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Impact of Optical Filter Bandwidth on Performance of All-optical Automatic Gain-controlled Erbium-doped Fiber Amplifiers

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We have investigated the impact of optical filter bandwidth on the performance of all-optical automatic gain-controlled (AGC) erbium-doped fiber amplifiers (EDFAs). In principle, an optical bandpass filter (OBPF) should be placed within the feedback gain-clamping loop to set the lasing wavelength as well as the passband of the feedback amplified spontaneous emission (ASE) in all-optical AGC EDFA. From our measurement results, we found that the power level of feedback ASE with 0.1 nm passband of the optical filter was smaller than the ones with >0.2 nm passband cases. Therefore, the peak-to-peak power variation of the surviving channel with 0.1 nm passband was much larger than the ones with >0.2 nm passband. In addition, no significant difference in the power level of the feedback ASE was observed when the passband of the optical filter was ranging from 0.2 nm to 4.5 nm in our measurements. From these results, we have concluded that the passband of the optical filter should be slightly larger than 0.2 nm by taking into account the effect of feedback ASE power and the efficient use of the EDFA gain spectrum for the lasing ASE peak.

Keywords : Erbium-doped fiber amplifiers, Automatic gain control
OCIS codes : (060.2320) Fiber optics amplifiers and oscillators; (060.2330) Fiber optics communications

I. INTRODUCTION

The function of automatic gain-control (AGC) in erbium-doped fiber amplifiers (EDFAs) is indispensable for alleviating the power excursion of the surviving channel during wavelength division multiplexed (WDM) signals add/drop multiplexing in dynamic optical transport networks [1-8]. Previously, many different approaches have been proposed and implemented to mitigate the power fluctuations of the surviving channels, such as all-optical AGC [1-4], pump power control [5, 6], link control [7], and hybrid control [8]. Among various approaches, an all-optical AGC scheme could be simply implemented by using the lasing oscillation of amplified spontaneous emission (ASE) noise to clamp the EDFA gain. In this simple all-optical AGC scheme, the performance of the EDFA could be degraded by the effects of spectral hole burning (SHB) and relaxation oscillation [9]. In [9], it has been reported that the relaxation oscillation was dominant in a long lasing wavelength (>1545 nm) while the power excursion due to the SHB was dominant on a shorter wavelength (<1540 nm). Thus the lasing wavelength of the feedback gain clamping loop should be chosen to minimize the impairments from spectral hole burning and relaxation oscillation [9]. Apparently, the performance of all-optical AGC EDFA would be also dependent on the power level of feedback ASE within the gain clamping loop. The feedback ASE could be used as an input into the EDFA during the signal add/drop multiplexing in dynamic optical transport networks. The power level of feedback ASE would be determined with the number of optical signal inputs into EDFA as well as the passband of the optical filter in the feedback gain clamping loop. Thus, in this paper, we have investigated experimentally the impact of the filter bandwidth on the performance of all-optical AGC EDFA. To optimize the optical filter bandwidth in all-optical AGC EDFA, the performance of the EDFA has

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been evaluated by changing the passband of the optical filter as well as the lasing wavelength of the feedback ASE. From our measurement results, we have found that the narrow filter passband of <0.1 nm was not suitable for the gain clamping of the EDFA. Therefore, the passband of the optical filter should be optimized by taking into account the power level of the feedback ASE and the efficient use of the EDFA gain spectrum.

II. RESULTS AND DISCUSSION

Figure 1 shows the experimental setup for the performance evaluation of the all-optical automatic gain-controlled (AGC) EDFA. For the gain clamping in all-optical AGC EDFA, the feedback loop was implemented with two optical couplers (OCs), a tunable optical bandpass filter (OBPF), a variable optical attenuator (VOA) and a power monitor (PM). As can be seen in Fig. 1, a small portion of EDFA output was launched into the EDFA input again after passing through a 90:10 OC, a tunable OBPF, a VOA, a PM and a 3-dB coupler. The lasing wavelength and the 3-dB bandwidth of the feedback ASE were adjusted with a tunable OBPF which could change the 3-dB passband as

