# Self-pulsations, excitability and polarized rogue waves induced by orthogonal optical injection in Vertical-Cavity Surface-Emitting Lasers

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Optical injection in vertical-cavity surface-emitting lasers (VCSELs) is a technique that is employed to improve the performance of these lasers without modifying their design. Optical injection can also induce rich nonlinear dynamics in the light emitted by the VCSEL. In contrast with edge emitters VCSELs have an extra degree of freedom associated to the polarization of light. An example of nonlinear polarization dynamics has been recently observed in 1550nm wavelength VCSELs subject to orthogonal optical injection[1,2]. In those experiments linearly polarized light from a tunable laser source is injected orthogonally to the linear polarization of a free-running VCSEL (parallel polarization). The control parameters are the master power $P_m$ and the detuning $\Delta\nu$, defined as the frequency difference between the master laser and the orthogonal polarization of the slave laser. When $P_m$ is increased polarization switching of the VCSEL to the polarization of the external injection and injection locking are obtained. Bistability, periodic, period doubling and irregular dynamics for both linear polarizations were observed before injection locking is achieved. Pulses observed in the irregular regime are similar to those resulting from excitability in optically injected quantum well and quantum dot edge-emitting semiconductor lasers[3]. Rare extreme pulses (rogue waves) have been also observed in optically injected 980nm wavelength VCSELs subject to parallel optical injection[4].

In this work we perform a theoretical study of the polarization-resolved nonlinear dynamics of a long wavelength single-mode linearly polarized VCSEL when subject to orthogonal optical injection. We use a rate equation model[1] based on the spin-flip model. We show that self-pulsations appear in the total power and in both linear polarizations at negative detuning when $P_m$ is smaller but close to the injection power required to achieve stable injection locking, $P_{IL}$. These self-pulsations correspond to those observed in 1550nm wavelength VCSELs subject to orthogonal optical injection[1,2]. When $P_m$ is slightly increased above $P_{IL}$, excitable pulses can be triggered by perturbing laser variables above a certain threshold level. Single, double, triple and multi-pulse behaviors are obtained at a detuning of -2, -2.5, -2.4 and -2.7GHz, respectively. These excitable pulses are identical to the self-pulsations obtained when $P_m < P_{IL}$. This behavior is observed in the deterministic case and when spontaneous emission noise is taken into account. Multi-pulse excitability can be due to *n*-homoclinic bifurcation tongues[5]. A periodic behavior is obtained at a detuning of -2, -2.5 and -2.4GHz in the deterministic case when $P_m < P_{IL}$. However, irregular multi-pulse behavior is obtained without spontaneous emission noise for -2.7GHz and $P_m < P_{IL}$ (see Fig. 1). In this case the parallel polarization is excited at the end of every pulse train. Train pulses are sporadic and the histogram show a long tail (see inset in Fig. 1 for the total power). We obtain pulses with a height higher than the mean value plus 8 standard deviations. This is one of the criteria used to define rogue waves[4]. Similar long-tailed histograms are obtained for the power of both polarizations. Then, polarized rogue waves are obtained in VCSELs subject to orthogonal optical injection.

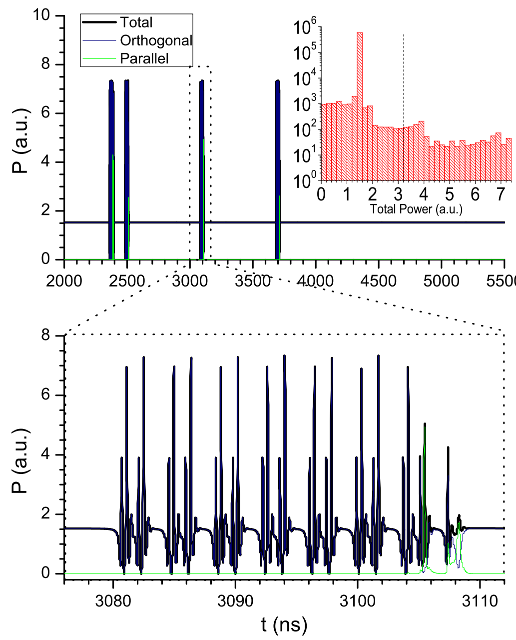


FIG. 1. Time traces of the total and both linear polarizations power at a detuning of -2.7GHz without noise. Inset: Histogram of the total power. The vertical dashed line denotes the mean value plus 8 standard deviations

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