The influence of current noise on the polarisation properties of VCSELs

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Vertical Cavity Surface Emitting Lasers (VCSELs) often present switching between two orthogonal polarisation states when varying parameters like e.g. current or temperature. Around such a switching point, the system randomly jumps between these two polarization states (mode hopping). Actually, noise drives the laser from one state to the other. In this contribution, we present experimental results showing the effect of coloured noise, externally added to the current, on the switching characteristics of a VCSEL.

Introduction

From a fundamental point of view, two sources of noise can be distinguished in semiconductor lasers. Spontaneous recombination of electrons and holes results in spontaneous emission noise due to a fraction of spontaneously emitted photons ending up in the lasing mode (referred to as field noise). On the other hand, the random and instantaneous character of each discrete recombination event leads to carrier inversion noise [1]. However, in practice, external sources contribute to extra noise on the injection current of the laser, resulting in a higher carrier noise level than the fundamental shot noise level. In this contribution, we present experimental results that show the effect of coloured noise, externally added to the current, on the switching characteristics of Vertical Cavity Surface Emitting Lasers (VCSELs).

VCSELs have the advantage of emitting in a single longitudinal mode due to their exceptionally short optical cavity. Moreover, oxide-confined VCSELs can exhibit quite a large domain of single transverse mode operation, emitting in a preferred linear polarization direction. Due to anisotropies in the laser cavity, a switching to the orthogonal direction can occur when varying several parameters like e.g. current or temperature.

Experimental results

In our research, we have used an oxide-confined VCSEL fabricated by ULM [2], lasing at 970 nm. It lases in a single longitudinal and transverse mode for the range of currents we are interested in, with a threshold for laser emission at 0.9 mA. This device emits continuously in a single linear polarization mode up to 1.42 mA, where it starts lasing in the orthogonal direction, corresponding to the orthogonal polarization mode. Around such a switching point, the system can jump randomly between the two polarization states. Actually, it is the noise which drives the laser from one state to the perpendicular one.

In our experimental set-up, which is sketched in Figure 1, the current noise is externally added through a bias-T to the driving pump source and finally send to the laser. This

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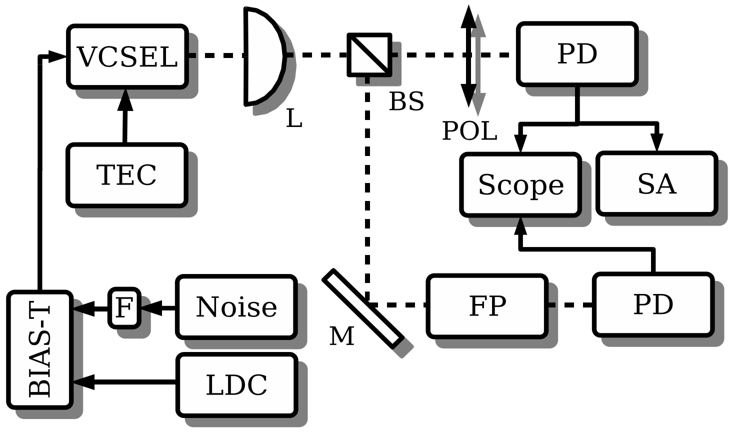

Figure 1: Scheme of the experimental set-up. VCSEL: Vertical Cavity Surface Emitting Laser; TEC: temperature controller; F: high-pass filter; L: collimating lens; BS: beam-splitter; POL: polarizer; M: mirror; PD: photodiode; FP: Fabry-Perot analyzer; LDC: laser driver controller; SA: spectrum analyser

coloured noise is generated with an arbitrary waveform generator (AWG), which has a 3-dB bandwidth of 400 MHz. The response of the AWG is measured to be flat within this bandwidth. The output of the AWG is further filtered out with a high-pass filter to avoid contributions of the current noise at thermal timescales, the thermal cut-off being below 1 MHz. For the detection, we are acquainted with a fast photo diode (3 GHz bandwidth), a fast oscilloscope (4 GHz bandwidth) and an electrical spectrum analyzer. Furthermore, we are able to resolve between the two orthogonal polarization directions of the outcoming light with the adequate optics.

When a VCSEL is mode hopping between the two possible orthogonal states, it stays for a certain time in one of the modes before jumping to the other one. This residence time varies from one device to another and it strongly depends on the switching conditions. It has also been found that the residence time can scale over several orders of magnitude for a given device if the switching point is changed by adding external stress [3]. In such a bistable system, it is a common technique to measure the residence time at the Maxwell point, the Maxwell point being defined as the value of the current where the laser spends equal time (on average) in each of the two orthogonal polarization modes.

