Low Sensitivity to Optical Feedback and Optical Injection of Discrete Mode Lasers

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Extremely low-cost semiconductor lasers are key components for a wide range of applications, including sensors and optical communications [1]. Manufacturing method and packaging have a decisive impact on costs. As a consequence, cost reduction must be based on a simplification of the fabrication and/or the packaging of the laser, such as direct coupling of the laser to the fiber [2]. However, most single-mode semiconductor lasers, like DFB lasers, require the introduction of an optical isolator between the laser and the coupling fiber in order to avoid alteration of their performances due to optical feedback [3]. Although, external optical feedback resistant DFB and VCSEL lasers were developed and recently demonstrated [4], [5], their fabrication cost remains high. The main drawback of VCSEL lasers is due to the high dependence of their emitting wavelength on the variations in thickness of the structure's epitaxial layers [6]. Such stringent fabrication conditions lead to an increase of their cost. On the other hand, fabrication of DFB lasers requires both extremely high resolution lithography and two or more epitaxial growth steps. The latter requirement particularly affects the reliability of DFB lasers, increasing their price.

In this communication, we demonstrate the low sensitivity to both external optical feedback and external optical injection of a new type of extremely low cost single-mode lasers, called "Discrete Mode" (DM) lasers. The concept of these lasers was built on the work of DeChiaro who demonstrated that the emission spectrum of a laser diode can be altered by introducing one or more artificial index perturbations in the laser cavity [7]. DM lasers are then obtained from ridge waveguide Fabry Perot (FP) lasers, in which the effective refractive index of the lasing mode has been perturbed. The perturbation of this index can be achieved by etching features into the ridge waveguide such that each feature has a small overlap with the transverse field profile of the unperturbed mode. Most of the light in the laser cavity is therefore unaffected by these perturbations whereas a proportion of the propagating light is reflected at the boundaries between the perturbed and the unperturbed sections. It has been demonstrated that suitable positioning of these interfaces allows the mirror loss spectrum of a FP laser to be manipulated in order to achieve single longitudinal mode emission (by reducing the threshold gain of an individual cavity mode below that of the other cavity modes) [8]. Note that the fabrication process does not involve epitaxial re-growth and requires only standard optical lithography. These two facts mean that these devices are cheaper to manufacture than DFB lasers.

The devices under study in this communications are a DFB and a DM laser, both commercially available and packaged in fiberised hermetically sealed packages. The DFB laser is characterised by an emission wavelength of 1545 nm, a threshold current of 9.9 mA and has an efficiency of 0.096 W/A. The DM laser has an emission wavelength of 1548.02 nm associated with a threshold current of 15.6 mA and has an efficiency of 0.09 W/A. All of these measurements have been made at 25ºC.

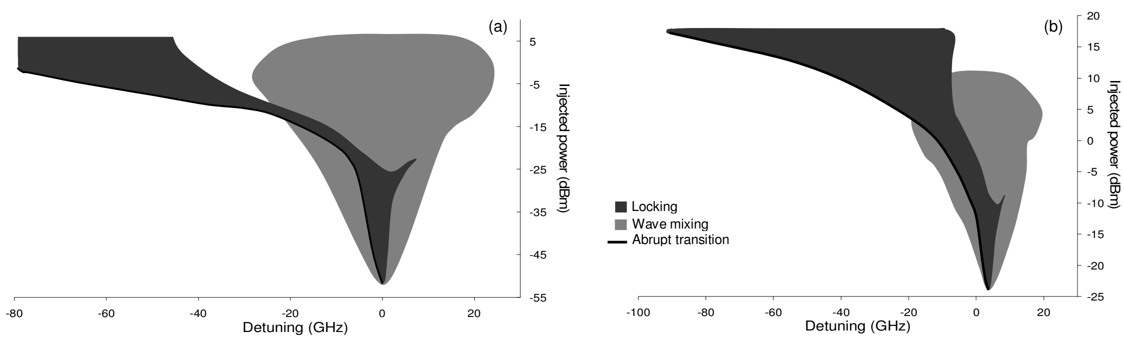

Figure 1: Measured mapping of the regimes encountered when a DFB (a) and a DM (b) lasers, biased at 4 I_{th}, are injected.

