Tunable, gain-clamped double-pass Erbium-doped fiber amplifier with a DBR lasing cavity including a fiber Bragg grating and a fiber reflection mirror

Lilin Yi, Li Zhan*, Chien Hsien Taung, Qinghao Ye and Yuxing Xia
Institute of Optics and Photonics, National laboratory on Fiber Optic Communication Networks & Advanced Optical Communication Systems, Shanghai Jiao Tong University, Shanghai 200240, China

Abstract---A tunable, gain-clamped (GC) double-pass Erbium-doped fiber amplifier (EDFA) using only one fiber Bragg grating (FBG) has been demonstrated, which solves the problem existing the conventional GC-EDFA using two 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 between a FBG and a fiber reflection mirror, and a variable optical attenuator (VOA) is used to change the loss of the laser, which is filtered solely from a narrowband filter for tuning the clamped-gain, however it does not change the signal power directly. Meanwhile, the double-pass configuration enhances efficiently the gain, therefore, compared with the single-pass configuration, the maximum possible input signal power for gain-clamping is greatly extended. Furthermore, the FBG can depress the strong backward amplification spontaneous emission in double-pass configuration, so it can reduce the noise figure a certain extent. Finally, a gain-tunable GC-EDFA with a wide dynamic input power range is demonstrated.

Index terms--- Erbium-doped fiber amplifier, gain-clamping, double-pass, fiber Bragg grating, filter.

*To whom correspondence should be addressed. Email: lizhan@sjtu.edu.cn

Ⅰ. INTRODUCTION

With the growing increase of the capacity requirement on optical communications, dense wavelength-division-multiplexing (DWDM) systems are achieving more and more channels. Nowadays, DWDM systems with 128 channels have been commercially available. For such a system, gain clamping, also called gain dynamic controlling is an important characteristic of Erbium-doped fiber amplifier (EDFA), which ensures that the gain performance of EDFAs is independent of the

Passive Components and Fiber-based Devices, edited by Yan Sun,
Shuisheng Jian, Sang Bae Lee, Katsunari Okamoto, Proc. of SPIE Vol. 5623
(SPIE, Bellingham, WA, 2005) · 0277-786X/05/$15 · doi: 10.1117/12.570906

input power of signals and the number of used channels in DWDM systems.

The all-optical gain-clamping technique in EDFAs has been the research key. Mostly, there are two kinds of all-optical gain-clamping technique. Basically, the all-optical GC-EDFA can be achieved by feed backing a portion of amplified spontaneous emission (ASE) to a fiber-ring cavity for producing lasing oscillation [1]-[4]. In such an EDFA, the clamped-gain can be tuned through modifying the loss of the lasing cavity. Also, gain clamping can be obtained using two fiber Bragg gratings (FBGs) to form lasing oscillation [5]-[6]. Usually, the clamped-gain in this scheme can’t be tuned due to a fixed reflection rate in FBG [5]. Using a variable optical attenuation (VOA) in the lasing cavity can tune the clamped-gain, but it also damages the signal power directly. Although the method in ref. [6] can also change the clamped-gain by tuning the FBG’s center wavelength, this scheme has a high requirement on the reflection performance of the chirped FBG. Moreover, the tuning of lasing wavelength may be possible to affect the utility of the DWDM channels.

In this letter, we demonstrate a new gain-tunable double pass GC-EDFA. It is combined with the advantages in above two kinds of all-optical GC-EDFA scheme. In this EDFA, we used a FBG and a fiber reflection mirror (FRM) to produce lasing oscillation for clamping the gain, while the lasing power passed through the narrowband (NB) filter can be changed modifying the loss of the lasing cavity by a VOA. Therefore, the clamped-gain can be tuned by VOA. Meanwhile, the signal power passes through the reflection port of the NB filter and is not affected by the VOA. Furthermore, an optical circulator (OC) and another FRM were used to form double-pass (DP) configuration [7]-[8] to enhance the signal gain. Compared with the conventional double-pass EDFA [7], the noise figure (NF) is greatly improved, as the FBG depresses the backward amplification spontaneous emission (ASE) in double-pass configuration. Finally, a gain-tunable GC-EDFA with a wide dynamic input power range is demonstrated.

