2.5-Gb/s Transmission Characteristics of 1.3-μm DFB Lasers With External Optical Feedback

F. Grillot, B. Thedrez, J. Py, O. Gauthier-Lafaye, V. Voiriot, and J. L. Lafragette

***Abstract*—All-optical networks will require low-cost laser source. In order to reduce the packaging cost and to design a module without optical isolator, the 2.5-Gb/s 300-ps/nm transmission characteristics of 1.3-μm distributed-feedback lasers is analyzed in the presence of strong external optical feedback. The penalty degradation when the laser is operating under optical feedback is discussed and its dependence with the coherence collapse onset is analyzed. Although a drastic increase of the penalty with the coherence collapse state is reported, floor-free operation is demonstrated with a return loss as high as −8 dB.**

***Index Terms*—Coherence collapse, feedback, laser diodes, transmission.**

I. Introduction

THE EXTENSION of today's optical networks to the home requires the development of extremely low-cost laser sources [1]. While wafer fabrication techniques allows massive production, packaging remains a cost bottleneck, as it is not supported by parallel processing. Cost reduction must, therefore, be based on packaging simplification, such as flip-chip bonding and direct coupling of the laser to the fiber [2]. However, such direct coupling requires the suppression of the isolator which, at rates over the gigahertz range, continues to remain a challenge. Floor-free transmissions have already been reported at 85 °C at 2.5 Gb/s under strong feedback regime [3], [4]. In this letter, we demonstrate floorless 2.5-Gb/s transmission under −8-dB return loss with 1.3-μm distributed-feedback (DFB) lasers. We discuss the penalty evolution when the laser operates under optical feedback and demonstrate the feasibility of floor-free transmission even above the coherence collapse state [5]. These results are very promising for high-performance laser to fiber connection without the need for any optics or optical isolator, and open the way for all-optical telecommunication networks.

II. Design and Technology

The device under study is a DFB laser with a high-reflection coating on the rear facet and an antireflection coating on the front facet in order to allow for high efficiency. The length of the device is 350 μm. The active layer is made of nine compressively strained InAsP quantum wells separated by InGaAsP tensile strained barriers. The optical confinement was provided by two Q1.1-μm 70-nm wide separate confinement layers. The 2″ grating was defined using holographic techniques and etched in a passive layer located above the upper separate-confinement-heterostructure. After a grating planarization regrowth using molecular beam epitaxy, the active region was etched and then buried using metal–organic vapor phase epitaxy (MOVPE), as for standard buried ridge structures (BRSs) [6]. The threshold current value is typically 8 mA with an average efficiency of 0.35 W/A at 25 °C and 0.2 W/A at 85 °C.

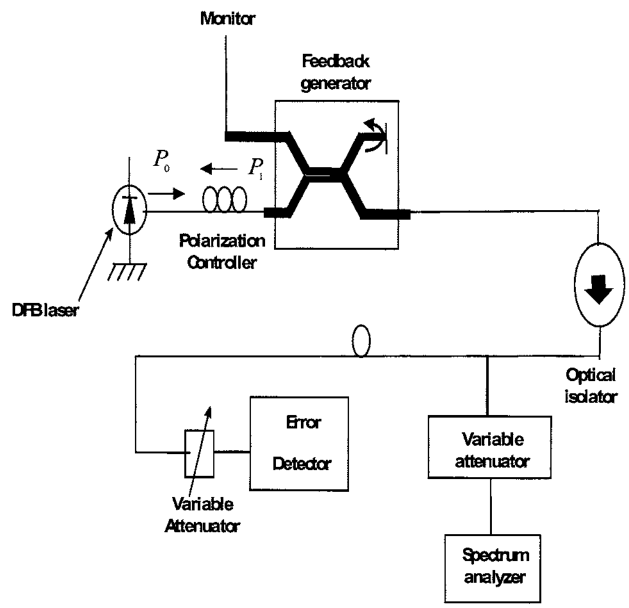

Fig. 1. Experimental setup for feedback study under 2.5 Gb/s with a 300-ps/nm dispersion fiber.

