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# Quantum dots lasers dynamics under the influence of double cavity external feedback

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ABSTRACT

This paper reports results on investigations of the dynamical behavior of a semiconductor laser with quantum dots active medium under the influence of a feedback from double external cavity. This configuration is treated in the framework of Lang-Kobayashi equations. The locus of external cavity modes is found to be elliptic, as in case of conventional optical feedback, but also represents different shapes, even with possible satellite bubbles. A bifurcation analysis is carried out revealing the points of saddle-node and Hopf bifurcations. Finally, the nature of bifurcations and the stability of steady state solutions are analyzed in dependence on different parameters.

## 1. Introduction

During recent years, the phenomena of control and stabilization, as well as the destabilization and chaos of laser emission by external cavities have received considerable attention due to its fundamental and applied interests. The main aim of technological progress is the production of structures with stable properties and the possibility of their application in different areas.

Stabilization of laser emission by external cavities has a long history [1–5] and is still of continuous interest [6–10]. Another well-known method of control is due to Pyragas [11] applied successfully to different systems [12–14]. The control of a laser subject to conventional optical feedback was studied in [15] where it was shown that by using a second branch and properly adjusting the feedback delays and strengths complex dynamical regimes can be stabilized. These control techniques found certain applications in information transmission systems.

On the other hand, different dynamical behaviors have been obtained for lasers under the influence of feedback from external cavities, including periodic and quasi-periodic pulsations, low frequency fluctuations, coherent collapse, optical turbulence, chaos (for more details, see [16]). The chaotic waveform is suitable for chaos-based communications. Recently, chaotic communications have become an option to improve privacy and security in date transmission, especially after the recent field demonstration of the metropolitan fiber networks of Athens [17]. In optical chaos-based communications, the chaotic waveform is generated by using semiconductor lasers with either all-optical or electro-optical feedback loops [18,19]. In particular, synchronized chaotic waveforms have found applications in chaos based communication systems.

Due to the continuing technological progress, lasers with active medium quantum dots have reach stable operation. Lasers with active medium quantum dots are compact and good candidacy for both applications: stabilization of laser emission and for chaos-based communications. Arakawa [20] predicted that semiconductor lasers with active medium quantum dots have small temperature dependence performance than the existing semiconductor lasers, and that they will not degrade at the high temperature. Other advantages of lasers with quantum dots active medium include the reduction of the threshold current and increase of the amplification coefficient [21]. In recent years, their dynamics has become the object of study and theoretical researches are necessary for the development and extension of the theory of nonlinear dynamics in semiconductor lasers with quantum dots active medium. Here we consider a configuration which includes feedback from an integrated double cavity. The paper is organized as follows. The device structure and mathematical model are described in Section 2. Section 3 is devoted to the analysis of stationary states. A detailed study of the dynamical properties of quantum dots lasers under the influence of double cavity feedback are discussed in Section 4. Finally, conclusions are drawn in Section 5.

## 2. Model and equations

In this paper, we focus on the investigation of the dynamical behavior of semiconductor lasers with quantum dots active

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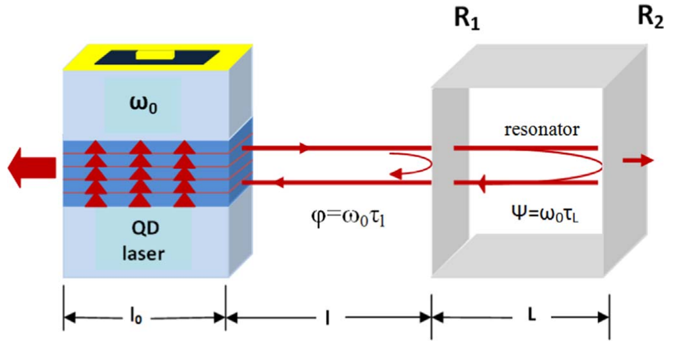

**Fig. 1.** Laser setup. $l_0$ is the length of the laser, $l$ is the distance between back facet of laser and the first mirror of resonator. $L$ is the distance between first and second mirrors, $\omega_0$ is free running frequency of laser, $\varphi$ is the feedback phase of the air gap, and $\psi$ is the phase within the resonator. $\tau_l$ and $\tau_L$ are external cavities round trip times.

medium shown in Fig. 1. The setup consists of laser operating under the influence of an external optical feedback from double cavity. The first mirror is located at distance $l$ from the laser front facet. The distance between first and second mirrors is $L$. The phase $\varphi$ in the air gap can be changed by a piezo-element. The optical feedback phase $\psi$ in the second cavity can be controlled by injecting current into the passive section. We assume that the current injected into passive section is small enough to affect only the refractive index, so that the optical length of the resonator is changed in the sub-wavelength range. On the other hand, the feedback phase $\varphi$ can be tuned, by the change in the delay time between the two mirrors.