Ⅱ. EXPERIMENT

Fig.1 shows the experimental configuration of our new GC-EDFA. In the configuration, a FBG reflects 70% of C-band ASE at 1553.33nm (ITU-T CH30) into the EDF with a 3dB bandwidth of 0.1nm; a NB filter, whose central wavelength corresponds to ITU-T CH30, was used to filter the amplified 1553.33nm light, and the FRM1 reflects back the 1553.33nm light into the EDF through the filter. Therefore, the lasing at 1553.33nm was oscillated between the FBG and the FRM1. Before FRM1, a variable optical attenuator (VOA) was inserted to change the loss of the lasing cavity. The amplified signal was exported from the reflection port of the NB filter, and then reflected by the FRM2 to form double-pass (DP) configuration for enhancing the gain. An optical circulator (OC) routes the amplified signal into an optical spectrum analyzer (OSA). For test, a tunable laser source (TLS) was used as the C-band input signal. In the experiment, a 12m long EDF of 240ppm Erbium ion concentration was used, and the power of 980nm pump LD was set at 90mW.

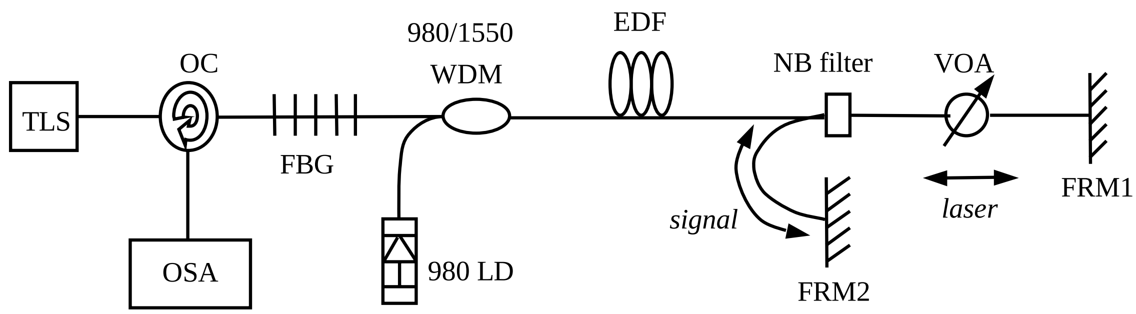

Fig.1. The schematic diagram of the suggested GC- EDFA.

For comparing the performance of the new GC-EDFA with that of the conventional single-pass EDFA under the same condition, the NB filter and the two FRMs was taken away and the OSA was connected at the position of the NB filter when testing the single-pass EDFA.

Ⅲ. RESULTS AND DISCUSSION

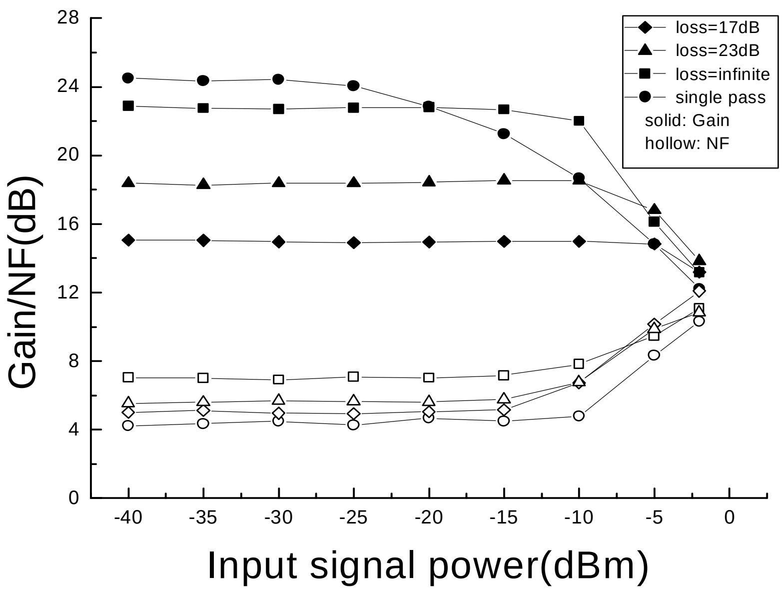

Fig.2. Gain and NF versus input signal power at 1550nm at different lasing cavity losses. In the figure, the solid symbols show the gains and the hollow symbols show the NFs.

