability in an all-fiber laser with a saturable absorber section. They perturbed the laser system with a secondary pump diode that generates pulses of varying amplitude and fixed pulse width. In this way, the presence or absence of a system response was shown to verify the excitability. It was observed a monotonous increase of the response rate from 0 to 1 over a well-defined range of perturbation amplitudes which is caused by the presence of the noise in the experience.
Furthermore, the authors showed a characteristic decrease in the delay of the response of the fiber laser as a function of the amplitude of the triggering perturbation pulse.

This paper is concerned with investigations of generation of pulses in an excitable DFB lasers with passive dispersive reflector. In Section II Laser structure and equations, we introduce the setup, and an appropriate model to describe it. Section III Results and discussions presents a study of pulse generation. Finally, conclusions are given at the end.

Laser structure and equations

A sketch of the investigated structure of DFB lasers and an additional passive dispersive reflector is shown in Figure 1. The pump current is applied to the active region. The small phase current is just for the control of phase. The active and passive sections are integrated together in a compound chip. The reflection between sections is considered to be very small. It is well known that similar devices are used for generation of high frequency single mode self-pulsations [12]. A single mode approximation was proposed in [13 - 16], and used to discuss the self-pulsating behavior and excitability. Here we concentrate our attention to generation of pulses when laser is operating in excitable mode.
We start our analysis based on the rate equations [14].

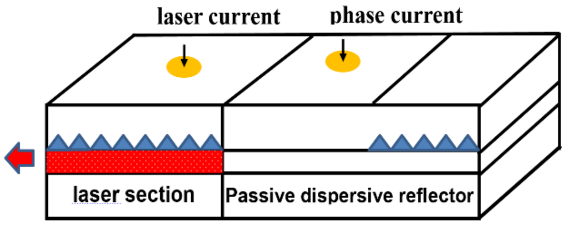

Figure 1. The DFB laser with additional passive dispersive reflector. The main injected current is applied to the laser section. The control current is applied to phase section for variation of detuning n_0.

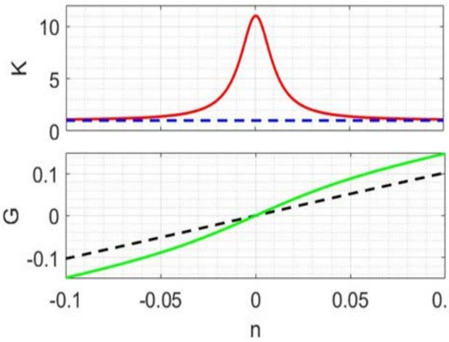

Figure 2. The dependences *K* and *G* on *n* from equations (3) and (4) for the following parameters: $A = 10$, $W = 0.02$, $n_0 = 0.0005$, $\alpha = 0.05$ and $\Delta n = 0.05$.

$$\frac{dn}{dt} = J - n - (1+n)K(n)p + n_{perturb}, \tag{1}$$

$$\frac{dp}{dt} = TG(n)p, \tag{2}$$

where *n* and *p* are the dimensionless carrier and photon numbers, respectively. τ is the dimensionless time. The parameter *J* is the relative excess injection rate ($1 < J < 10$). The ratio between the carrier and photon lifetimes is denoted by *T*. The functions *K(n)* and *G(n)* in equations (1)-(2) describe the influence of reflector on the laser dynamics approximated by [14].

$$K(n) = K_0 + \frac{AW^2}{4(n-n_0)^2 + W^2}, \tag{3}$$

$$G(n) = n + \alpha \cdot \Delta n \cdot \tanh\left(\frac{n}{\Delta n}\right), \tag{4}$$

where *A*, *W*, K_0, n_0 are constants. n_0 is the detuning between the resonance peak of *K(n)* and the threshold density $n = 0$. This detuning can be controlled in the real devices by tuning the phase current (see Figure 1).

The rate equations (1)-(4) have two stationary solutions, corresponding to laser “off” and “on”. We are not interested in laser state “off” but in the laser “on”.

$$n = 0 \quad \text{and} \quad p = \frac{J}{K(0)}. \tag{5}$$

This state has sense only for $J > 0$. Thus, we consider $J = 2$. When varying the detuning n_0, while keeping all other parameters fixed, the resonance structure of *K* causes a dip of the photon number *p*. However, within a certain range on the low n_0 side of this dip, the phenomena of excitability can be observed [12]. The unstable i.e. self-pulsating region that appears in the system is described into details in [14]. We mention that for fixed set of parameters $A = 10$, $W = 0.02$, $n_0 = 0.0005$, $\alpha = 0.05$ and $\Delta n = 0.05$ the lasers is operating in the excitable regime.