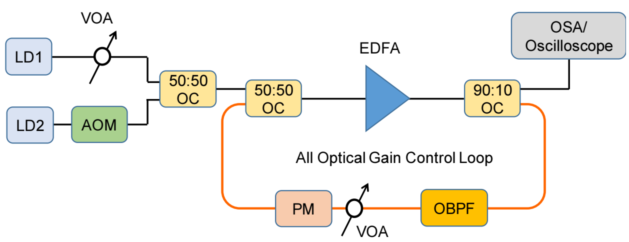

FIG. 1. Experimental setup for the performance evaluation of all-optical automatic gain-controlled (AGC) erbium-doped fiber amplifier (EDFA). Acronyms are Laser Diode, LD; Acousto-Optic Modulator, AOM; Variable Optical Attenuator, VOA; Optical Coupler, OC; Erbium-Doped Fiber Amplifier, EDFA; Optical Band Pass Filter, OBPF; Power Monitor, PM; Optical Spectrum Analyzer, OSA.

well as the center wavelength of the filter. The power level of the feedback ASE could be also adjusted with a VOA. Then the power level of the feedback ASE was measured with a PM to evaluate the impact of the feedback ASE power on the performance of all-optical AGC EDFA. Two laser diodes (LDs) were used to simulate a surviving channel and a signal add/drop multiplexing in optical transport networks. LD1 operating at a wavelength of 1553.328 nm (@ 193 THz) was used as a surviving channel while LD2 (@ 1550 nm) was used to simulate the signal add/drop multiplexing in a dynamic network environment. The power levels of LD1 and LD2 into the EDFA were measured to be -21.08 dBm and -9.14 dBm, respectively. The power difference between the LD1 and LD2 was around 12 dB, thus LD2 could emulate 16 signal channels add/drop multiplexing compared to the power level of the surviving channel. An acousto-optic modulator (AOM) driven at 0.5 Hz was used to emulate the signal add/drop of LD2. Then, the performance of AGC EDFA was evaluated with an optical spectrum analyzer (OSA) and an oscilloscope. For the oscilloscope measurement, the surviving channel (LD1) was detected after passing through an arrayed waveguide grating for WDM demultiplexing and a photo diode.

Figure 2 shows the optical spectra of the all-optical AGC EDFA output measured with three different passbands of the tunable OBPF; 0.1 nm, 0.5 nm and 2.5 nm. The center wavelength of the tunable OBPF was set to be 1560 nm for all measurements. Here, a 1560 nm of feedback ASE was used since a longer lasing wavelength (>1545 nm) had a small power excursion than a shorter wavelength (1540 nm) [4, 9]. We have also evaluated the impact of different lasing wavelength and described in Fig. 5. For the case of 0.5 nm passband, the power levels of the feedback ASE were measured with the PM to be -9.5 dBm for LD2 drop and -11.8 dBm for LD2 add, respectively. As shown in Fig. 2(a), the output powers of the surviving channel were measured to be -2.24 dBm and -2.57 dBm for LD2 channel drop and add cases, respectively. For the case of 2.5 nm passband, the power levels of the feedback ASE were measured to be -9.4 dBm and -11.7 dBm during

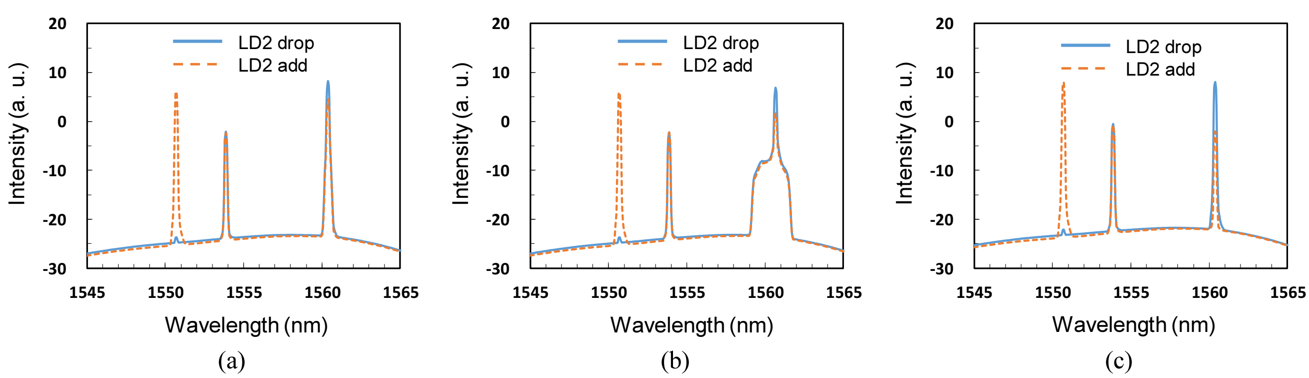

FIG. 2. Optical spectra of all-optical AGC EDFA output measured with three different passbands of the tunable OBPF: (a) 0.5 nm, (b) 2.5 nm, and (c) 0.1 nm.

