Experimental study of the nonlinear dynamics of semiconductor lasers to control the coherence of the laser light

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Semiconductor laser diodes are widely used as illumination light sources in imaging applications because they are are low-cost, emit a stable output, and cover a wide range of wavelengths. However, illumination with coherent laser light produces a spatial interference pattern, known as speckle pattern, which degrades the image quality. The speckle pattern is a granular, noise-like structure that results from the interference of coherent waves, and which contains spectral information of the waves, and statistical information of the scattering medium that generates the pattern. When laser light propagates through a diffusive medium that creates speckle, useful information may be obtained from the analysis of the speckle pattern [1, 2, 3].

A typical measure used to quantify speckle is the speckle contrast [4], which is the ratio between the standard deviation of the patterns intensity and its average intensity, $SC = \sigma_I/\bar{I}$.

In this contribution we analyze how the laser light coherence emerges during the transition from spontaneous to stimulated emission as the laser turns on. Specifically, we perform experiments with a semiconductor laser with optical feedback from an external mirror.

The experimental control parameters are the laser pump current and the feedback strength that modify the spectral characteristics of the laser light and, consequently, its degree of coherence, which we quantify by calculating SC in the speckle images recorded with a CMOS camera.

In Fig. 1(a) we show the experimental setup, in which we are able to control the amount of light that is fed back to the laser and record the speckle images. The feedback strength is controlled by a variable attenuator that allows to regulate the amount of feedback light that passes through it. The scattering medium used to create the speckle patterns is a Multi-Mode Fiber (MMF), and speckle is created by the interference of different guided modes in the fiber. We also measure the spectrum of the light using an optical spectrum analyzer (OSA).

The effect of the feedback strength on the emergence of the coherence in the laser is shown in Fig. 1(b). We find for pump currents near $I_{th}^0 = 42.90$ mA, the transition to coherent emission varies from being smooth to being rather abrupt as the amount of feedback light increases.

The sudden transition to coherence is visualized in the speckle patterns shown in Fig. 1 (c). Both images were recorded for the same condition of feedback strength, just before and after the transition, and the change can be estimated from SC = 0.27 low coherence in the left image, to SC = 0.50 higher coherence in the right image.

For larger pump currents (above the transition) we notice in Fig. 1(b) that SC decreases in comparison to the value of the solitary laser (without feedback), revealing a partial loss of the coherence in the emitted light (due to feedback induced chaotic oscillations).

To summarize, the speckle contrast provides a non-spectral way to examine the coherence of the laser light, and we have used it to uncover an abrupt transition to coherence when the laser is subject to strong optical feedback. Ongoing work is devoted to characterize the properties of the transition, while future work will be aimed to analyze the effect of mechanical vibrations on the external mirror that provides feedback, actuated with a piezoelectric device.

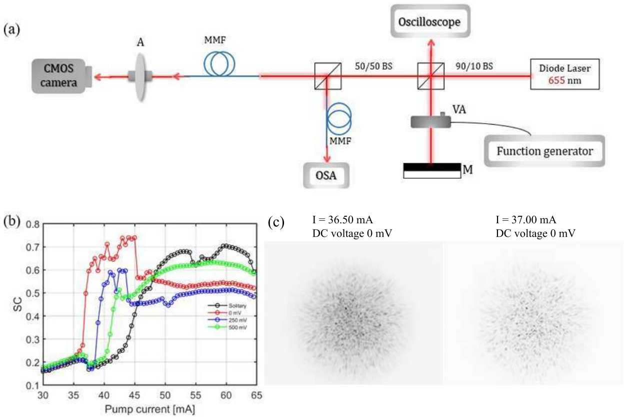

Fig. 1. (a) Experimental setup. (b) Speckle contrast as a function of the laser pump current, under different amount of feedback. (c) Speckle images before and after the sudden transition to coherence (left and right, respectively) for maximum feedback strength (i.e., with 0 voltage in the attenuator).

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