Identifying and characterizing dynamical transitions in a semiconductor laser with optical feedback.

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Identifying transitions to complex dynamical regimes is a fundamental open problem with many practical applications. Semiconductor lasers with optical feedback are excellent testbeds for studying such transitions, as they can generate a rich variety of output signals. Here we perform an experimental investigation of the onset of two well-known dynamical regimes: low frequency fluctuations (LFFs) and coherence collapse (CC) [1, 2]. We apply three nonlinear analysis tools to quantify various aspects of the dynamical transitions that occur as the laser pump current increases. The experimental setup is described in [3].

The first diagnostic tool is based in the analysis of the standard deviation, σ, of intensity time-series recorded with different oscilloscope sampling rate. For each set of (pump current, sampling rate), 10 time series with 10^7 intensity data points each were recorded. Fig. 1a displays the 10σ values vs. the laser pump current, for three sampling rates. In this plot we can identify different behaviours as the pump current increases: at low current the wide spread in the values of σ captures the coexistence between stable noisy emission and LFF dropouts [1]; for higher currents there is an almost linear increase of σ, which captures the increase of the depth and of the frequency of the LFF dropouts; at even high pump currents (above $\mathrm{I/I_{th}} \sim 1.08$), σ saturates or decreases depending in the sampling rate, which captures the fact that the dropouts become irregular and allows to quantitatively identify the onset of coherence collapse [2].

The second diagnostic tool is based in the analysis of the number of threshold-crossing events: first, each time series is normalized to zero mean and $\sigma = 1$, then, in each time-series we count the number of times the intensity drops below a give threshold, and plot the number of threshold-crossing events vs the pump current, for various thresholds (see [3] for details). The results are presented in Fig. 1b where we can again distinguish different regions: at low and high currents the number of events depends on the threshold, which reveals that the intensity dropouts are irregular; in contrast, for intermediate currents the number of events is the same for the different thresholds, which captures the fact that the dropouts are of similar depth.

The third diagnostic tool is based in ordinal symbolic analysis [4], by which a time series y(t) is divided into non-overlapping segments of length L, and each segment is assigned a symbol, s, (known as ordinal pattern, OP) according to the ranking of the values inside the segment. For example, with $L = 3$, if $y(t) < y(t+1) < y(t+2)$, $s(t)$ is '012', if $y(t) > y(t+1) > y(t+2)$, $s(t)$ is '210', and so forth. In this way, the symbols take into account the relative temporal ordering of the values in the series. We apply the ordinal method to the sequence of time-intervals between consecutive threshold-crossing events. Specifically, we calculate the probability of consecutive intervals being increasingly shorter. The results are presented in Fig. 1c, where again one can identify well-defined regions, with $\mathrm{I/I_{th}} \sim 1.08$ corresponding to maximum probability of the '10', '210', etc. ordinal patterns.

Taken together, these three diagnostic tools allow delimiting the region of regular LFF dropouts, delimiting the region of coexistence LFF-stable emission, and allow identifying the onset of the CC regime. They can be used for characterizing dynamical properties of the laser output, which can be valuable for applications that exploit the complex output signals generated by semiconductor lasers with optical feedback.

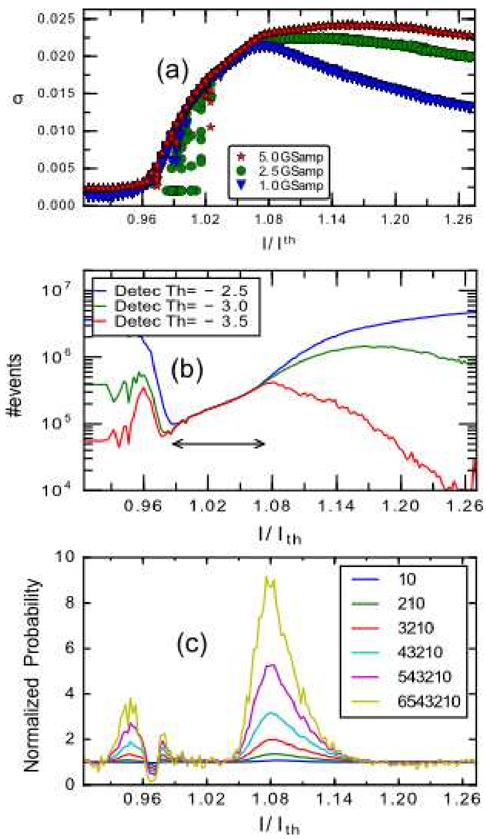

Figure 1: (a) Standard deviation, σ, of the intensity time series recorded with different oscilloscope sampling rate. (b) Number of threshold-crossing events, computed with different thresholds (in units of σ). (c) Probability of the decreasing trend ordinal pattern, normalized to the value expected if all the patterns are equally probable. In these plots different regions are observed with $\mathrm{I/I_{th}} \sim 1.08$ indicating the onset of the CC regime.

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