For modeling of the dynamics of quantum dots laser under the influence of double optical feedback we use the following equations [22,23] for dimension less quantities

$$\frac{dE}{d\tau} = \frac{1}{2}(1 + i\alpha)\Big[-\gamma_{np} + g(2\rho - 1)\Big]E + \Gamma_1 e^{-i\varphi}E(\tau - \tau_l) + \Gamma_2 e^{-i(\varphi+\psi)}E(\tau - (\tau_l + \tau_L)), \qquad (1)$$

$$\frac{d\rho}{d\tau} = -\gamma_{ns}\rho - (2\rho - 1)|E|^2 + (CN^2 + BN)(1 - \rho), \qquad (2)$$

$$\frac{dN}{d\tau} = J - N - 2\Big[(CN^2 + BN)(1 - \rho)\Big], \qquad (3)$$

where $E$ is the complex amplitude of the electric field, $N$ is the carrier density in the quantum well, and $\rho$ is the occupation probability in the quantum dot. $\tau_l$=0.05, $\tau_L$=0.2 are external cavity round trip times which correspond to $l$=7.5 mm, and $L$=1 cm, respectively. $g$=1200 is the differential gain, and $J$=20 is pumping parameter. The constants $B$=0.012 and $C$=40 describe the transport of charge carriers through carrier–phonon interaction. $\alpha$=2 is the line width enhancement factor, $\gamma_{ns}$=1.0, and $\gamma_{np}$=500. These parameter values are used for the calculated results that are shown in all figures of the paper. The parameters $\Gamma$ and $\tau$ describe the feedback connection and the delay time, respectively. $\Gamma_1$ and $\Gamma_2$ represent the feedback levels governed the mirror reflectivity $R_1$ and $R_2$, respectively. We assume that both facets of the material cavity can be coated to change their reflectivity. The feedback phase $\varphi$ can be tuned by a small current or be controlled with a piezo actuator. Thus, the feedback strengths $\Gamma_1$ and $\Gamma_2$, as well as, the airgap phase $\varphi$ are the main parameters to be varied.

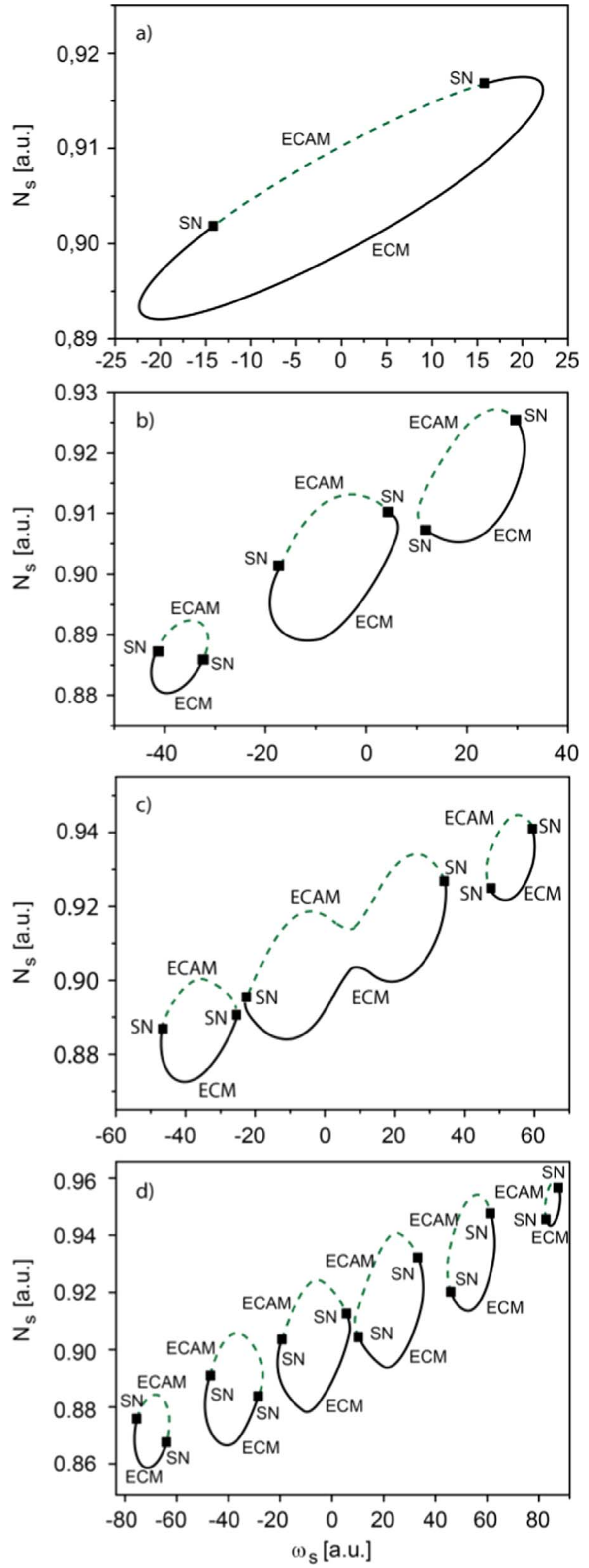

**Fig. 2.** Location of ECMs in the plane of ($N_s - \omega_s$) for fixed external resonator phase $\psi=\pi/2$, and different feedback strengths (a) $\Gamma_1=10$, $\Gamma_2=0$ (COF), (b) $\Gamma_1=10$, $\Gamma_2=10$, (c) $\Gamma_1=10$, $\Gamma_2=20$, (d) $\Gamma_1=20$, $\Gamma_2=20$. ECAM, external cavity antimodes (dashed green line). SN, saddle-node bifurcation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

## 3. Stationary states

We begin our analysis by considering the stationary lasing