Statistical characterization and control of nonlinear dynamics of semiconductor lasers

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Semiconductor lasers with optical feedback are important and widely used devices. Because of the complex output signals that they generate can be exploited for several applications, including sensors, ultra-fast random number generation, reservoir computing and life science applications. In absence of external perturbations, semiconductor lasers show an stable output while subject to optical feedback or injection exhibits a rich variety dynamical behaviors.

The research in our lab is focused on the influence of optical feedback over semiconductor laser dynamics. We mainly study the low-frequency fluctuations (LFFS) and coherence collapse (CC) regimes. While the LFFs regime, in its slow time scale, is characterized abrupt and sudden dropout of the laser intensity followed by a gradual recovery, the CC collapse regime consists of fast and chaotic intensity fluctuations [1]. With the aim of quantitatively characterize the dynamical response of the system we apply new statistical tools based on information theory.

In this talk we aim to address the following questions: Can these regimes be quantitatively distinguished? Can the onset of each regime be quantitatively identified? We show that, by using three diagnostic tools applied to experimental intensity time-series we are able to quantify these transitions [2]. We use these tools to analyze how noisy fluctuations (close to lasing threshold) gradually transform into well-defined and apparently randomly distributed dropouts (i.e., LFFs regime, at higher pump currents), which then merge into fast and irregular fluctuations (i.e., CC regime at even higher pump currents). We also establish the coexistence region, where the dropouts alternate with stable noisy emission and find a region of pump currents where occasionally, extremely depth dropouts occur.

In the second part of the talk we investigate if a semiconductor laser with optical feedback is able to adapt its natural rhythm to an external weak periodic signal. Entrainment or locking phenomenon [3] between the natural frequency of the system and the external perturbation is typically achieved by increasing the amplitude of the forcing signal until the system adjusts its frequency to that of the forcing signal. However, it is not always possible to achieve the locked state by increasing the forcing amplitude, since too strong forcing might damage the system that one aims to control. Optimal conditions for entraining the system have been studied, and methods for achieving entrainment with minimum forcing power, minimum transient time, maximum coherence, and widest locking range will be discussed [4, 5]. To that end, the role of the modulation amplitude and frequency, and the role of the DC value of the laser pump current (that controls the natural spike frequency) in the entrainment quality will be analyzed.

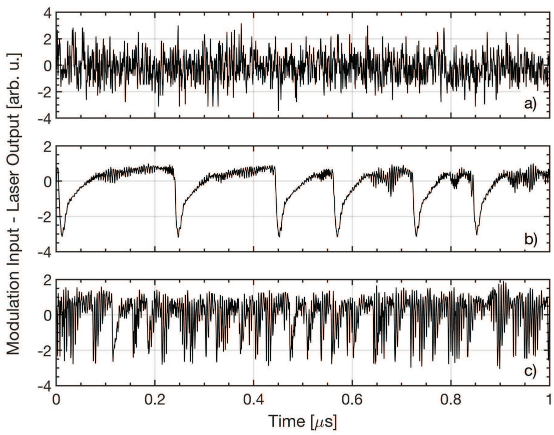

Fig. 1. Normalized to zero-mean and unit variance time-series for a semiconductor laser with optical feedback. (a) Noisy fluctuations, (b) low frequency fluctuations, and (c) coherence collapse regimes. The DC pump current normalized to the solitary lasing threshold is $I/I_{\text{th}} = 0.95$, 1.02, and 1.20, respectively.

We are currently working in tuning of the system to a region where the laser spikes are rare and at the same time highly sensitive to an external perturbation. Find this region parameters could be significant for sensing applications.

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[3] A. Pikovsky, M. Rosenblum, and J. Kurths, *Synchronization. A Universal Concept in Nonlinear Sciences* (Cambridge University Press, 2001).

[4] J. Tiana-Alsina, C. Quintero-Quiroz, M. Panozzo, M. C. Torrent, and C. Masoller, Experimental study of modulation waveforms for the entrainment of the spikes emitted by a semiconductor laser with optical feedback, Opt. Express **26**, 9298-9309 (2018).

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