Coexistence of Multiple Stable Continuous-Wave States in Micro-Integrated External-Cavity Diode Lasers

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We report the results of numerical and experimental investigations of the dynamics of an external cavity diode laser (ECDL) device [1] composed of a semiconductor laser, a several millimetre long external volume holographic Bragg grating, and a glass lens closely located at the inner facet of the active section (see Fig. 1). The Bragg grating provides optical feedback and can stabilize the emission wavelength as required by many applications. For example, the compact, narrow linewidth ECDL is ideally suited for quantum optical experiments in space. However, frequently ECDLs have more than one stable stationary or non-stationary attractor, see Fig. 2 and Refs. [2,3]. In general, each of these stable attractors can be observed by an appropriate tuning of laser parameters in simulations or increase and a consequent decrease of the device heating or injected current in experiments. Fig. 3 shows how up and down sweep of the injected current allows finding of two coexisting stable continuous wave (cw) states with different wavelengths and emission intensities.

Our mathematical modelling is based on the 1 (space) + 1 (time) dimensional traveling wave equations for the slowly varying complex amplitudes of the counter-propagating optical fields, which are nonlinearly coupled to the carrier rate equation within the active part of the ECDL [2,3]. Based on this model, we perform a detailed analysis of instantaneous optical modes [4], find all corresponding relevant cw states, and discuss their stability [2]. A semi-analytic continuation of optical modes and corresponding stationary states with tuned model parameters [2,5] give us a detailed understanding of almost-periodic state transitions shown in Fig. 3.

Fig. 1 Schematic representation of the ECDL.

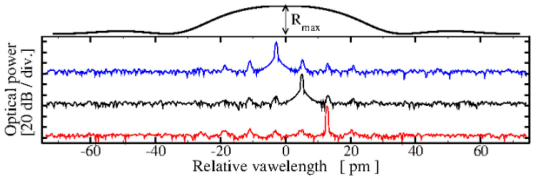

Fig. 2 Simulated three coexisting stable cw states

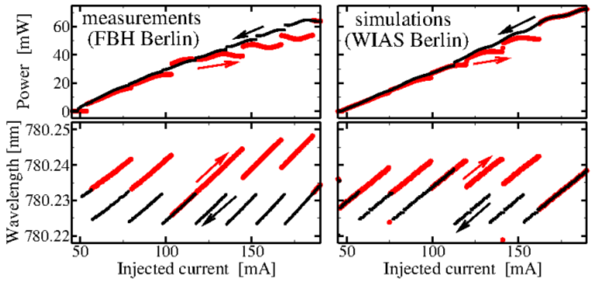

Fig. 3 Emission intensity (top) and dominant lasing wavelengths (bottom) as functions of the increased (red) or decreased (black) bias current in experiments (left) and simulations (right).

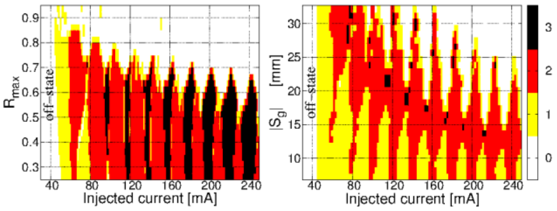

Fig. 4 Number of simulated stable cw states for different pumping and maximal BG reflectivity R_{max} (left) or air gap length $|S_g|$ (right). White areas show off state or existence of a stable non-stationary attractor.

Our simulations and analysis allow us to understand, to reproduce, and to predict measured dynamics of ECDLs, to identify crucial model parameters implying the multistability or dynamical multi-mode instability, and to give recommendations that should help to manufacture single-cw-state devices with the suppressed mode beating dynamics. In particular, Fig. 4 suggests a suppression of the non-stationary dynamics and a reduction of the number of coexisting stable cw states in ECDLs with the decreased Bragg grating reflectivity (left panel) or the shortened air gap (right panel).

References

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