Polarization-resolved nonlinear dynamics induced by orthogonal optical injection in 1550 nm-Vertical-Cavity Surface-Emitting Lasers

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Abstract— We report a first experimental study of the polarization-resolved nonlinear dynamics of a 1550nm single-mode VCSEL when subject to orthogonal optical injection. Periodic, period doubling and chaotic dynamics are observed for both polarizations.

VCSELs; orthogonal optical injection; nonlinear dynamics

I. INTRODUCTION

Vertical-Cavity Surface-Emitting Lasers (VCSELs) emitting at the telecom wavelength of 1550 nm are very promising devices due to their inherent advantages in comparison with edge-emitting devices [1]. Optical injection in VCSELs is an attractive method to obtain bistable behaviour and nonlinear switching that can be used for all-optical signal processing. Polarization switching and optical bistability have been reported in VCSELs subject to orthogonal optical injection [2-5]. In that configuration linearly polarized light from a tunable laser is injected orthogonally to the linear polarization of a free-running VCSEL. Switching from that polarization to the orthogonal polarization is observed as the injected power increases [2-5]. Optical injection is also a method that can induce a rich variety of nonlinear dynamics in the light emitted by the VCSEL. An example of those dynamics has been obtained with a 850 nm wavelength VCSEL subject to orthogonal optical injection [2]. Recently attention has been focused on the study of orthogonal optical injection in 1550nm VCSELs [3-5]. A stability map has been reported for the total power identifying the boundaries between regions of different behavior, including periodic dynamics, chaos and polarization switching (PS) [5]. In this work we perform an experimental study of the polarization-resolved nonlinear dynamics of a 1550 nm wavelength single-mode VCSEL when subject to orthogonal optical injection. The RF spectrum of both polarizations is measured for different frequency detuning and injected power values.

II. EXPERIMENTAL RESULTS

The orthogonal optical injection from a tunable laser into a commercial 1550nm VCSEL (Raycan) is achieved by using the all-fiber setup shown in Fig. 1. A polarization beam splitter is used to select the polarization direction in which the RF spectra

Figure 1. Experimental setup

are measured. The free-running VCSEL emits in the fundamental transverse mode with a threshold current $I_{th}=1.64$ mA at a temperature of 298 °K. The lasing mode has a linear “parallel” polarization along the whole current range. A bias current of 8 mA was applied to the device. A Side Mode Suppression Ratio of 43 dB was measured for the orthogonal “perpendicular” polarization, which is shifted 0.49 nm to the long wavelength side with respect to the dominant one. We show in Fig. 2 the mapping of the dynamics of the total power when the frequency of the injected signal, ν_{ML} , is swept around the frequency of the perpendicular polarization, ν_{perp} , the frequency detuning being, $\Delta\nu=\nu_{ML}-\nu_{perp}$. Fig. 2 also shows the injected power required for PS to the perpendicular polarization of the VCSEL. Different regions corresponding to different dynamical regimes are shown in Fig. 2. Region SL represents the stable locking range, regions P1 and P2 show periodic (period 1) and period doubling dynamics, respectively, and region CH corresponds to irregular and possibly chaotic dynamics. It is found that PS is always accompanied with stable locking for negative $\Delta\nu$. However, PS can be also observed in a periodic dynamical regime, including both P1 and P2 behaviors, for positive values of frequency detuning. Period doubling is obtained for both positive and negative $\Delta\nu$. However, the irregular behavior is only obtained for negative values of the frequency detuning. RF spectra for the two polarizations are shown in Figs. 3-5 for different dynamical regimes. They correspond to a fixed frequency detuning of -1.5 GHz and different values of the injected power, P_{inj} . For small values of P_{inj} a peak appears in the RF spectrum of both

Figure 2. Mapping of the dynamics of the VCSEL subject to orthogonal optical injection. SL: stable locking region. P1: period 1 region. P2: period doubling region. CH: irregular dynamics. PS is also shown with open circles.

polarizations (Fig. 3) that correspond to two-mode limit cycle dynamics (period 1). This behavior has been also observed in 850 nm VCSELs [6]. When P_{inj} is increased oscillations appear at half the frequency of the limit cycle (period doubling, Fig. 4) for both polarizations. A further increase in P_{inj} leads to a wide RF spectra for both polarizations (Fig. 5) that are the signature of chaotic dynamics. In contrast with [2] chaotic behavior is obtained for negative values of the frequency detuning. Stable injection locking accompanied with PS is achieved for a further increase of P_{inj} .

Figure 3. Left (right): RF spectrum for perpendicular (parallel) polarization for an injected power of 58.5 μW and $\Delta\nu = -1.5$ GHz.

Figure 4. Left (right): RF spectrum for perpendicular (parallel) polarization for an injected power of 67.6 μW and $\Delta\nu = -1.5$ GHz.

Figure 5. Left (right): RF spectrum for perpendicular (parallel) polarization for an injected power of 84 μW and $\Delta\nu = -1.5$ GHz.

III. CONCLUSIONS

In this work we report a first experimental study of the polarization-resolved nonlinear dynamics of a 1550 nm wavelength single-mode linearly polarized VCSEL when subject to orthogonal optical injection. We have measured the mapping of the dynamics in the plane of detuning between the frequency of the injected signal and the free-running frequency of the VCSEL versus injected power for an applied bias current well above threshold. Different dynamical regimes including periodic, period doubling and irregular and possibly chaotic dynamics are observed for both polarizations. In contrast with the results found for 850 nm wavelength VCSELs [2] the irregular behavior is obtained for negative values of the frequency detuning.

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