III. Measurements and Results

A. Experimental Setup

We used the transmission test setup sketched in Fig. 1. The laser was coupled to a back reflector apparatus through a polarization control element. The distance between the laser and the external reflector was optically measured to be $L_e = 13.6$ m which corresponds to a roundtrip time of $\tau_e = 130$ ns. 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 back reflector was designed so as to allow direct transmission into the 300-ps/nm dispersion transmission line. These experiments were performed at 298 K with the laser biased at an

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average output power of 10 mW under modulation. The laser was coupled to the transmission line by using an enlarged mode fiber and a 300-ps/nm fiber dispersion with 5-mW power coupled into the fiber. The behavior under high extinction ratio (ER) was carefully studied without optical feedback. Devices under study showed no floor down to 10^{-12} and penalties lower than 0 dB at T = 298 K with ER = 13 dB. The evaluation of the resistance to feedback was then carried out under 13-dB ER for DFB lasers with efficiency in the range from 0.32 W/A to 0.45 W/A and an average of 0.41 $\pm$ 0.04 W/A. The experimental value of the sidemode suppression ratio (SMSR) was $\approx$45 dB at 10 mW. The laser spectra were recorded in presence of optical feedback with an optical spectrum analyzer having 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, respectively, the powers that are injected into the fiber and reflected by the system (Fig. 1). The amount of light which effectively returns into the laser depends on the optical coupling loss of the device to the fiber which was kept to about C = 3 dB during the whole experiment. The amount of light Γ injected into the laser cavity is given by the relation

$$\Gamma_{\mathrm{dB}} = RL_{\mathrm{dB}} - 2C_{\mathrm{dB}}.$$

The amount of light injected into the cavity Γ range from -47 dB to -14 dB. In what follows, we suggest to look closer at the characteristics of the transmission in presence of external optical feedback.

B. Transmission Measurements Analysis

In this paragraph, we investigate the effects of the feedback on the transmission of 1.3-μm DFB lasers. Five distinct regimes of feedback based on spectral observation were reported for 1.55-μm DFB lasers [7]. However, as the length of the external cavity (L_e = 13.6 m) is large, not all regimes of feedback were observed in our experiments. The feedback impact on the transmission was carefully studied for several regimes: first, for the lowest level of feedback $\Gamma = -47$ dB, second for $\Gamma = -33$ dB, and then for $\Gamma = -14$ dB when the laser operates under the coherence collapse state [5]. The experimental coherence collapse threshold value Γ_C is comprised between -20 dB and -25 dB for all the lasers that we have studied. Moreover, the spectra relatives to the different regimes were also measured. In Fig. 2(a), the spectra for the lower level of feedback ($\Gamma = -47$ dB) is shown. The laser line operates on a single longitudinal mode with a weak impact of the external optical feedback. In Fig. 3, the bit-error-rate (BER) plots are measured. In solid line (a), the back-to-back curve without feedback can be compared with transmission [solid line (b)] at $\Gamma = -47$ dB. The value of the sensibility and penalty at 10^{-10} are, respectively, -34.8 dBm and $\approx$0 dB, with no floor above 10^{-12} BER. As the feedback level increases, harmonic spectral oscillation peaks on the emission profile can be observed. Peaks are located at multiples of the relaxation frequency f_r which is about 8 GHz at 10 mW. The amplitude of these oscillations is enforced when the feedback increases. Nevertheless, the penalty only increases from 0 dB (for $\Gamma = -47$ dB) to 0.2 dB (for $\Gamma = -33$ dB). The impact of the feedback on the transmission under these regimes is remarkably weak. Moreover, for $\Gamma = -33$ dB [Fig. 2(a)], a splitting at the top of laser spectrum attributed to mode hopping with a separation of $\approx$25 pm can be observed [7]. For $\Gamma = -20$ dB, the laser operates at the beginning of the coherence collapse regime. In Fig. 2(b), a typical spectra corresponding to this regime is shown (for $\Gamma = -14$ dB). This regime does not depend on the external cavity length and the feedback phase [7]. The main effect of this regime is a drastic reduction in the coherence length of the laser, namely, an important increase of the spectral linewidth. The linewidth at -20 dB is about 45 GHz compared with $\approx$10 MHz for the spectra without optical feedback. In Fig. 3, the result in transmission is presented [solid line (c)]. The penalty at 10^{-10} under such strong reflection is shifted to 1.6 dB but no floor is observed above 10^{-12} BER. The value of the sensitivity is about -33.9 dBm. The same behavior in transmission with penalty less than 0.9 dB can be obtained for all the lasers under test with efficiency ranging from 0.32 W/A to 0.45 W/A. Floor-free operation was realized for all the measurements. In Fig. 4, we show the penalty versus the level of feedback. The coherence collapse threshold for this laser is represented by a dark square line ($\Gamma_C = -24$ dB). In Fig. 4, the penalty difference between the back-to-back without feedback and the back-to-back with feedback is represented (solid line). The penalty difference between back-to-back with feedback and transmission with feedback is also shown (dotted line). In all cases, before the coherence collapse regime, the penalty increase remains insignificant. On the other hand, when the feedback level is greater