Here, we report a shift of the Maxwell point when the strength of the external, coloured, current noise is increased. It has been experimentally found that the Maxwell point shows a linear dependence with the strength of the current noise, moving towards higher values of the current for higher values of the noise. As shown in Figure 2, this shift of the Maxwell point is remarkable, ranging from a starting current of 1.4 mA up to 1.9 mA. The upper limit is restricted by the maximum strength of the noise that our waveform generator can produce, which is approximately the twenty per cent of the injected current. We have also measured the scaling of the residence time at the Maxwell point while the Maxwell point is shifting due to the current noise. This is a very unique situation since the coloured noise allows us to fine-tune the Maxwell point for a broad range of currents, and this can be done in a reproducible manner. In this case, it turns out that the scaling of the residence time is not the expected exponential decrease for an increasing strength of

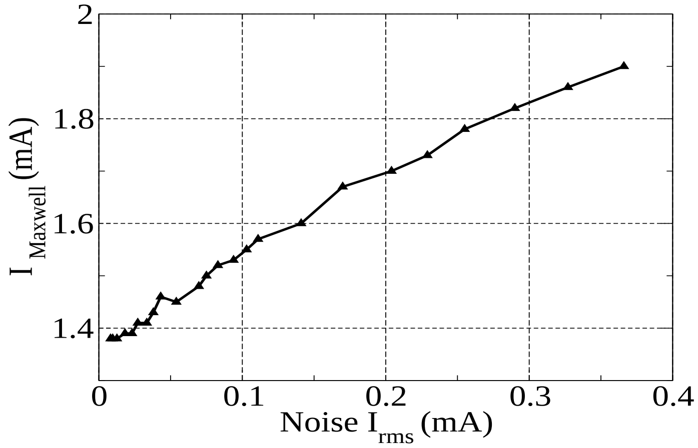

Figure 2: Position of the Maxwell point as a function of the strength of the current noise.

the noise, see Figure 3. Note the logarithmic scale on the vertical axis of Fig. 3, which would turn an exponential dependence into a linear one.

The observable trend of the residence times differs from the exponential dependence for bigger values of the noise. These values correspond to higher current values of the Maxwell point. In the absence of coloured noise, the relation between the emitted intensity and the spontaneous emission defines the rate of switchings. For a given device, it is known that the average residence times at the Maxwell point is bigger when the Maxwell point is further from the threshold. Since the random mode-hopping is driven by the spontaneous emission noise, the probability of a switching is smaller when the output intensity is bigger and the spontaneous emssion remains constant.

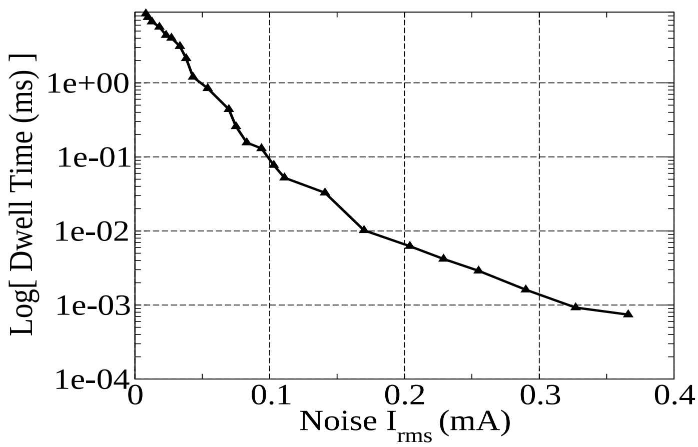

Figure 3: Residence time at each Maxwell point for different values of the strength of the current noise. The bias currents for each Maxwell point are the same as in Figure 2

When the coloured noise is added to the current, the position of the Maxwell point is shifted. As said earlier, the expected average residence time would be bigger for higher currents. This phenomenon counteracts the exponential decrease the average residence time would show with the only presence of the coloured noise. Finally, it is worth noting that the residence time scales over four orders of magnitude in our measurement range.

Modelling

We have described the VCSEL using a rate equations model. Two rate equations describe the time evolution of the amplitude of the two orthogonal polarization modes, and another equation accounts for the time evolution of the carriers. A complete description of this model can be found in [3]. In order to simulate the coloured noise, a fourth equation describing the fluctuations of the current has been used, see Equation 1.

$$\frac{d\delta J}{dt} = -\frac{\delta J}{T} + \sqrt{\frac{2D_J}{T}}\tilde{F}, \tag{1}$$

where δJ denotes the fluctuations of the current, T defines the correlation time of the coloured noise, D_J is the strength of the coloured noise, and $\tilde{F}$ is a white gaussian noise source of zero mean and unit variance.
Preliminary, numerically obtained, results show that the fluctuations in the current affects differently the two polarization modes. Thus, these fluctuations introduce an extra asymmetry into the system. Analogous to the experiment, it is seen that the current noise enhances the probability of the mode emitting at threshold.

Conclusions

The extra coloured noise added to the current source driving the VCSEL changes the symmetry of the bistable system defined by the two polarization modes, shifting the Maxwell point towards higher values of the current. Thanks to this characteristic effect, it has been possible to measure the distribution of the dwell times at the Maxwell point for different injection currents.
Further work on the analytical model is required. The complexity introduced by the finite correlation time of the current noise forces us to make certain assumptions, whose validity is still to be confirmed by comparison with numerical simulations [4].

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