Tunable gain-clamped double-pass Erbium-doped fiber amplifier

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Abstract: A tunable, gain-clamped (GC) double-pass Erbium-doped fiber amplifier (EDFA) with a linear laser-cavity configuration has been demonstrated. It solves the problems existing in the conventional linear-cavity GC-EDFA based on two fiber Bragg gratings (FBGs), in which the clamped-gain is very difficult to be tuned. In the new GC-EDFA, the lasing oscillation for clamping the gain is produced in a linear cavity comprised by a FBG and a fiber reflection mirror (FRM). Between them, a filter filters out the lasing light, and then a variable optical attenuator changes the loss of the laser cavity for tuning the clamped-gain. Meanwhile, the double-pass configuration is used to enhance the gain efficiency, and therefore the level of the clamped-gain is greatly improved.

OCIS codes: (140.4480) Optical amplifiers; (060.2320) Fiber optics amplifiers and oscillators

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1. Introduction

With the rapid increase of the capacity requirement on optical communications, dense wavelength-division-multiplexing (DWDM) systems are achieving more and more channels. Recently, DWDM systems with 1046 channels have been demonstrated [1]. In dynamic WDM networks that employ reconfigurable optical cross-connection in the optical domain, adding or dropping channels will affect the gain performance of the existing channels for the

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Erbium-doped fiber amplifier (EDFA). So for such a system, gain clamping is an important requirement on EDFAs, which ensures that the gain performance of EDFAs is independent of the input power of signals and the number of used channels within the dynamic gain-clamped range. The performance of gain-clamping can be achieved by using either electric or optical control, or the combination of both methods in EDFAs. Among these schemes, all-optical gain clamping is a commonly used technique owing to the fast respond speed.

Generally speaking, there are two kinds of all-optical gain-clamping techniques. First, the all-optical GC-EDFA can be achieved by feeding back a portion of amplified spontaneous emission (ASE) to a fiber-ring cavity for producing laser oscillation [2-4], which is called the fiber-ring laser-cavity configuration. In such a GC-EDFA, the clamped-gain can be tuned through varying the loss of the lasing cavity, but there is additional signal loss because of the optical coupler, which will reduce the gain efficiency. In addition, gain clamping can be obtained using two fiber Bragg gratings (FBGs) to form lasing oscillation [5-7], which is called the linear laser-cavity configuration. The latter has an advantage of having no additional signal loss and a simple configuration, but the clamped-gain in this scheme can't be tuned owing to a fixed reflection rate of the FBG [5]. Although the methods in refs. [6] and [7] can change the clamped-gain by tuning the center wavelength of the chirped FBG, the configurations have a high requirement on the FBG, and hence the cost inevitably increases. Moreover, the tuning of lasing wavelength may affect the utility of the DWDM channels.

In this paper, we demonstrate a gain-tunable double-pass GC-EDFA with a linear laser-cavity, which combines the advantages of the above two kinds of all-optical GC-EDFA configurations, namely the tunable clamped-gain, no additional signal loss and the fixed lasing wavelength. In this EDFA, a FBG and a fiber reflection mirror (FRM) are used to produce a linear laser-cavity, while the lasing power passing through a thin-film filter can be changed by varying the loss of the lasing cavity. Therefore, the clamped-gain can be tuned by a variable optical attenuator (VOA). In our EDFA, an optical circulator (OC) and another FRM are used to form double-pass (DP) configuration [8]-[9] to enhance the signal gain. Finally, a gain-tunable GC-EDFA with a high clamped-gain and wide dynamic input power range is demonstrated.