Results and discussions

The generation of pulses in our case is related to excitable properties of laser shown in Figure 1. In this section, we discuss the behavior of laser when a perturbation is applied to the system. The applied perturbation is done as follows. At time $t = 0$ we allow to the system to reach the steady state.

Subsequently, over time, i.e. delay time 0.5 ns, we act with a small pulse on the system. The duration of the action is 0.05 ns. After this time the amplitude of the injected pulse returns to zero. We analyze the evolution of the system over time (for example see red line in Figure 3a). We notice that the amplitude of the system rises suddenly and then it decreases. For some values of parameter *T* the amplitude decreases with the presence of a delay time, named refractory time, and for other values of the parameter *T* we notice that the decrease is similar to the increase.

Let us analyze the influence of parameter *T* (ratio between the carrier and photon lifetimes) on the generation of pulses by PDRL. The parameter *T* determine the slow –fast nature of our model. Figure 3a shows the evolution in time of photon number for different values of *T* and set of parameters as in Figure 2. The perturbation amplitude is above threshold 0.5. From this figure we distinguish the slow-fast nature of the system for small *T*. Thus, for *T* = 100 the output photon number *P* increases and then forming a long (slow) excursion in the phase space return back to the stationary state (see Figure 3b-black line). For large *T* the long excursion in the phase plane disappears. The amplitude of output photon number is smaller and the pulse are practically symmetric. Thus one can conclude that for a ratio between the carrier and photon lifetimes of 500 the shape of generated pulses will be symmetric and the amplitude sufficient large to be use in different applications. In what follows, we vary the perturbation of injected pulse and look for the laser output. Figure 4 shows maximum of output number *P* in dependence of amplitude of perturbation.

As long as the amplitude is small, the response of the laser system is negligible. For amplitude of 0.21 a jump of the response of

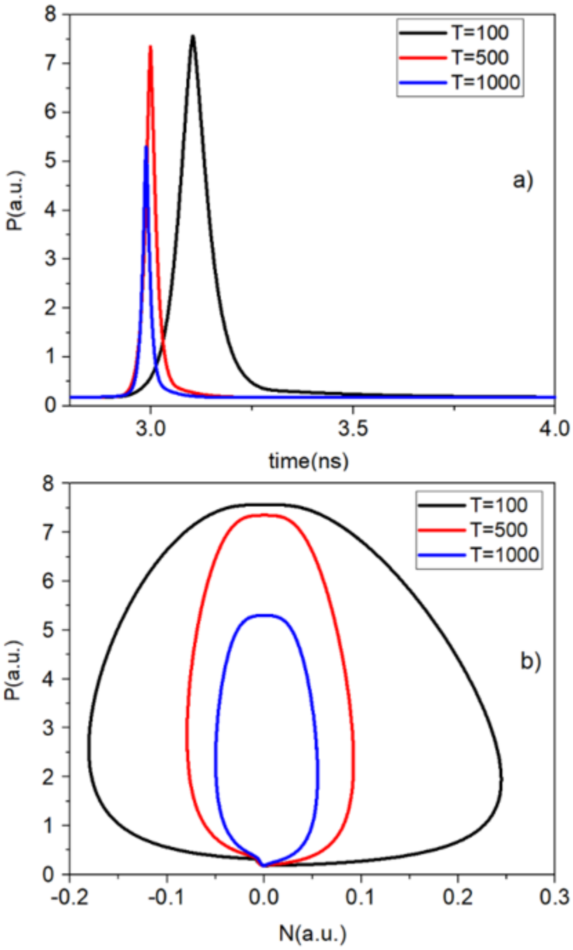

Figure 3. a) The evolution in time of photon number *P* for different values of parameter *T*. b) The phase portraits in the plane *(P-n)*. The parameters are the same as in Figure 2.

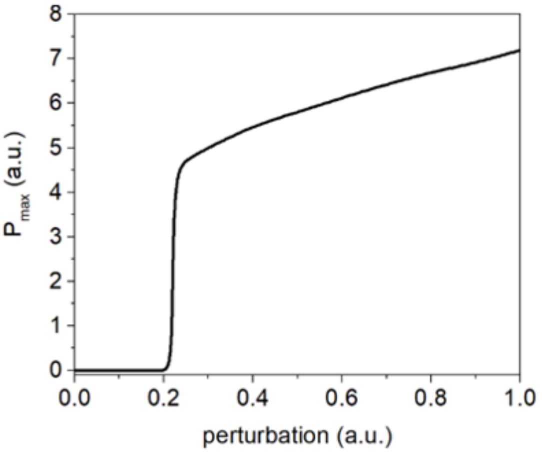

Figure 4. The dependence of maximum of output photon number on the applied perturbation. The parameter *T* = 500. Other parameters are as in Figure 2.

the system is observed. This is a requirement of phenomena of excitability, where the threshold has to be present. When the amplitude is increased the $P_{\max}$ is slightly increased.

