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Effects of the Injected ASE Bandwidth on the Performance of Wavelength-locked Fabry-Perot Laser Diodes

Kun-Youl Park, Jin-Serk Baik, and Chang-Hee Lee

Dept. of Electrical Engineering and Computer Science, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong Youseong-gu, Daejeon, 305-701, KOREA

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We investigate effects of the injected ASE (Amplified spontaneous emission) bandwidth on the performance of the wavelength-locked Fabry-Perot laser diodes (F-P LDs) under constant injection power density and constant injection power. For the constant injection power density, we can determine the minimum injection bandwidth by the required intensity noise or the bit-error rate (BER) performance. On the other hand, there exists the optimal ASE bandwidth for the constant injection power to minimize the intensity noise.

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I. INTRODUCTION

There have been several attempts to implement a cost-effective WDM (Wavelength division multiplexed) source for optical access networks [1-3]. Recently, a wavelength-locked Fabry-Perot laser diode (F-P LD) with external narrow-band ASE injection was proposed. It is very attractive because of its cost effectiveness and wavelength self-management characteristics [1]. The injected ASE forces the F-P LD to operate as a quasi-single mode and suppresses the mode partition noise. The F-P LD also has suppressed the intensity noise of the injected light. However, the output intensity noise of the wavelength-locked F-P LD is larger than that of the coherent light, since the injected ASE has the intensity noise (ASE-ASE beating noise) that depends on the bandwidth of the spectrum sliced ASE [4]. As we decrease the bandwidth of the injected ASE, the noise performance of the wavelength-locked F-P LD gets worse. On the other hand, the system capacity of the WDM-PON (wavelength division multiplexed passive optical network) may be increased, since we can use a narrow-band filter for the spectrum slicing. Thus it is important to understand effects of the injected ASE light bandwidth on the performance of the wavelength locked F-P LD.

In this letter, we investigate the effects of the injected ASE bandwidth on the performance of the wavelength-locked Fabry-Perot laser diodes under the constant injection power density and the constant injection power. From this result, we can estimate the maximum capacity of the WDM-PON using wavelength-locked F-P LDs based on the optimum injection bandwidth.

II. EXPERIMENTAL RESULTS

The experimental setup to measure the relative intensity noise (RIN) of the wavelength-locked F-P LD is shown in Fig. 1. The mode spacing of the F-P LD was 75 GHz. The front facet of the F-P LD was anti-reflection coated in order to increase the ASE injection efficiency and to reduce the reflected power. The measured reflectivity was about 1 %. The receiver bandwidth was 110 MHz for 155 Mb/s signal transmi-

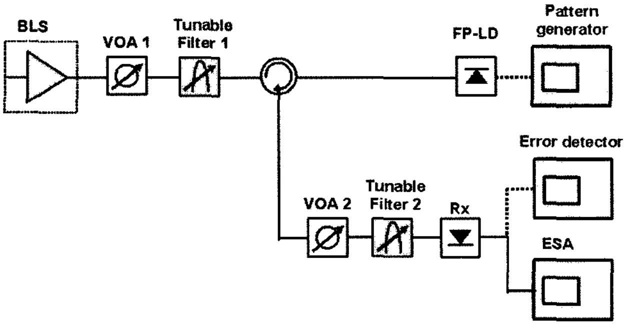

FIG. 1. The experimental setup. (BLS: broad band light source, VOA: variable optical attenuator, Rx: Receiver, FP-LD: Fabry-Perot laser diode, ESA: electrical spectrum analyzer).

ssion. The narrow-band ASE was generated from the BLS and the tunable optical filter 1. It was injected into the F-P LD through the optical circulator. The optical power in front of the receiver was maintained constantly for RIN measurement by VOA2 (Variable optical attenuator).

The measured optical spectra of the wavelength-locked F-P LD are shown in Fig. 2. The F-P LD oscillates in multimode without the narrow-band ASE injection. When we injected the ASE into the F-P LD, the laser oscillates in a quasi-single mode. The bias current of the F-P LD is 1.5 I_{th}, where I_{th} is the lasing threshold current. The injection power is -13 dBm. The wavelength detuning between the narrow-band ASE and one of F-P LD modes is 0 nm. We maintained these parameters for the RIN measurement.