2. Experiment

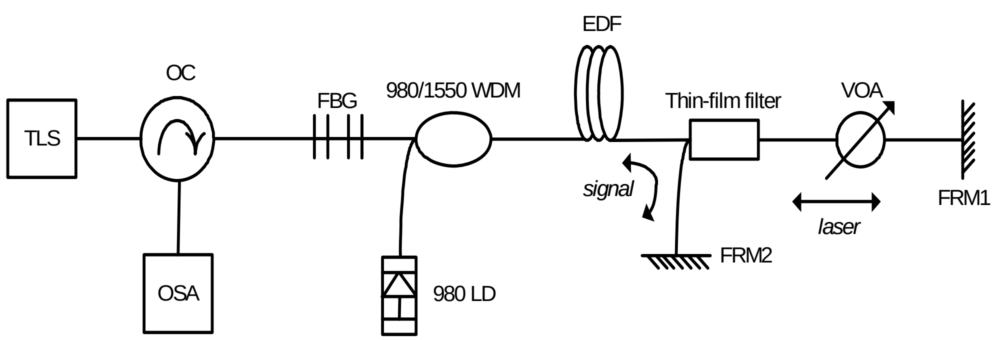

Fig. 1. The schematic diagram of the suggested GC- EDFA.

Figure 1 shows the experimental configuration of our new GC-EDFA. In the configuration, a FBG reflected 70% of the C-band ASE power at 1553.33 nm back into the EDF with a 3-dB bandwidth of 0.1nm; a thin-film filter, whose central wavelength is also at 1553.33 nm, was used to filter out the amplified 1553.33-nm light, and then a FRM1 reflected it back into the EDF through the filter. Therefore, the lasing oscillation at 1553.33 nm was formed between the FBG and the FRM1. Between them, a variable optical attenuator (VOA) was inserted to change the loss of the lasing cavity. While the amplified signal light was exported from the reflection port of the thin-film filter, and then reflected back into the EDF by a FRM2 to form

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double-pass (DP) configuration for enhancing the gain. An optical circulator (OC) routed the amplified signal into an optical spectrum analyzer (OSA). For measuring the gains, a tunable laser source (TLS) was used as the C-band input signal source. In the experiment, a 10-m EDF of 240ppm Erbium ion concentration was used, and the power of 980-nm pump LD was set at 80 mW.

For comparing the performance of the double-pass GC-EDFA with that of the conventional single-pass EDFA under the same condition, the thin-film filter, the FBG and the two FRMs were taken away from the configuration and the OSA was connected at the output end of the EDF when testing the single-pass EDFA.

3. Results and discussion

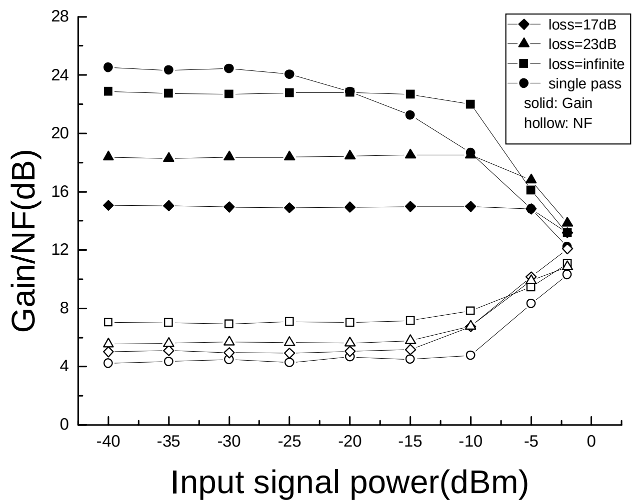

Fig. 2. Gain and NF versus input signal power at 1550 nm with different lasing cavity losses.