Figure 5 shows the generation of pulses by PDRL under the influence of train of perturbation with different amplitudes. The supplied current pulses with 0.05 ps pulse width

have the 0.05 delay time between them. For low amplitude of perturbation the response of laser is very small and close to the stationary state (red line in Figure 5).

On the other hand, for an increase of perturbation amplitude to 0.5 the train of pulses is generated by system (see Figure 5b). The output is almost periodic.

Figure 6 shows the evolution of photon number on the influence of sequences of pulses for different delay time between pulses. The response for in Figure 6a is seldom and more complicated for Figure 6b.

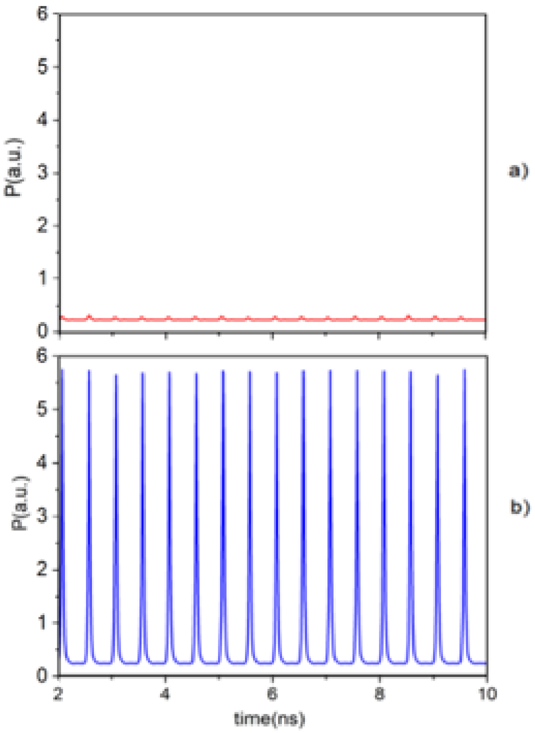

Figure 5. The dependence of photon number on time for different applied perturbation. Amplitude = 0.2, Width = 0.05, Delay = 0.5 ns, red line, b) Amplitude = 0.5, Width = 0.05, Delay = 0.5 ns, blue line.

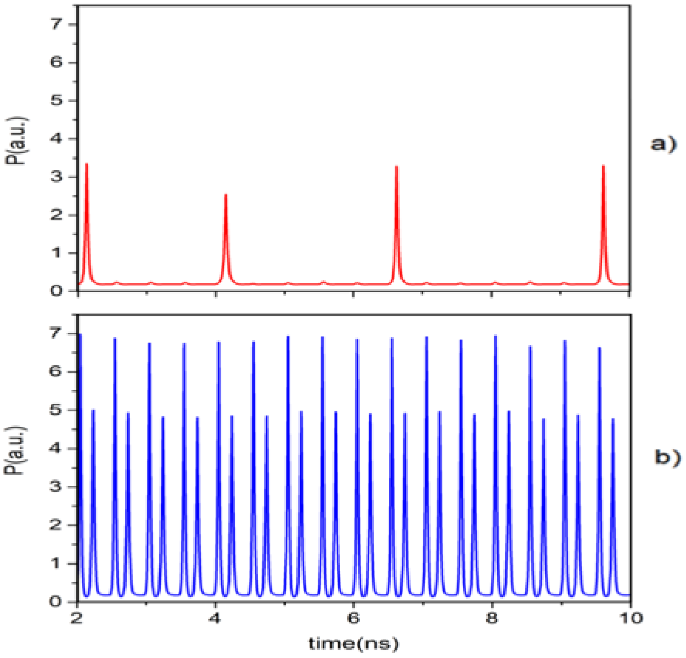

Figure 6. The same as in Figure 5 for: a) Amplitude = 0.22, Width = 0.05, Delay = 0.5 ns, red line, b) Amplitudine = 1, Width = 0.05, Delay = 0.25 ns, blue line.

Thus, for small delay between perturbations the output pulses are deformed and not suitable for applications.

Conclusions

We have carried out investigations on pulse generation by an excitable DFB laser with incorporated passive dispersive reflector. In the fremework of rare equation model, first we looked for set of parameters when the system is operating in excitable regime. Under the excitable regime we injected into the system a small perturbation and analyze the response. In particular, we got the symmetric pulse generated. The increase of ratio between the carrier and photon lifetimes reduces the amplitude of pulses. We also injected into system the sequence of perturbations and look for the response. We found that under small perturbations no response was observed. On the other hand, when perturbation is increased the periodic response was observed. The delay time between perturbations influences the response of system by losing the periodicity. We believe that the results presented in this paper suggest that the proposed design is promising for the pulse generation.

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