Aspects of feedback and noise in Vertical-Cavity Surface-Emitting Lasers

This PhD thesis comprises a combined experimental and theoretical study of the dynamical properties of Vertical-Cavity Surface-Emitting Lasers (VCSELs) subject to two external perturbations: current noise on the one hand and optical feedback on the other hand.

VCSELs offer some particular advantages compared to most edge-emitting semiconductor lasers. In about twenty years, VCSELs have evolved from a laboratory curiosity into one of the world's most produced semiconductor lasers as they can show single longitudinal and single transverse mode emission and can be produced and tested in 2-dimensional arrays. As most semiconductor lasers, VCSELs exhibit an interesting dynamical behaviour that is further enriched by the polarization degree of freedom, due to the cylindrical symmetry of these devices.

The dynamics of VCSELs is affected by the presence of external perturbations. With this PhD thesis we contribute to that subject by studying the influence of external current noise and external optical feedback on the dynamical properties of VCSELs, including the relaxation oscillation dynamics, polarization mode dynamics and delay induced instabilities.

We show that the addition of extra carrier noise has a damping effect on the relaxation oscillation dynamics of a single polarization mode VCSEL. The change of the damping rate can be caused by a change of the non-linear gain compression with the current noise. We also show that the addition of extra carrier noise can alter the polarization mode dynamics of polarization bistable VCSELs. We find that the position of the polarization switching point changes with the current noise.

Semiconductor lasers are known to be very sensitive to external optical feedback and VCSELs are not an exception. The dynamical behaviour of VCSELs subject to optical feedback is phenomenologically rich and their analysis is mathematically demanding. In this thesis, we study the dynamics of VCSELs subject to polarized optical feedback on the one hand and frequency-shifted feedback on the other hand. The influence of polarized optical feedback on single-mode VCSELs is of fundamental interest since single-mode VCSELs can be considered as simple non-linear optical oscillators. We show experimental and numerical results of a particular regime of feedback-induced dynamics, the Low Frequency Fluctuations (LFFs) dynamical regime. The VCSEL biased below the solitary laser threshold shows pure single mode LFF in the dominant polarization mode.

Above the solitary laser threshold, we observe short pulses in the secondary polarization, with a delay of the order of ns with respect to the drop-out events of the dominant mode. In addition, we find that polarization bistable VCSELs show an enhanced sensitivity to frequency-shifted feedback when they are biased in the vicinity of a polarization switching point. This can be utilized for practical applications such as Laser Doppler Velocimetry.

Finally, we study the influence of current noise on a VCSEL subject to polarized optical feedback. When both perturbations are applied simultaneously to the laser, we find either the individual effects as described in the corresponding chapters of this PhD thesis or even interactions of the noise-induced dynamics and the feedback-induced dynamics.

Altogether, the consideration of noise, both in experiments and modelling, is of critical importance for the understanding of semiconductor lasers. According to the results presented in this thesis, current noise has an ambivalent character since noise has a damping effect on the relaxation oscillation dynamics but a destabilizing effect in some types of feedback-induced dynamics.

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