Figure 2 shows that the gain and NF vary with the input 1550-nm signal power under different losses of the lasing-cavity, in which, the solid symbols and the hollow symbols show the gain and NF, respectively. In the conventional single-pass EDFA, the gain at a small input signal power is about 24.5 dB, and decreases rapidly with the increase of the signal power. Hence, obviously, such an EDFA can’t support DWDM system, which requires that adding or dropping the channels doesn’t change the gain of the existing channels. In our new EDFA, the gain is clamped at a fixed level since a laser forming between the FBG and FRM1 fixes the population inversion of the EDF to a certain value. Meanwhile, the clamped-gain can be tuned by changing the power of the laser using a VOA. In this demonstration, we tune the clamped-gain in a linear-cavity GC-EDFA by using a VOA for the first time. The clamped-gain is respectively about 23.0 dB, 18.4 dB and 15.0 dB, when the lasing cavity loss is infinite, 23 dB and 17 dB, respectively. The dynamic gain-clamped range of the input signal power is up to -15 dBm, -10 dBm and -5 dBm respectively, and the variations of the clamped-gain are lower than 0.2 dB within it. The lasing power becomes less with the increase of the cavity-loss so that the signal can obtain more pump power and the clamped-gain becomes higher. The infinite loss refers that the lasing-cavity is open. Nevertheless, a little portion of the 1553.33-nm light is still reflected back into the EDF owing to the reflectivity of the fiber end, thus the lasing light can also be formed to lock the gain. In the all-optical GC-EDFA, when the input signal power exceeds the critical input power, which corresponds to the input signal power where the gain drops about 0.2 dB from the maximal signal gain [10], the laser disappears and the gain cannot be clamped. Then, the gains will drop rapidly with the increase of the input signal power. Beyond the critical input power, the gain curve is almost overlapped with that of the conventional EDFA and the saturated gains are equal owing to the absence of the laser [4]. However, in our double-pass GC-EDFA, the saturated gains are higher than those of the conventional single-pass EDFA and the dynamic gain clamped ranges are extended under all kinds of cavity-loss. Particularly, at the infinite cavity-loss, the clamped-gain is as high as 23 dB and the dynamic gain clamped range can be extended by about 10 dB, while the maximal output power is about 1.2 dB higher than that of the conventional EDFA. That is because the double-pass configuration greatly enhances the gain in comparison with the single-pass configuration. It is well known that in all-optical GC-EDFA, the signal gain drops owing to the presence of the lasing power. However, in our new GC-EDFA, the maximal clamped-gain is only about 1 dB smaller than the maximal gain in the conventional EDFA because of the gain enhancement using the double-pass technique.

The NF variation with the input signal power in our new GC-EDFA is also shown in Fig. 2. The NF in the conventional EDFA is ~4.3 dB and those in the double-pass GC-EDFA at the small input signal power are 5.0 dB, 5.5 dB and 7.0 dB respectively, when the cavity-loss is 17 dB, 23 dB and infinite. Compared with the single-pass EDFA, the NF here is degraded because the lasing light in the new configuration disturbs the amplification and transmission of the signal, while the strong backward ASE in the double-pass configuration also degrades NF [8]. The less the lasing cavity loss is, the stronger lasing power will compress the backward ASE generation; thus a lower NF is obtained. Nevertheless, the low NF is based on the expense of the gain, since the stronger lasing power leads to a reduction in the gain [2].

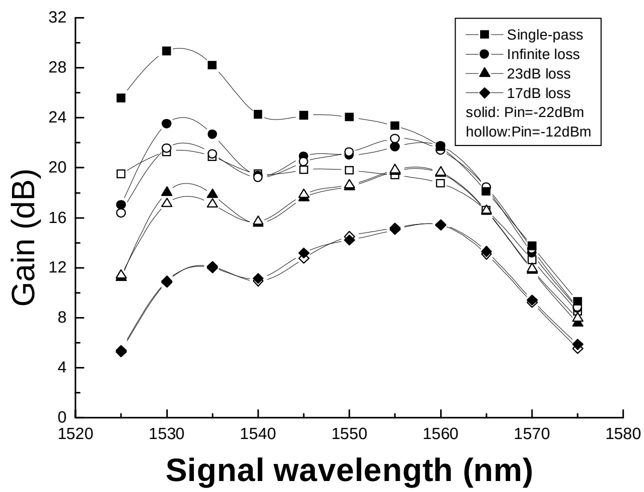

Fig. 3. Gain against input signal wavelength at different cavity-losses. In the figure, the solid symbols and the hollow symbols represent the –22-dBm and –12-dBm input signal power respectively.

Figure 3 shows the gains vary with the input signal wavelength both in the single-pass EDFA and the new double-pass GC-EDFA, in which the solid symbols and the hollow symbols respectively represent the cases at the –22 and –12-dBm input signal power. In the single-pass EDFA, when the input power increases to –12 dBm, the gain decreases by 4~8dB (at the range from 1525 to 1560 nm) owing to the gain saturation. The gain at 1530-nm band decreases most rapidly (by ~8dB) because of the strong spectral-hole burring (SHB) effect at this wavelength-band. It is obvious that the gains at all wavelengths cannot be clamped in the single-pass EDFA. Although the new EDFA has the gain-clamping effect, the gain is not totally clamped since the - 12-dBm input signal power would exceed the critical input power at some wavelengths. As shown in Fig. 3, at the infinite cavity-loss, the gain at –12-dBm signal power decreases slightly compared with that at the – 22-dBm signal power. Also, the