To characterize the RIN of the wavelength-locked F-P LD, we consider both the constant injection power and the constant injection power density. The constant injection power means that the power injected into the F-P LD is a constant, while the constant injection power density implies that the ASE power density injected into F-P LD is a constant.

The RIN of the wavelength-locked F-P LD with the constant injection power density was measured as a function of the bandwidth of the injected ASE. The results are shown in Fig. 3 (a). For comparison, we also show the RIN of the injected ASE itself. It is inversely proportional to the bandwidth of the ASE as shown by the thick solid line [4]. The RIN of the wavelength-locked F-P LD output was smaller than that of the input ASE. In other words, the wavelength-locked F-P LD suppresses the input intensity noise. As the filter bandwidth increases, the RIN of the wavelength-locked F-P LD is improved because the RIN of the injected ASE decreases. However, the intensity noise suppression ratio, i.e. the difference of the RIN between the output of the wavelength-locked F-P LD and the injected input ASE, decreases as we increase the ASE bandwidth. The injected ASE between the F-P LD lasing modes does not experience intensity noise suppression. Therefore, the intensity noise suppression ratio decreases as we increase the injection bandwidth.

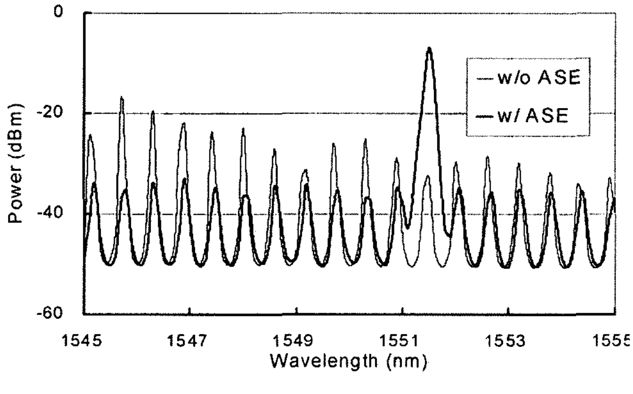

FIG. 2. Optical spectra of the wavelength-locked F-P LD.

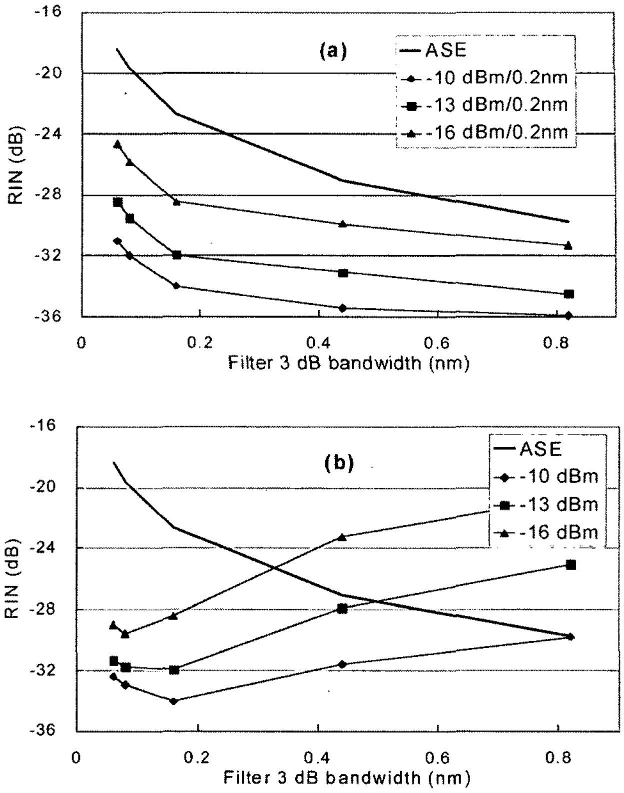

FIG. 3. Measured RIN for (a) constant injection power density and (b) constant injection power.

The RIN of the wavelength-locked F-P LD is decreased by increasing the injected power density, since the injection effect on the F-P LD gets stronger. The origin of the RIN improvement of the wavelength-locked F-P LD is the gain suppression due to the injected ASE. The intensity noise suppression ratio decreases, as the power density increases.

