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Experimental investigation of stochastic processes in vertical-cavity lasers

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Abstract

We review the experimental characterization of stochastic processes in vertical cavity lasers. The system described here allows for several promising experimental studies which are presented in this work.

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The noise-induced dynamics in a bistable system is the subject of deep investigations since long time, due to its general interest which involves several fields, such as biology, economics, geophysics. In all those fields, the experimental studies are usually difficult and not well detailed, due to the lack of reproducibility of most systems and because laboratory, controllable conditions are generally not achievable. The most accurate results are usually obtained from numerical simulations or by implementing a model with electronic circuits.

Recently, a different possibility was offered by the vertical cavity semiconductor laser (VCSEL), which often presents a bistable emission and a fast and controllable response.

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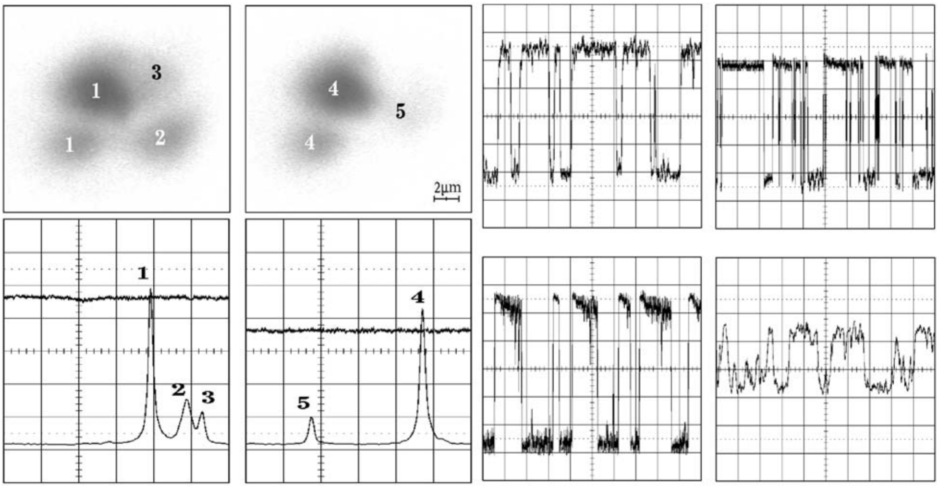

Fig. 1. Left: optical spectra and patterns corresponding to two states involved in the bistable configuration. The horizontal trace refers to the polarized intensity in the two states. Right: Time series of the polarized output intensity for different polarization switchings regions in the same laser sample. Horizontal units are, from left to right: 0.5 μs/div and 50 ns/div (top), 5 μs/div and 0.5 s/div (bottom).

Main characteristics of VCSELs are a short cavity with high Fresnel number and a highly symmetric geometry. As a consequence, the emission is on a single longitudinal mode, but usually with a non-trivial transverse structure. Moreover, the crystal axes directions define two perpendicular, linear polarizations that can both be present in the laser emission. In particular, when sweeping the pump current the laser polarization can switch from one direction to the other and a polarization bistable region can exist. In such regions, the laser shows noise-induced jumps between the two polarizations and the transition rates can be controlled both by selecting the working point and by adding a well-defined amount of extra noise. This behaviour has been observed both in single transverse mode lasers [1] and in multiple transverse modes samples [2], where the polarization switch often comes together with a change of the lasing mode.

A more involved situation, of particular interest for the studies of stochastic processes, is found in VCSELs with a broad emitting area presenting spatially localized inhomogeneities. Due to these properties, the lasing action is in well-defined, localized regions, in general with different wavelengths. For our samples, the typical size of such spots is about 2 μm on a 15 μm diameter cavity. The position of the spots (emitters) remains the same, changing laser current and temperature: the pattern maintains a regular structure, differently from the filamentation in broad-area VCSELs [3]. For such lasers, the switches are not only on the emission polarization, but also in the spatial configurations: the single emitters can switch on and off, or change polarization and wavelength. As a consequence, the system behaviour can be monitored by the detected intensity after selecting the polarization or a spatial region. An example is shown in Fig. 1 (left). When biasing the laser within the bistable region, random jumps occur between the emission configurations following a Kramers statistics.