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gain at 1530-nm band decreases mostly due to the SHB effect. With the reduction of the cavity-loss, the dynamic gain clamped range is longer and the critical input power gets larger. In Fig. 3, at 23-dB cavity-loss, the gain-clamped performance is better than that at the infinite cavity-loss, and only the gain at 1530-nm band has a slight reduction. When the cavity-loss is 17 dB, the gain-clamped performance is the best, and the two gain curves at different input signal power are almost overlapped. According to the figure, we can also see that the gain peak shifts to the longer wavelength, especially when the cavity-loss is 17 dB, because the double-pass configuration is equal to double the length of the EDF.

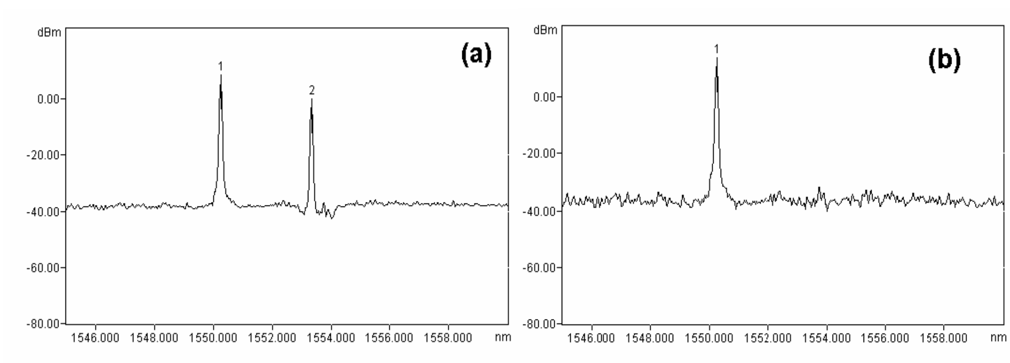

Fig. 4. The output spectra at 1550-nm signal wavelength with 17-dB cavity-loss. (a) the input 1550-nm signal power is –10 dBm; (b) the input 1550-nm signal power is –2 dBm.

Finally, to indicate intuitively the lasing function on gain-clamping, we present the output spectra of the new GC-EDFA at 1550-nm signal wavelength with 17-dB cavity-loss in Fig. 4. Fig. 4(a) is the output spectrum with the –10-dBm input signal power, in which the output power at 1550 nm is 5.02 dBm and the lasing power at 1553.33 nm is –3.12 dBm. As we have known from Fig. 2, when the cavity-loss is 17 dB, the clamped-gain is 15 dB and the dynamic gain-clamped regime is up to –5 dBm. Fig. 4(a) obviously shows that the gain is clamped at 15 dB because of the existence of the lasing light. Fig. 4(b) is the output spectrum at the –2-dBm input signal power, in which the power at 1550 nm is 11.02 dBm and the 1553.33-nm laser disappears. Because of the cross gain saturation effect, the lasing at 1553.33 nm cannot form lasing oscillation when the input signal power is larger than the critical input power. From Fig. 4, we can also define the critical input power as the input signal power where the lasing oscillation just disappeared. Beyond this, the signal is no longer clamped.

4. Conclusion

A new gain-tunable double-pass all-optical GC-EDFA using a linear-cavity configuration is demonstrated to solve the problems existing in the conventional GC-EDFA using two FBGs, in which the clamped-gain is difficult to be tuned. In the new GC-EDFA, the gain-clamping characteristic attributes to the lasing oscillation, and the lasing cavity loss can be easily changed by the VOA to tune the clamped-gain. Meanwhile, the double-pass configuration efficiently enhances the clamped-gain, which is a little low owing to the presence of the lasing light in the conventional GC-EDFA. The maximal clamped-gain of 23 dB and the dynamic gain clamped regime up to –5 dBm can be obtained. Intergrading all the advantages above, such a GC-EDFA may be very suitable for the application in dynamic WDM systems.

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