Influence of parameter mismatch on synchronization of quantum dots lasers

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Abstract **— In this paper, we show the numerical results on the dynamical behavior of semiconductor laser with quantum dots active medium under the influence of multiple feedback. The dynamic behavior is studied in terms of the Bloch equation model. We find the optimal conditions for chaotic operation. The synchronization of two unidirectional-coupled (master–slave) systems and the influence of parameters mismatch on the synchronization quality are also studied.**

Index Terms **— quantum dots lasers, chaos, synchronization.**

I. INTRODUCTION

During recent years, the synchronization of chaotic oscillators has been the subject of different studies due to the applications in the chaos-based communications systems [1], [2]. Semiconductor lasers subject to the influence of optical feedback is characterized by different dynamical behaviors as periodic and quasi-periodic pulsations, low frequency fluctuations and coherent collapse (for more details, see [3]). Typically, to achieve chaotic behavior of lasers with feedback a delay roundtrip time of at least few hundreds of picoseconds is needed. On the other hand, lasers with multi section external cavities could be suitable candidates for integrated chaotic emitters. Here we have a laser with quantum dots active medium and a different configuration of feedback from an integrated multi section external cavity. Lasers subject to feedback from cavities with air gaps have been considered in the literature [4], [5]. In particular, feedback from a two phases sections have been used to control the chaotic dynamics of semiconductor lasers with optical feedback.

The dynamics of the system of quantum dots laser with feedback proposed in this paper can be described by Bloch equation model [6]. Thus, in this paper we analyze the synchronization properties of two quantum dots lasers with multi section feedback coupled unidirectionally. The influence of parameters mismatch on the synchronization quality is also studied.

II. MODEL AND EQUATIONS

In this article, we consider a semiconductor laser with quantum dots active medium subject to feedback from an external multi sections cavity with the aim of generating a complex chaotic waveform suitable for applications in chaos-based communications. The scheme of the system is depicted in Fig. 1.

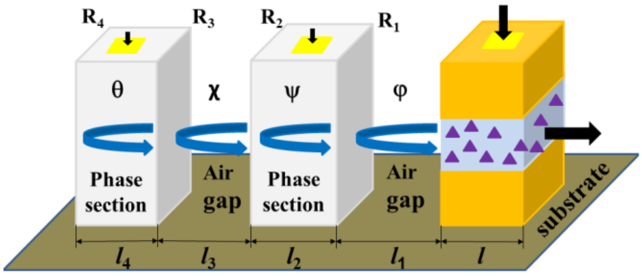

Fig. 1. Laser with quantum dots under the influence of multi cavity external optical feedback. $l_1 = l_2 = l_3 = l_4 = 2$ cm.

The dynamical behavior of the system is described with Bloch equations [6]:

$$\frac{dE}{d\tau} = -kE + 2Z^{QD}\Gamma gP + \frac{Z^{QD}\Gamma\beta}{\tau_{eff}E}\left(\frac{D+1}{2}\right)^2 + \\ +\Gamma_1 e^{-i\varphi}E(\tau-\tau_1) + \Gamma_2 e^{-i\psi}E(\tau-\tau_2) + \\ +\Gamma_3 e^{-i\chi}E(\tau-\tau_3) + \Gamma_4 e^{-i\theta}E(\tau-\tau_4), \quad (1)$$

$$\frac{dP}{d\tau} = -\gamma P + gDE, \quad (2)$$

$$\frac{dD}{d\tau} = -4gEP + \frac{d_0 - D}{T_1} - \frac{1}{\tau_{eff}}\left(\frac{D+1}{2}\right)^2, \quad (3)$$

where E is the complex amplitude of the electric field, P is the polarization, and D is the inversion. k is the photon decay rate. g and β represent the coupling and spontaneous emission factors. Z^{QD} is the number of quantum dots in the active region of laser. Γ represents the confinement factor that characterizes the fraction of the quantum dots within the mode volume, which are contributing to the laser emission. T_1 and d_0 are the inversion lifetime and pump strength.

III. RESULTS

It is well known that the synchronization of two lasers can be quantified by measuring the cross-correlation coefficient, and its quality depends on the similarity between master and slave lasers. In this paper, we focus on the influence of the mismatch on the two feedback phases of air gaps that are not easy to control in experiment. Figure 2 shows the dependence of the cross-correlation coefficient on the phase difference (phase master − phase slave) for feedback strengths $\Gamma_1 = \Gamma_2 =$

$= \Gamma_3 = \Gamma_4 = 20$ ns^{-1} and coupling strengths $k = 20$ ns^{-1}. The black line shows the degradation of the synchronization due to a mismatch in the air gap phase φ.