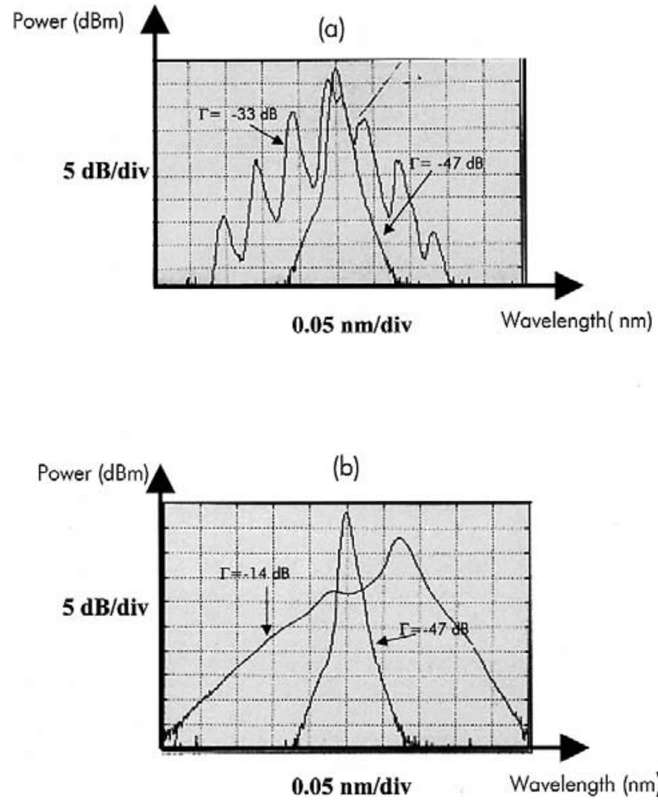

Fig. 2. Experimental spectra at 10 mW under feedback operation. (a) For $\Gamma = -47$ dB and $\Gamma = -33$ dB; $\lambda\mathrm{peak}$ = 1303.6 nm. (b) For $\Gamma = -47$ dB and $\Gamma = -14$ dB (coherence collapse regime); $\lambda\mathrm{peak}$ = 1303.6 nm.

