'Phase portraits' for characterizing advanced lasers

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1. Introduction

Lasers play a crucial role in dense WDM systems, and so the characterization of their performance is critical [1]. Commercially, lasers are characterized by parameters such as: linewidth, typical static spectra, side-mode-suppression ratio, modulation response, slope efficiency and wavelength stability. However, the dynamic performance is rarely specified in detail, such as the time-resolved optical frequency waveform of the modulated laser, and the interplay between instantaneous power and frequency. The time relationship between the power and optical frequency crucial if the pulse evolution in fibers is to be calculated, for example. Furthermore, in tunable devices, the time and frequency while the laser is being re-tuned is critical, as the tunable laser could pollute live channels during tuning [2].

In this paper, it is shown that the 'phase portrait' of instantaneous time versus frequency gives valuable information on the transient and stability characteristics of fixed and tunable semiconductor lasers. From the recognizable shapes in the portrait, the deficiencies in the laser are easily identified. Furthermore, the impact of frequency and power deviations can be assessed. This is topical because commercial instrumentation to measure instantaneous time and frequency is now available [3], so that phase portraits are easily plotted from the two measurements.

2. Generation of a Phase Portrait

To generate a set of standard portraits of devices with known characteristics and deficiencies, numerical simulation was used. This comprised of semiconductor laser models based on a modified Transmission-Line Laser Model (TLLM) [4], incorporating wide-band simulation based on complex field [5] representation, but formulated using fundamental transmission-line analogies to avoid spurious stop-bands in the modeled spectrum. The TLLM is a large-signal dynamic model with longitudinal discretization that accounts for many transient effects and instabilities in complex lasers [6]. TLLMs can be interconnected bidirectionally to form multi-section devices, such as mode-locked and tunable lasers. The simulations run on the Photonic Transmission Design Suite [7]. The phase portraits were generated by detecting the instantaneous power and frequency of the simulated waveform of the laser. These were low-pass filtered (–3dB @20-GHz), and plotted on an x-y graph. A typical schematic is shown in Fig. 1.

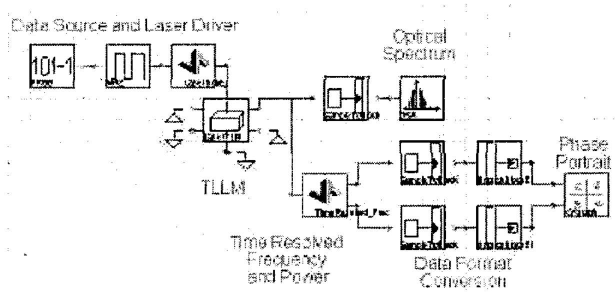

Fig. 1: Typical PTDS simulation set-up for simulating a phase portrait of a modulated laser

3. Phase Portraits of Bulk and MQW DFB laser transients

The turn-on transient of a laser produces a dynamic frequency chirp due to the change in carrier density with time, changing the refractive index of the device. In bulk Fabry-Perot devices the relationship between time and frequency is relatively straightforward: the frequency drops during the peak of the transient then an adiabatic chirp gives a power-dependent frequency offset due to gain. In DFB lasers, spatial hole burning can lead to longer-term frequency dynamics. In MQW lasers, the carrier density in the SCH region contributes significantly to the refractive index seen by the optical mode, and the carrier density in the SCH region phase-leads the carrier density in the active region during turn-on [4].

Fig. 2 the phase portraits of uniform bulk and MQW laser structures [5] with 95% and 1% facets, and one AR-coated facet. Both show the rise in power and drop in frequency during the initial pulse. The bulk laser spirals towards a steady-state, indicating low damping, whereas the MQW's steady state is lower than the peak frequency excursion of the first pulse, indicating a lowering of the MQW carrier density in the longer term. These plots clearly show that the performance in systems would be very different.

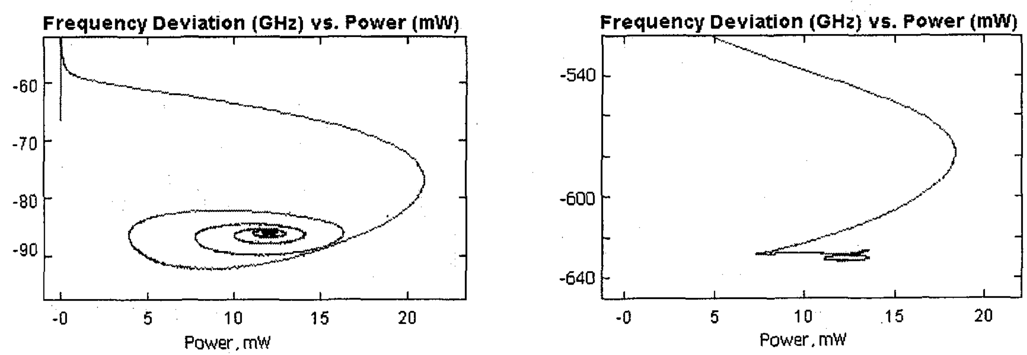

Fig. 2. Turn-on transients of 95%-1% facets (180 deg./ 0 deg.) Bulk (left) and MQW (right) lasers at 60-mA.