the LD2 channel drop and add, respectively, which is almost equal to the case of the 0.5 nm passband. The output powers of the surviving channel were measured to -2.43 dBm and -2.56 dBm for LD2 channel drop and add cases (in Fig. 2(b)), respectively. However, for the case of 0.1 nm passband, the power levels of the feedback ASE were decreased to be -11.6 dBm and -16.8 dBm while the output powers of the surviving channel were increased to -0.7 dBm and -1.1 dBm for LD2 channel drop and add cases (in Fig. 2(c)), respectively. Due to the narrow passband of the OBPF and the reduced power level of feedback ASE, the output powers of the surviving channels were increased, which, in turn, increased the power difference of the surviving channel between the signal add and drop cases.

Apparently, the performance of the all-optical AGC EDFA would be strongly dependent on the power level of the feedback ASE. Thus, the power level of the feedback ASE was measured as a function of the tunable OBPF passband for three different power levels (three symbols; ●, ■, ▲, represent the different power level of feedback ASE with the signal add and drop cases), as shown in Fig. 3. In our measurement, the power level of feedback ASE was almost equal for all three different power levels as long as the passband of OBPF was larger than 0.2 nm (up to 4.5 nm in our measurement as shown in Fig. 3). From the results shown in Figs. 2(a) and 2(b), the power level of feedback ASE power was almost equal even though the peak feedback ASE power was decreased from 8.13 dBm for the 0.5 nm case to 6.8 dBm for the 2.5 nm case. That is to say, with a wide passband of OBPF (@ 2.5 nm), the peak power level of the feedback ASE was decreased, thus the total power within the passband of OBPF was almost identical with the 0.5 nm case. However, for the case of the 0.1 nm, the power level of feedback ASE was decreased drastically as shown in Fig. 3. From the results shown in Fig. 2(c), the power levels of lasing ASE peak were measured to be 8.02 dBm for LD2 drop and -2.02 dBm for LD2 add case. Thus, it is clear that for the case of the 0.1 nm passband, the feedback ASE power (@-2.02 dBm for signal add case) was not enough to clamp the EDFA gain due to the low power level of feedback ASE, which in turn increase the power fluctuation during the signal add/drop multiplexing. From these measurements, we found that the passband of the OBPF with the all-optical feedback loop should be larger than 0.1 nm to clamp the EDFA gain properly. In addition, no significant difference in the performance of all-optical AGC EDFA was observed when the passband of the OBPF was ranging from 0.2 nm to 4.5 nm in our measurement. We also believe that the passband of the OBPF should be narrow in order not to waste the gain spectrum of EDFA for the gain clamping.

The power fluctuations of the surviving channel during the signal add/drop multiplexing was measured as a function of the feedback ASE power with 0.5 nm passband of the tunable OBPF and a lasing wavelength of 1560 nm, as shown in Fig. 4. The peak-to-peak power variations of the surviving channel were measured with an oscilloscope when the LD2 was added and dropped. The power level of the feedback ASE in Fig. 4 represent the power for the LD2 drop case. The peak-to-peak power variation of the surviving channel was less than 40 mV as long as the power level of feedback ASE was larger than -12.5 dBm. However, the peak-to-peak power variation was increased to be larger than 200 mV when the power level of feedback ASE was reduced to be -15.5 dBm. Three insets were also included in Fig. 4, which were the power traces of the surviving channel measured with the oscilloscope.

