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Return-map for semiconductor lasers with optical feedback

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It is well known that a semiconductor laser exposed to moderate optical feedback and biased near threshold exhibits the phenomenon of low-frequency intensity fluctuations (LFF) [1-6]. While this behavior can be numerically simulated using the so-called Lang-Kobayshi model [2], the interpretation of the phenomenon has remained a controversy [1-6]. The LFF consist of a sudden drop in intensity followed by a build-up in steps of the external cavity roundtrip time, τ, before a new drop-out occurs. The phenomenon has been attributed to a kind of chaotic itinerancy [3] and a bifurcation cascade has been identified very recently [6]. These results give insight into the behavior observed on a short time-scale, but do not explain some of the pronounced features of the LFF seen for moderate feedback levels; namely the stepwise build-up and its characteristic time of about 15 steps close to the solitary laser threshold. In this paper we present new results related to the slow time-scale behaviour of LFF which give a simple explanation of these general characteristics, as well as providing a new tool for studying the statistics of the LFF.

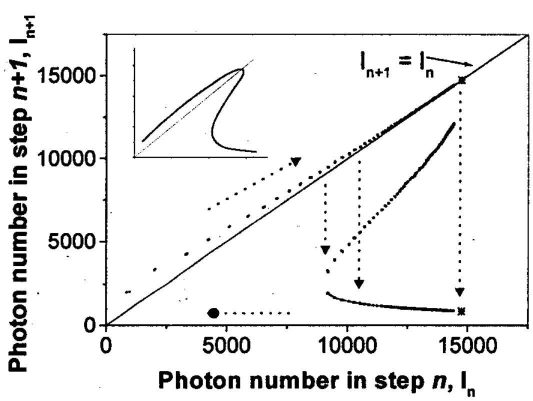

Fig. 1. Calculated return-map for low-frequency fluctuations. Feedback level κ=0.15, bias current J=J_{th} (threshold current without feedback). The inset shows a schematic of the return-map. In the actual calculation, two iterations of the r ... are show

Fig. 2. Time-dependence of photon number calculated from the return-map and a stochastic noise term.

Fig. 1 shows the calculated return-map for the syste etween the intensity at step n and the following step, $n+1$. Calculations are based on the iterative model derived in [2,4] which treats the entire spectrum of the laser emission within τ as the basic variable and therefore is valid even in the case where fast and irregular, posssibly chaotic, dynamics occur on a very short time scale. Starting out from the stationary state, the intensity drops to the lower branch of the map due to noise-induced switching over a potential barrier [1], the barrier maximum corresponding to the position of an unstable solution [2]. The intensity is now forced to build up until the point $I_n = I_{bi}$ is reached. After this point, the system is bistable and a new switching to the low intensity branch is possible after a stochastic dwell time

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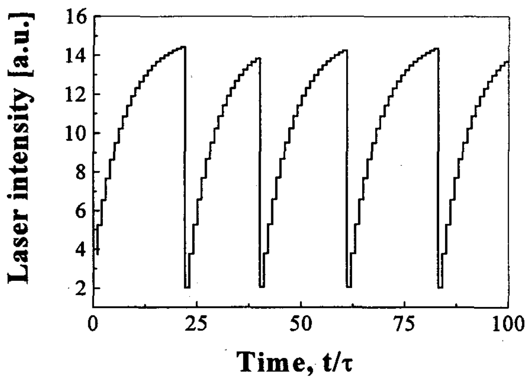
determined by the noise of the system. This explains the overall slow time scale behaviour observed experimentally. In Fig. 1 we have made two cycles of iteration and the discrete points are seen to fall almost exactly on the same curve, demonstrating for the first time that a return-map can describe the dynamics. Fig. 2 shows an example of a calculated time trace using the map when a stochastic noise term is added, and closely resembles experimental observations.

In Fig. 3 we investigate the parameter dependence of the number of steps needed to reach



the point of bistability, n_{bi}, which gives a lower limit to the period of the LFF, $T_{low}=n_{bi}\tau$. For fixed feedback strength, κ, the period increases rapidly when the threshold current with feedback is reached and drops for increasing bias current. Conversely, when the laser is biased close to the threshold current without feedback, J_{th}, about 15 external roundtrips are required for the intensity to build-up, varying only weakly with κ. Both of these predictions of the return-map are in good agreement with experimental observations, and provides, to our knowledge, the first explanation of these generally observed dependencies. The return-map also provides a straightforward explanation of the "dead" or "forbidden" zone of LFF periods recently observed experimentally [5], and should be useful for studying the statistical properties of the LFF.

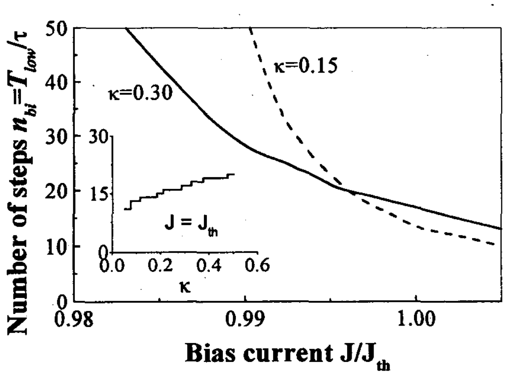


Fig. 3. Bias current dependency of the number of external cavity roundtrips to achieve bistability for feedback levels κ=0.15 and 0.30. The inset shows the κ dependency when the laser is biased at the threshold current of the laser without feedback.

[1] C. H. Henry and R. F. Kazarinov, IEEE J. Quantum Electron., **QE-22**, 294 (1986).
[2] J. Mørk, B. Tromborg, P. L. Christiansen, IEEE J. Quantum Electron., **24**, 123 (1988).
[3] I. Fischer et al., Phys. Rev. Lett., **76**, 220 (1996).
[4] B. Tromborg, J. Mørk, and V. Velichansky, Quantum Semiclass. Opt., **9**, 831 (1997).
[5] D. Sukow, J. R. Gardner, and D. J. Gauthier, Phys. Rev. A., **56**, R3370 (1997).
[6] A. Hohl and A. Gavrielides, Phys. Rev. Lett., **82**, 1148 (1999).