When we injected the ASE light into the F-P LD with constant power density, the output RIN decreases monotonically with the injection bandwidth, as shown in Fig. 3(a). Then, the minimum bandwidth can be determined by the RIN that satisfies the required bit-error rate. In our preliminary experiment, we could achieve error-free transmission when the RIN was less than -26 dB. For example, when the injected power density is -16 dBm/0.2nm, the minimum ASE filter bandwidth is about 0.1 nm. In this case, the intensity noise suppression ratio is about 6 dB. The minimum bandwidth can be decreased by increasing the injection power density.

The RIN of the wavelength-locked F-P LD was measured also under the constant injection power. The result is summarized in Fig. 3 (b). For each curve, there exists the optimal bandwidth of the injected ASE to minimize the output RIN. For example, the optimal filter bandwidth is about 0.1 nm at -16 dBm injection power. As the filter bandwidth increases, the power density of the injected ASE decreases. Then, the RIN of the wavelength-locked F-P LD increases eventually. On the other hand, as the filter bandwidth decreases, the RIN of the injected ASE increases. It brings about asymptotic increase of the RIN of the wavelength-locked F-P LD output for narrow injection bandwidth. Thus between these two extreme cases, we have the optimum bandwidth to minimize RIN. The optimal filter bandwidth broadens when we increase the injected ASE power. As the injection power increases, the intensity noise suppression ratio decreases and the optimum ASE bandwidth shifts to the wider bandwidth side.

In certain conditions, unlike the constant power density case, the output of the wavelength locked F-P LD under the constant injection power has higher RIN compared with the injected ASE as shown in Fig. 3(b). In this case, the injection power density is not enough and the mode partition noise is not suppressed sufficiently. Therefore, the intensity noise of the wavelength-locked F-P LD is increased.

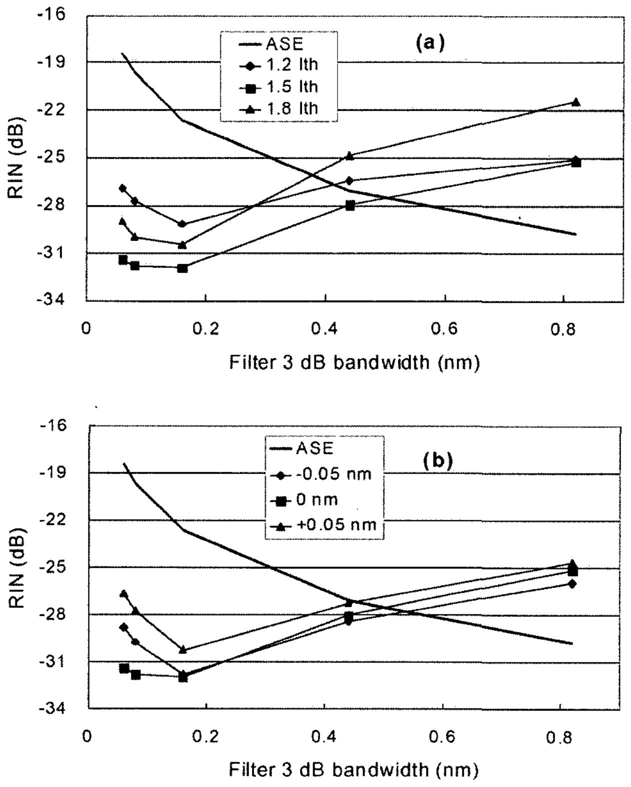

FIG. 4. Measured RIN with (a) different bias conditions at injection power of -13 dBm and (b) different wavelength detuning at bias current of 1.5 I_{th}.

To investigate the effects of the bias current and the detuning between the injection wavelength and the F-P LD mode, we measured the RIN of the wavelength-locked F-P LD under the different bias current and the wavelength detuning, respectively. The injection power is -13 dBm and the bias current is 1.5 I_{th}. As shown in Fig. 4, the optimal bandwidth weakly depends on the bias current and the detuning.