The impact of lasing ASE wavelength on the performance of the all-optical AGC EDFA was also measured with the oscilloscope, as shown in Fig. 5. The power levels of feedback ASE were measured to be -22.1 dBm,

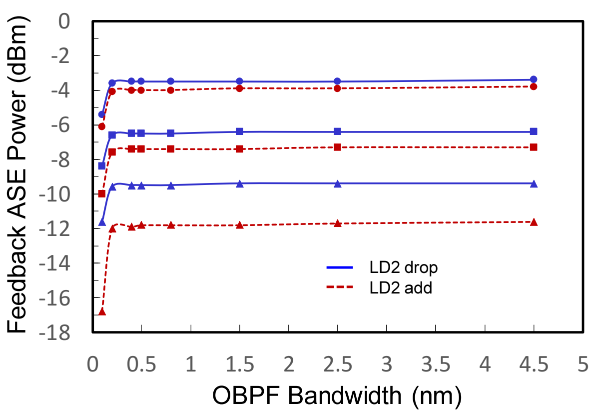

FIG. 3. Measured power of the feedback ASE as a function of the tunable OBPF passband for three different power levels. Three symbols; ●, ■, ▲, represent the different power level of feedback ASE with the signal add and drop cases.

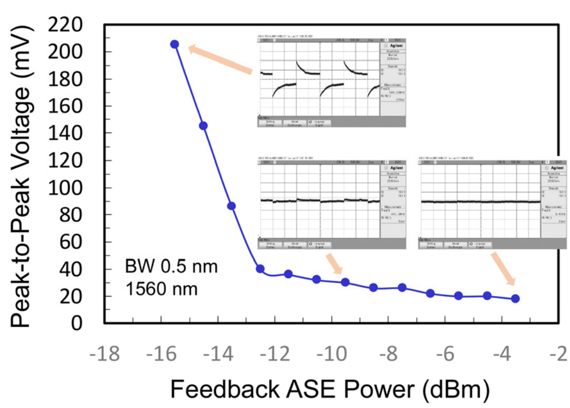

FIG. 4. Measured peak-to-peak power variation of the surviving channel during the signal add/drop multiplexing as a function of the feedback ASE power with 0.5 nm passband of the tunable OBPF and a lasing wavelength of 1560 nm. Three insets are the traces of the peak-to-peak power variation of the surviving channel with three different powers of the feedback ASE.

-11.9 dBm and -5.2 dBm for the lasing wavelength of 1535 nm, 1540 nm and 1545 nm with 0.5 nm passband of the tunable OBPF in Figs. 5(a), 5(b) and 5(c), respectively. This reduced power level of feedback ASE for a shorter wavelength compared to the case of 1560 nm in Fig. 5(d) was mainly caused by the driving condition of our all-optical AGC EDFA [10]. In other words, the power level of feedback ASE would be dependent on the driving condition of AGC EDFA, thus this power reduction in a shorter wavelength would not happen generally. However, it is clear that the power level of feedback ASE for the different wavelength would be also decreased with a narrow passband of the OBPF even though the ASE power level of the different wavelength is dependent on the EDFA driving condition. In Fig. 5, the passband of the OBPF was set to be 0.5 nm for the comparison of the different lasing wavelengths. One thing we have found is that the peak-to-peak power variations of the surviving channel in shorter wavelengths (Figs. 5(a)-5(c)) were larger than the one in 1560 nm of lasing wavelength (Fig. 5(d)). For example, with the ~-12 dBm power of the feedback ASE power, the peak-to-peak power variations of the surviving channel were measured to be 466 mV for the lasing wavelength of 1540 nm (in Fig. 5(b)) and ~40 mV for the lasing wavelength of 1560 nm (in Fig. 4), respectively. These results agreed well with the claim in [9], where a shorter wavelength (<1540 nm) had a larger power excursion than a longer wavelength (>1545 nm). Thus, regarding the peak-to-peak power variation of the surviving channel, we have re-confirmed that the 1560 nm of lasing wavelength would have a better performance than the 1535 nm or 1540 nm.

III. SUMMARY

The impact of optical filter passband on the performance of all-optical AGC EDFA has been evaluated with an OSA and an oscilloscope. From our measurement, the performance of all-optical AGC EDFA would be strongly dependent on the power level of the feedback ASE. We found that the power level of feedback ASE was not high enough to clamp the EDFA gain during the WDM signal add/drop multiplexing with a narrow passband of optical