3. Phase Portrait of an AR-coated uniform Bulk laser at high powers

Uniform-DFB lasers with perfectly-symmetrical structures exhibit self-pulsation at high powers due to the build-up of power at one end of the laser, driven by an increasing carrier density (and hence reflectivity at the lasing mode, excluding power) at the other end [5]. The end with the large carrier density will then reach threshold itself, and produce a large transient pulse, relaxing the laser to its original state. The phase portrait illustrates this oscillation, and the extent of the frequency and power excursions.

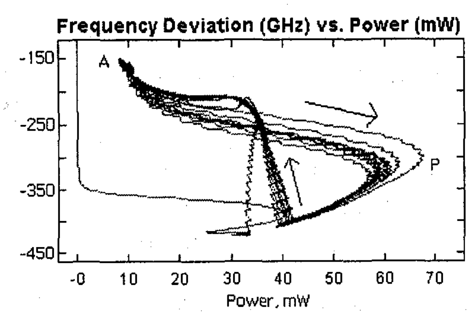

Fig. 3. Phase portrait for a uniform DFB laser driven at 160 mA showing unstable operation.

Fig. 3 shows the portrait of a uniform bulk DFB laser with 0.1% facets driven at 160-mA. This shows the initial transient tends towards a quasi-steady-state before the laser heads towards an instability. After the onset of instability, the laser increases in frequency and lowers in power to point 'A', then produces a large chirped pulse 'P' before heading back up in frequency to 'A'. The relaxation frequency is 1-GHz.

4. Phase Portraits of a tunable passive-DBR/FP laser

It is well known that Fabry-Perot lasers with an extended DBR region with a high bandgap will provide discontinuous tuning over several modes of the Fabry-Perot region [2]. However, the transient dynamics of tuning are important to prevent or minimize crosstalk into working channels during turn-on or re-tuning. Phase portraits map out the extent of the frequency and power deviation of a tuned laser, as shown in Fig. 4. The laser was tuned by applying a 0-400 mA ramp waveform to its passive region over 12.8 ns. This leads to a nonlinear change in index because of the high-order recombination coefficients. However, the laser will hop by equal frequency intervals due to its Fabry-Perot cavity. The hopping induces power fluctuations as during tuning, and transient chip as the active regions power changes.

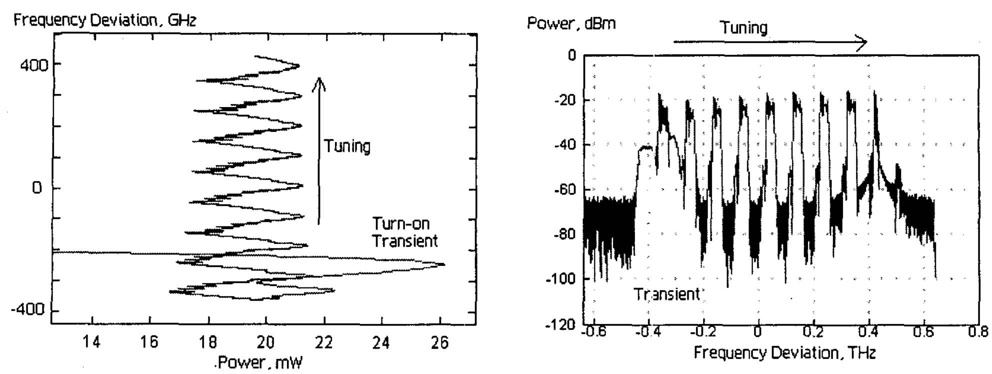

Fig. 4. Phase portrait and time-averaged optical spectrum during tuning of a FP-DBR laser.

Conclusions

Phase portraits give an instantly recognizable fingerprint of the dynamic operation of lasers, and the important interplay between optical frequency and optical power. The systems implications are easily judged, as frequency excursions at low powers are relatively unimportant to the performance of a system. Instantaneous frequency and power are now measurable using commercial instrumentation, so that a simple change of graph axis will enable lasers to be characterized in this informative way.

References

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[7] The Photonics Transmission Design Suite is a product of Virtual Photonics Inc.