We also measured the bit-error rate (BER) curves for the constant injection power density and the constant injection power. The measurement results are shown in Fig. 5. The operating conditions of the wavelength-locked F-P LD are the same as for the Fig. 1. The injection power and the injection power density were -16 dBm and -16 dBm/0.2nm, respectively. The wavelength-locked F-P LD was modulated at 155 Mb/s. The BER performance is improved by increasing the injected ASE bandwidth for the constant injection power density (See Fig. 5 (a)), while it has the optimal value of the bandwidth for the constant injection power (See Fig. 5 (b)). The optimum value for the best BER is very similar to that of the best RIN.

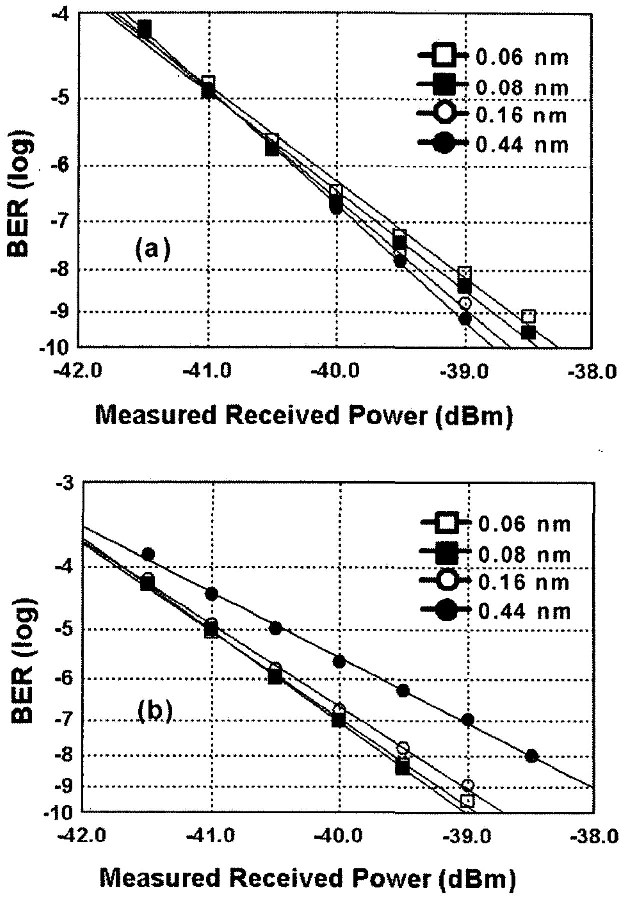

FIG. 5. Measured BER curves (a) constant power injection. (b) constant power density injection.

III. DISCUSSION AND CONCLUSION

The BLS is usually implemented by EDFAs (Erbium-doped fiber amplifiers). The total output power of the BLS over the total bandwidth can be determined by the pump power. If we use a comb filter in the mid-stage of the EDFA, we can increase the power at the pass band of the comb filter. In this case, the bandwidth of the injected ASE is determined by the comb filter. Even though the ASE bandwidth is varied, the optical power of each pass band is nearly constant because of the highly saturated EDFA. Therefore, the above result of the constant injection power is used to determine the optimal ASE bandwidth. If the comb filter is not used in the BLS, the result of the constant injection power density can be used to determine the minimum injection bandwidth.

In conclusion, we investigate the noise performance of the wavelength-locked F-P LD as a function of the injection bandwidth. There exists the minimum injection bandwidth that is determined by the required BER performance, when the injection power density is a constant. For the constant power injection, we have the optimal injection bandwidth which gives us the minimum RIN. With either the minimum or the optimum bandwidth, we can maximize the system capacity of the WDM-PON using wavelength-locked F-P LDs. For example, when the injected power density is -16 dBm/0.2nm, the optimal ASE bandwidth is about 0.1 nm. The BLS is implemented by EDFAs and its bandwidth is about 32 nm. When the comb filter period is 0.2 nm to have 0.1 nm bandwidth, we can accommodate 160 optical channels at 155Mb/s. Therefore, the total capacity of WDM-PON using wavelength-locked F-P LDs is about 24.8 Gb/s. When we use the spectrum-sliced ASE as the WDM source, the 3 dB bandwidth should be larger than 0.4 nm. In this case, the total capacity is reduced by a factor of 4.

* Corresponding author : chl@ee.kaist.ac.kr

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