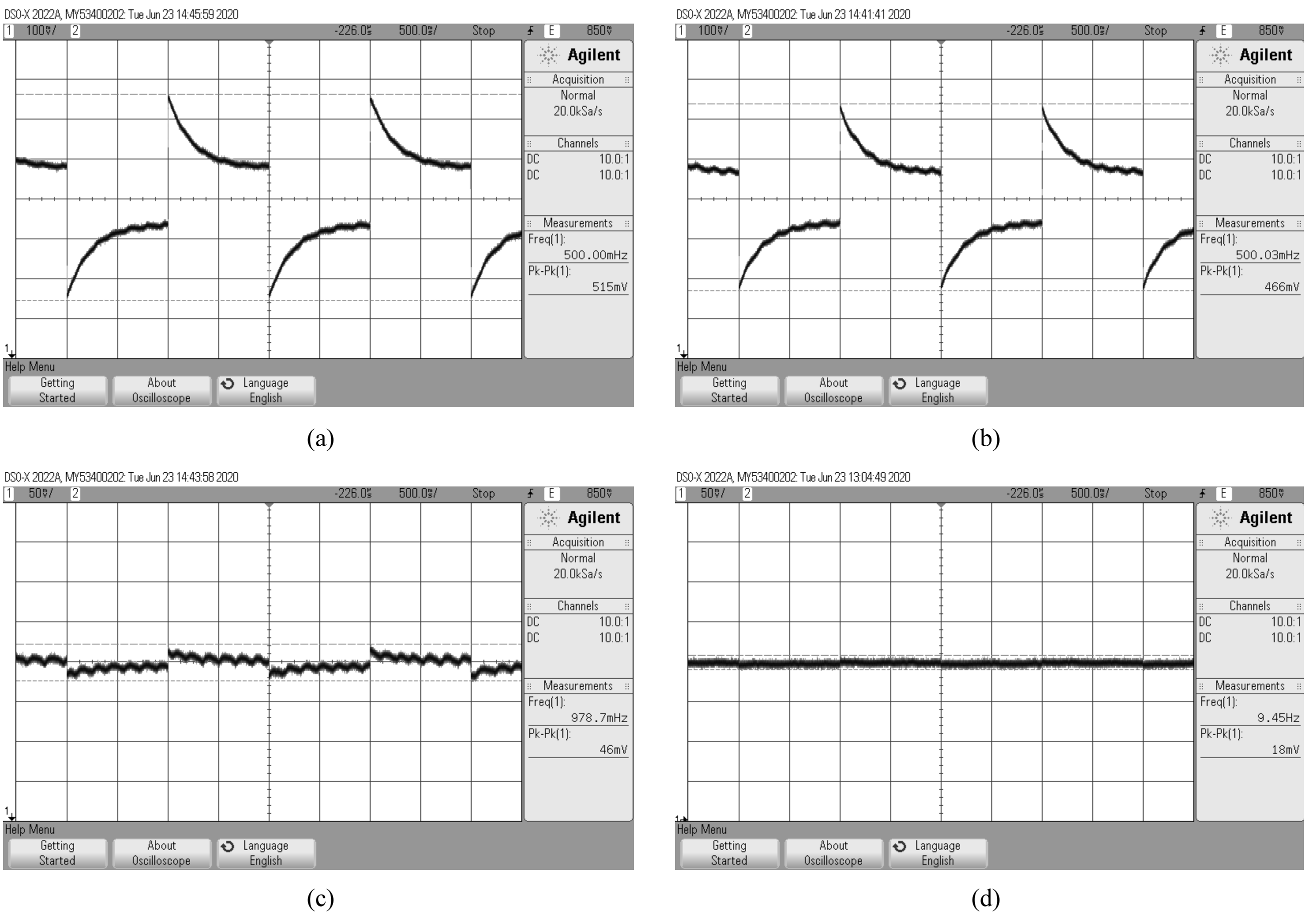

FIG. 5. Measured traces of the power of the surviving channel with the LD2 signal add/drop multiplexing with a lasing wavelength of (a) 1535 nm, (b) 1540 nm, (c) 1545 nm, and (d) 1560 nm. The passband of the tunable OBPF was set to be 0.5 nm for all measurements.

filter. Thus, the power fluctuation of the surviving channel was increased with a narrow passband (~0.1 nm) of the optical filter within the feedback gain clamping loop, compared to the wide passband of the filter. In addition, with an optical filter passband of >0.2 nm (up to 4.5 nm in our measurement), no significant difference in the feedback ASE power and the power fluctuations of the surviving channel was observed. It would be straightforward that a wide passband of the optical filter might waste the gain spectrum of the EDFA. Therefore, from our measurement results, we have concluded that the passband of the optical filter should be slightly larger than 0.2 nm by taking into account the effect of power fluctuation of the surviving channel as well as the efficient use of EDFA gain spectrum.

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