Multistability of semiconductor lasers with integrated delayed optical feedback

A. Loose[1]**, B. K. Goswami**[2]**, H.-J. Wünsche**[1]**, and F. Henneberger**[1]

1. AG Photonik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12485 Berlin, Germany
2. Laser and Plasma Technology Division, Bhabha Atomic Research Centre, Mumbai 400085, India

A new regime of operation, where optical feedback enables a semiconductor laser to operate in one of several stable states, is revealed in experiment [1]. Our experimental device exibits tristability and may become interesting for ternary optical logic, optical switching and memory applications. The Lang-Kobayashi model of delayed optical feedback is used to derive general conditions for the multistability which are shown to be consistent with the experiments and simulations.

The experimental device integrates the delayed optical feedback by using a passive waveguide and an amplifier section on the same chip as the distributed feedback (DFB) laser [2]. Feedback phase and strength can be adjusted by applying a direct current to the passive and amplifier section, respectively. Biasing the laser section closely above threshold, three different continuous wave states spaced 0.4 nm apart from each other is found to coexist for multiple ranges of applied currents. Simulations using a traveling wave model, taking into account all relevant device parameters, were run [2]. They show that while the amplifier section is of crucial importance for the adjustment of the feedback strength, no new dynamics are introduced by the amplifier in the selected regime. In this sense, the feedback can be considered passive.

Representing amplifier and phase section by a passive cavity with equivalent feedback strength, the generic Lang-Kobayashi (LK) model is applicable and provides deeper insight into the physics of this multistability. As is well known, delayed optical feedback may cause complex dynamical behaviour. For sufficiently strong feedback, pairs of modes and antimodes originate and vanish in saddle-node bifurcations. In our ultrashort-cavity case with the laser biased only slightly above threshold, a mode becomes unstable only by a Hopf bifurcation due to the existence of an antimode with the same threshold gain [3], and it is possible to derive an analytic formula for the number of stable cw states M. For optimal combinations of feedback strength and phase, $M = 2 + \mathrm{int}\left([\alpha - \arctan\alpha]\pi^{-1}\right)$, with α beeing the value of the linewidth-enhancement factor. α was determined to lie in the range from 5 to 7 in our device. Therefore three stable states can be expected in very good agreement with experiment. The device-realistic simulations confirm the general features of the LK scenario and additionally allow for exploration of dynamics not captured by the simplified model.

Several properties of our tristable system sharply differ from other types of multistability. In our case the coexisting states are stationary, unusually robust and coexist within large parameter windows. Furthermore, the theoretical analysis reveals a systematic way to increase the number of coexisting states even beyond three.

References

[1] A. Loose, B. K. Goswami, H.-J. Wünsche and F. Henneberger. "Tristability of a semiconductor laser due to time-delayed optical feedback", to appear in Phys. Rev. E.

[2] S. Bauer, O. Brox, J. Kreissl, B. Sartorius, M. Radziunas, J. Sieber, H.-J. Wünsche, and F. Henneberger, "Nonlinear dynamics of semiconductor lasers with active optical feedback", Phys. Rev. E **69**, 016206 (2004).

[3] M. Wolfrum and D. Turaev, "Instabilities of lasers with moderately delayed optical feedback ", Optics Communications **212**(1-3), 127-138 (2002).