Fig.2 shows that the gain and NF vary with the input 1550nm 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 the small input signal power is about 24.5dB, and decreases rapidly with the increase of the signal power. Hence, such an EDFA can't obviously support DWDM system, which requires adding or dropping the channel doesn't change the gain of the existing channels. In our new EDFA, the gain is clamped and independent of the input signal power, since a laser formed between the FBG and FRM1 fixes the population inversion of the EDF to a certain value. Meanwhile, the clamped-gain can be tuned through changing the power of the laser using a VOA. The clamped-gain is respectively about 23.0dB, 18.4dB and 15.0dB, when the lasing cavity loss is respectively infinite, 23dB and 17dB. The dynamic gain clamped range of the input signal power is respectively 25dB, 30dB and 35dB, corresponding to the range from –40dBm to –15dBm, -10dBm and –5dBm. The variations of clamped-gain are lower than 0.2dB in the gain-clamped range. With the loss increases in lasing cavity, the lasing power becomes less, so that the signal can obtain more pump power and the clamped-gain become higher. The infinite loss refers to that the lasing-cavity is open. Nevertheless, there is still a little portion of the 1553.33nm light to be reflected into the EDF due to the reflectivity of the fiber end, thus, the lasing at 1553.33nm 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 is corresponding to the gain drop about 0.2dB from the maximum signal gain [9], the laser disappears and the gain cannot be clamped. Then, the gains will reduce rapidly with the increase of the input signal power. Beyond the gain-clamped range of input signal power, the gain performance almost keeps consistent with those in the conventional EDFAs [4]. Interestingly, in our new GC-EDFA, the maximum output powers in the gain-clamped range are higher than those of the conventional single-pass EDFA under all kinds of cavity loss. This means the gain-clamped range of the input signal power can exceed the critical input power in the conventional single-pass GC-EDFA. Especially, when the 23dB clamped gain, the dynamic input power range can be extended by about 10dB. This 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 lasing will reduce the signal gain. However, in our new GC-EDFA, the maximum clamped-gain is only smaller about 1dB than the single-pass unclamped-gain at the small input signal power due to the gain enhancement using the double-pass technique.

Fig.2 also shows the NF variations with the input signal power in our new

GC-EDFA. The NF in the single EDFA is about 4.3dB and those in the new GC-EDFA at small input signal power are respectively 5.0dB, 5.5dB and 7.0dB when the cavity-loss is 17dB, 23dB and infinite. Compared with the single-pass EDFA, the NF here is degraded because the lasing in the new configuration disturbs the amplification and transmission of the signal, and the strong backward ASE in the double-pass configuration also degrades NF [7]. However, compared with the conventional double-pass EDFA [7], the NF in the new configuration is efficiently reduced, as the FBG depresses the strong backward ASE in double-pass configuration [8]. The less the lasing cavity loss is, the stronger lasing power will compress the backward ASE generation, and therefore, a lower NF was 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].

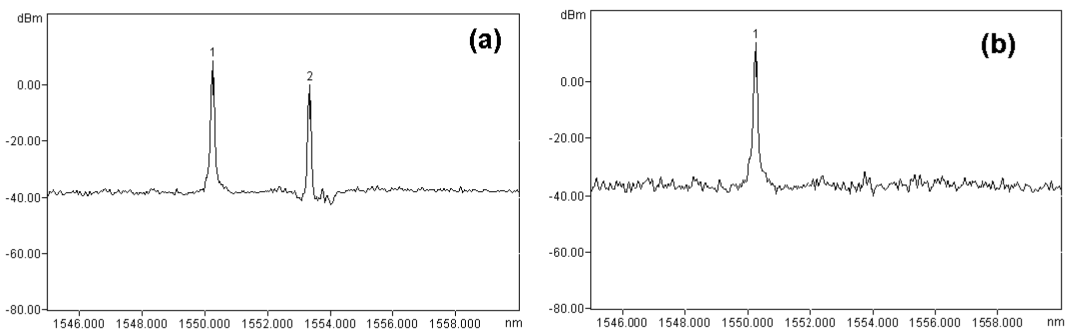

Fig.3 The output spectrum at 1550nm signal input with 17dB cavity-loss. (a) the input 1550nm signal power is –10dBm; (b) the input 1550nm signal power is –2dBm.