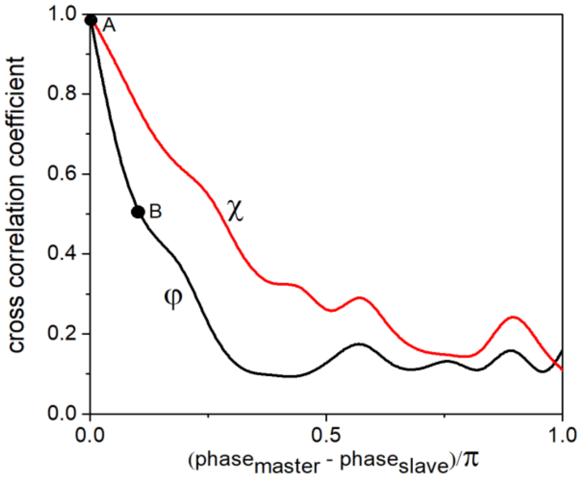

Fig. 2. The cross-correlation coefficient as a function of the feedback phase difference (phase master − phase slave) for coupling $k = 20$ ns^{-1}. Parameter: $\varphi_s = 0$, $\psi_m = \psi_s = \pi/5$, $\chi_m = \chi_s = \pi/6$, $\theta_m = \theta_s = \pi/4$.

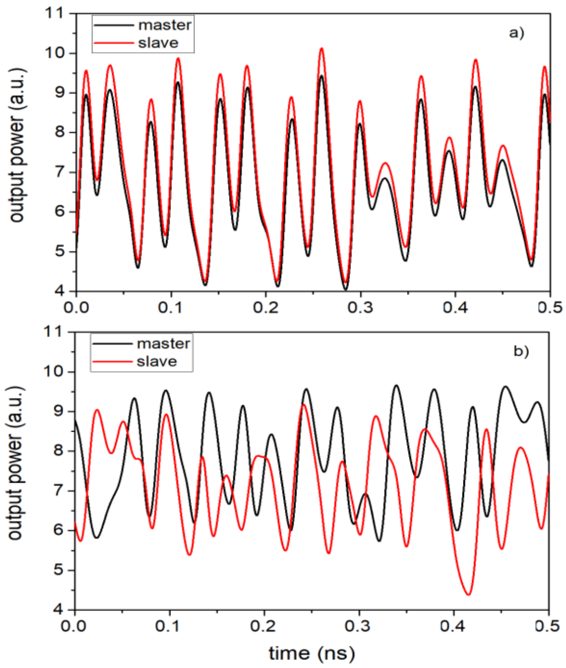

Fig. 3. Pulse traces of output power for coupling parameter $k = 20$ ns^{-1}. Other parameters: $\Gamma_1 = \Gamma_2 = \Gamma_3 = \Gamma_4 = 20$ ns^{-1}.

The phase $\varphi_s = 0$ while φ_m is varied from 0 to π. The red line shows the effect of a mismatch in the air cavity feedback phase χ. We consider $\chi_s = 0$ while χ_m is varied from 0 to π. When the feedback phases coincide, the system shows perfect synchronization with a cross-correlation coefficient approaching unity. An increase of the mismatch in any of the feedback phases induces degradation of the synchronization, which is indicated by a reduction of the cross-correlation coefficient. As the mismatch is increased, the degradation is clearly more severe in the case of mismatch in the feedback phase of the air cavity φ that is located near to the active region.

Figure 3a) shows the optical power time trace of master and slave laser under the influence of external optical feedback for point A of Fig. 2, when the synchronization is perfect and cross-correlation coefficient $C = 0.995$. Fig. 3b) shows the same pulse traces for point B of Fig. 2 when the cross-correlation coefficient is $C = 0.5$. In this case, one can observe that the process of synchronization is sometimes observable.

IV. Conclusions

We have studied the synchronization of quantum dots lasers under the influence of multi section optical feedback. Such a feedback implies a more complex behavior for compact devices. We have shown that two of these devices can be synchronized when operating in the chaotic regime in a master–slave configuration. However, synchronization is degraded when there is a mismatch in the phases of air gap sections of the master and slave systems. A mismatch in the first air gap feedback phase turns out to have stronger effects in the master–slave cross-correlation than a mismatch in the second air gap phase.

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