Investigations of external cavity diode lasers: simulations, analysis and experiments

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***Abstract* - We report the results of numerical and experimental investigations of the dynamics in an external cavity diode laser device composed of a semiconductor laser and a distant Bragg grating, which provides an optical feedback. The traveling wave model was used to simulate and analyze the nonlinear dynamics of the considered laser device. Finally, it is shown, that the simulation results are in good agreement with experiments.**

I. INTRODUCTION

During recent years the control and stabilization of laser emission of semiconductor laser (SL) by an external cavity has received considerable attention. In particular, wavelength stabilized SL are required for different applications such as frequency conversion, quantum-optical accurate experiments in space, space communications, spectroscopy etc. It is well known, that the integration of a Bragg grating into a laser chip leads to the stabilization of the lasing wavelength. Recently, a novel micro-integration approach was used to build a compact, narrow linewidth External Cavity Diode Laser (ECDL) with a volume holographic Bragg grating [1]. The laser module is ideally suited for quantum-optical precise experiments in space.

Semiconductor lasers subject to the delayed optical feedback from a distant mirror have been investigated extensively during the past two decades. Different dynamical regimes, including continuous-wave (CW) states, periodic and quasi-periodic pulsations, low frequency fluctuations, and a coherent collapse were examined (see [2] and references therein). A simplest method for modeling a SL with a *weak* optical feedback is given by the Lang-Kobayashi (LK) model [3]. The LK modeling approach was also successfully used to get a deeper understanding of the stabilization or destabilization of the CW state by different configurations of the external cavity. A more appropriate way to describe the dynamics of semiconductor lasers with a *short* external cavity is given by the Traveling Wave (TW) model, which is a partial differential equation model that includes the spatial (longitudinal) distribution of the fields [4,5]. The TW model is used in the present paper, which is devoted for an investigation of the dynamics of the ECDL device composed of an amplifying semiconductor section and a distant Bragg grating that provides an optical feedback. The paper is organized as follows. The device structure and mathematical model are described in Section II. Section III presents the related numerical and experimental results. Finally, some conclusions are given in Section IV.

II. SETUP AND EQUATIONS

We focus on the ECDL device, schematically represented in Fig.1. It consists of an active section S_a containing the laser chip, an external holographic volume Bragg grating S_b, and a glass lens S_l located close to the inner facet of the laser chip. Two air gaps $S_{g'}$ and $S_{g''}$ separate the active section from the lens and the lens from the Bragg grating, respectively.

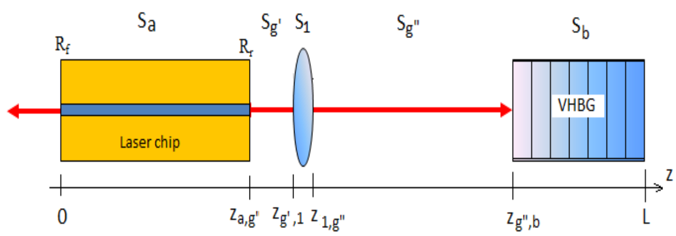

Fig. 1: Schematic representation of the ECDL device.

We use the traveling wave equations for the slowly varying complex amplitudes $E^+(z,t)$ and $E^-(z,t)$ of the counter-propagating optical fields within each section of the laser

$$\frac{n_g}{c_0}\partial_t E^\pm = \left[\mp\partial_z - i\beta(\mathrm{N},\mathrm{I})\right]E^\pm - i\kappa E^\mp + F^\pm_{sp}, \qquad (1)$$

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where c_0 is the speed of light in vacuum, $F_{sp}^{\pm}$ is the stochastic contribution of spontaneous emission in the active section, n_g is the group index, and κ is the field coupling coefficient.

The carrier rate equation used reads as follows:

$$\partial_t N = \frac{I}{q\sigma|S_a|} - \left(AN + BN^2 + CN^3\right) - \frac{c_0}{n_g}\mathrm{Re}\sum_{\nu=\pm}\left\langle E^{\nu*}\left|g(\mathrm{n}) - D\right|E^{\nu}\right\rangle_a . \quad (2)$$

For a detailed description of the remaining model equations and parameters we refer to [6].

III. RESULTS AND DISCUTIONS

We begin our analysis by studying the stationary lasing states of system (1)-(2). It is well known that an analysis of the optical modes can provide a deeper understanding of different dynamical effects in various multi-section semiconductor lasers and, particularly, in ECDL devices. Fig. 2 (bottom) shows the simulated complex frequencies of the most important instantaneous modes. Note, that 5 modes located within the stop-band of the Bragg grating (see Fig.2 top) have rather small damping (imaginary part of frequency). Thus, a strong influence of the side modes still can be expected, even though the ECDL operates at a CW state determined by one of these modes.

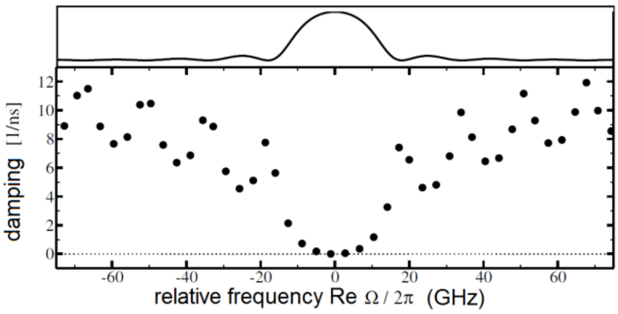

Fig. 2: Complex frequencies of the most important instantaneous modes. Solid curve on the top shows corresponding intensity reflectivity spectrum of the Bragg grating.

In what follows we perform numerical simulations of the TW model considering the influence of the injection current on the laser dynamics. The results of the numerical calculations of the output power and relative position of main optical mode against injected current are shown in Fig. 3 (right). Fig. 3 (left) shows the experimentally measured same characteristics of the ECDL with the volume holographic Bragg grating. Good agreement was obtained between measurements and simulations.

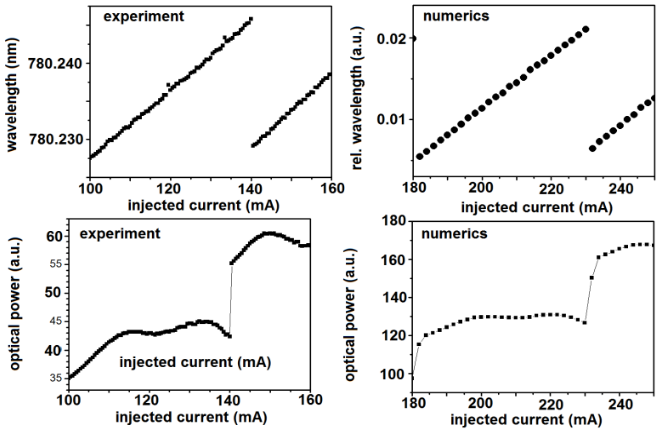

Fig. 3: Output power (top) and lasing wavelengths (bottom) as function of the injected current.

IV. SUMMARY AND CONCLUSIONS

We have carried out numerical and experimental investigations of the dynamics of a semiconductor laser under the influence of feedback from an external Bragg reflector. The results presented show that under appropriate conditions the laser is capable of generating a CW robust behavior appropriate for quantum-optical accurate experiments in space. Moreover, good agreement was obtained between measurements and theoretical simulations.

ACKNOWLEDGMENT

This work was supported by projects 11.817.05.17F and MANUMIEL (BMBF FKZ 01DK13020A). VZT acknowledges the support from the CIM–Returning Experts Programme.

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