Figure 1 presents measured mappings of the locking and wave mixing regimes encountered when a DFB laser (a) and a DM laser (b), biased at four times their threshold, are submitted to external optical injection. The experiment consists of a unidirectional coupling, imposed by the presence of an optical isolator, between two lasers: the Master Laser (ML), which is injected into the Slave Laser (SL) without affecting the ML. The ML is a commercially available single mode tunable external cavity semiconductor laser, with a precision of 1 pm (125 MHz), which delivers a power up to 3 mW. This power can be increased thanks to a polarization maintaining (PM) optical amplifier (+23 dB), which contains a high coefficient isolator (70 dB isolation) that ensures unidirectional injection from the master to the slave. Moreover, all the devices of the set up are PM, so that a good reproducibility of the results can be observed. The main difference between the behaviour of these two types of single mode lasers under optical injection lies in a lower sensitivity to optical injection for a DM laser, as shown by Figure 1. In fact, the first effects of optical injection for a DM laser are observed for injected powers of at least -25 dBm, whereas an injected power of -53 dBm is sufficient to perturb a DFB. This observation tends to indicate that the use of DM lasers for optical injection purposes is limited since much higher injected powers are required than those required by DFB lasers. However, these results can be considered as a first demonstration of the low sensitivity of these lasers to optical feedback.

To further confirm these observations, the impact of optical feedback on the laser performances has been studied. Even if five distinct regimes, based on spectral observation, can be observed in 1.55 µm semiconductor DFB lasers [3], we mainly focus this study on the evolution of the coherence collapse threshold when the emitted power of the laser is varied. In fact, the coherence collapse regime is known to be the regime that considerably alters the dynamic performances of lasers in transmission. It has been already theoretically [9] and experimentally [10] demonstrated that the penalty degradation in the bit error rate (BER) plots is strongly linked to the threshold of the coherence collapse regime.

These characterizations were done using the setup sketched in Figure 2(a). The laser was coupled to a back reflector through a polarization control element. Polarization was adjusted so as to have the reflected light in the transverse electric (TE) laser mode. A calibrated back reflector monitor was used to check the amount of reflected light. The laser spectra, in presence of optical feedback, were then recorded with an optical spectrum analyzer characterized by a resolution of 10 pm. The amount of injected feedback into the laser is defined with the ratio (return–loss ratio) $RL=P_1/P_0$ through the variable feedback reflector, where P_0 and P_1 are the powers that are injected into the fiber and reflected by the system respectively (Figure 2(a)). The amount of light which effectively returns to the chip depends on the optical coupling efficiency of the device to the fiber, C (C=3.5 dB for the DFB laser and 2.6 dB for the DM laser). The amount of light reflected towards the laser cavity is given by the relation $\Gamma_{dB}=RL_{dB}-2C_{dB}$. The coherence collapse threshold is the amount of reflected light, Γ_{dB}, required to induce coherence collapse. Figure 2(b) displays the evolution of this threshold as a function of the laser output power, $P_{out}=P_0+C_{dB}$. The threshold increases with P_{out}, and at 10.5 dBm output, the threshold is -17.1 dB and -22.1 dB for DM and DFB lasers respectively.

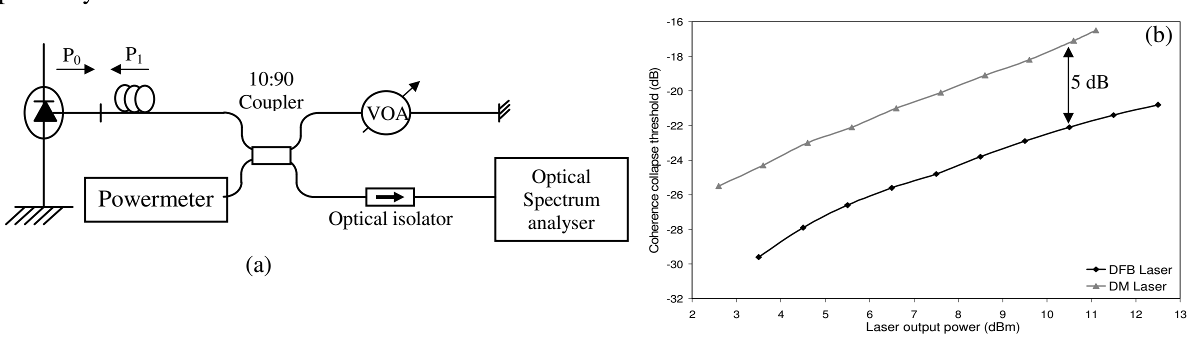

Figure 2: (a) Experimental setup for feedback study. (b) Evolution of the coherence collapse threshold against the laser emitted power.

By employing a new type of low-cost single mode semiconductor lasers, the DM lasers, we demonstrated a reduction of 28 dB of the laser sensitivity to external optical injection in comparison to a commercially available DFB laser. These lasers also exhibit a low sensitivity to external optical feedback since the coherence collapse threshold is around 5 dB higher in comparison to a commercial DFB laser.

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