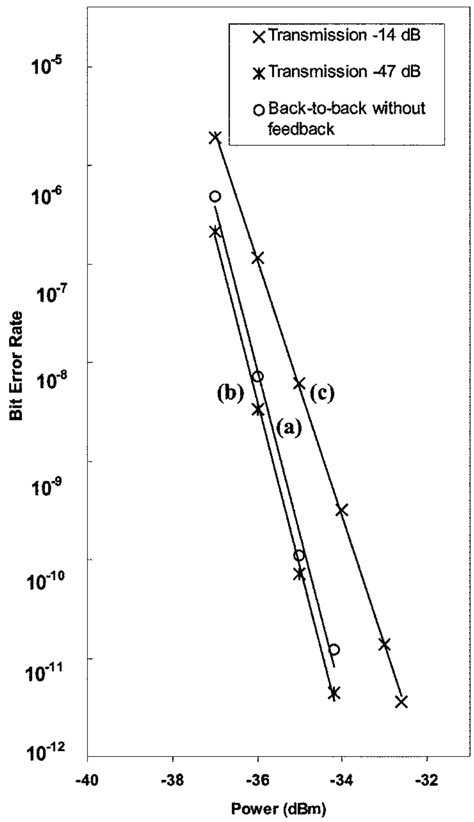

Fig. 3. BER at 2.5 Gb/s with a 330-ps/nm dispersion fiber under various optical feedback with ER $= 13$dB, temperature T $= 298$K, and laser output power P $= 10$ mW. (a) Back-to-back without feedback. (b) Transmission for $\Gamma = -47$ dB. (c) Transmission for $\Gamma = -14$ dB.

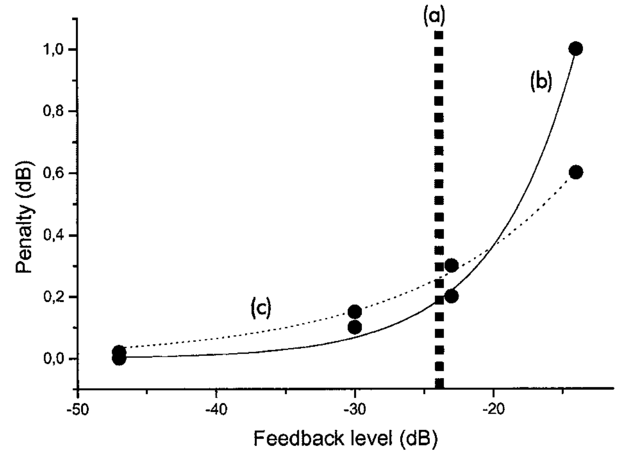

Fig. 4. 2.5-Gb/s 300-ps/nm transmission penalty versus return loss. (a) Vertical dotted line: Coherence collapse threshold ($\Gamma c = -24$ dB). (b) Solid line: Penalty between back-to-back without feedback and back-to-back with feedback. (c) Dotted line: Penalty between back-to-back with feedback and transmission with feedback.

than the coherence collapse regime, a drastic penalty increase is observed. This is consistent with the theoretical results of [8]. However, a more gradual increase of the penalty than predicted in [8] is measured, and a range of feedback level can be found where transmission under coherence collapse is feasible. This behavior of the penalty in presence of feedback is reproducible for all the lasers, and can be obtained without the use of a partially corrugated grating such as in [3]. In Fig. 4, the sum of the two penalties increases from 0 to 0.2 dB before the coherence collapse regime leading to 1.6 dB after this regime, a typical value for all measured devices. This increase can be explained through two major physical effects. Firstly, on the solid line plot (c), only the impact of the intensity noise due to feedback is represented. When the laser operates in transmission, the phase noise and the chirp is converted into intensity noise by the fiber. This results in an extra penalty which is depicted on the dotted line (b). It can be seen that the phase induced penalty mostly appears above the coherence collapse. As compared with the case without transmission, phase noise adds only a 0.6-dB penalty for $\Gamma = -14$ dB. Hence, the feedback induced phase penalty degradation is much weaker even under 300 ps/nm than the one created by intensity noise.

IV. Conclusion

We have presented the characteristics of 1.3-μm DFB lasers for 300-ps/nm 2.5-Gb/s transmission in presence of external optical feedback. A full analysis of the transmission for several regimes has been realized. We have experimentally demonstrated that the penalty degradation remains low below and increases steeply above the optical chaotic state, although floor-free transmission is still possible. In that case the penalty degradation is mostly induced by intensity noise rather than frequency noise, even under 300-ps/nm dispersion. In conclusion, we have demonstrated 2.5-Gb/s transmission with no floor and low penalties above the coherence collapse regime allowing the use of 1.3 μm directly modulated DFB laser for high bit rate and long distance transmissions without optical isolator.

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