To indicate intuitionisticly the lasing function on gain-clamping, we present the output spectrum of the new GC-EDFA at 1550nm signal input with 17dB cavity-loss in Fig.3. Fig.3 (a) is the output spectrum when the –10dBm input signal power, in which, the output power at 1550nm is 5.02dBm and the lasing power at 1553.33nm is –3.12dBm. We have known from Fig.2, when the cavity-loss is 17dB, the clamped-gain is 15dB and the gain-clamped range of signal power is up to –5dBm. Fig.3 (a) obviously shows that gain is locked at 15dB due to the existence of the lasing with the signal. Fig.3 (b) is the output spectrum when the –2dBm input signal power, in which the power at 1550nm is 11.02dBm and the 1553.33nm laser disappears. Owing to the cross gain saturation effect, the lasing at 1553.33nm cannot form oscillation when the input signal power is larger than the critical input power. From Fig.3, we can also define the critical signal power as the condition that the lasing is just produced. Beyond this, the signal gain is no longer clamped.

Fig.4 shows the gains variation with the input signal wavelength both in the single-pass EDFA and in the new GC-EDFA, in which, the solid symbols and the hollow symbols represent the cases at the –22 and –12 dBm input signal power respectively. In the single-pass EDFA, when the input power increases to –12dBm, the gain decreases by 4~8dB (at the range from 1525 to 1560nm) duo to the gain saturation. The gain at 1530nm band decreases most rapidly (by ~8dB), because the spectral-hole burring (SHB) is strongest at this wavelength-band. It is obvious that the gain of all wavelengths cannot be clamped in the single-pass EDFA. Although the new EDFA has the gain-clamping effect, the gain in the new GC-EDFA is not clamped as the -12dBm input signal power exceeds the critical input power at some wavelengths. As shown in Fig. 4, at the infinite loss of lasing cavity, the gain at –12dBm signal input decreases slightly in comparison with the – 22dBm signal input. Also, the gain at 1530nm band decreases mostly due to SHB. With the reduction of the cavity-loss, the dynamic gain variation range is longer and the critical input power gets larger. From Fig.4, when 23dB cavity-loss, the gain-clamped effect is better than that at the infinite loss of lasing cavity, only the gain at 1530nm band has a slight reduction. When the cavity loss is 17dB, the gain clamped effect is best, and the two gain curves for different input signal power are almost overlapped.

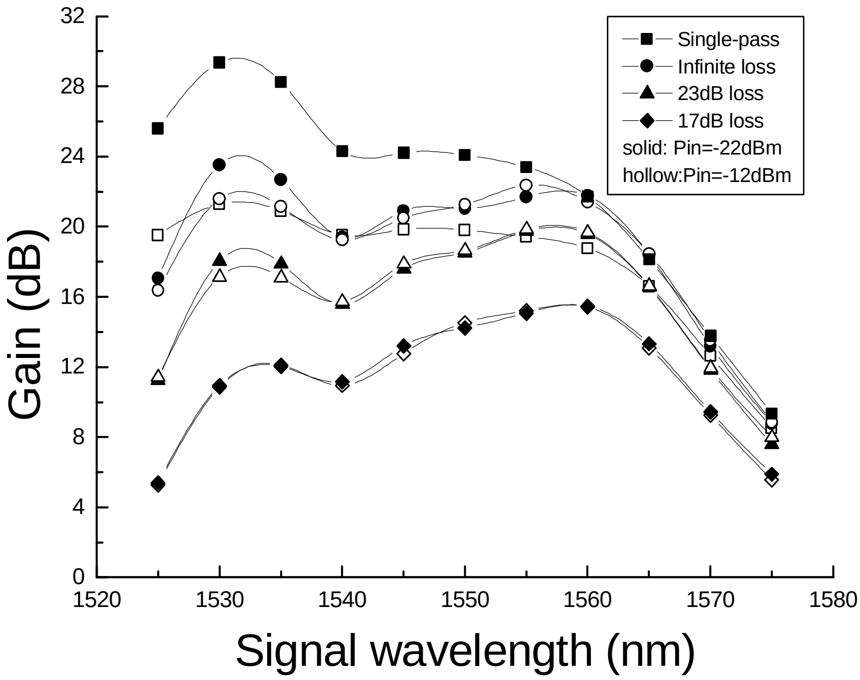

Fig.4. Gain against input signal wavelength at different cavity-losses. In the figure, the solid symbols and the hollow symbols represent the –22dBm and –12dBm input signal power respectively.

Ⅳ. CONCLUSION

A new gain-tunable all-optical GC-EDFA using a FBG 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 attributes to the lasing oscillation, and the lasing cavity loss can easily be varied to tune the clamped-gain. Meanwhile, the double-pass configuration enhances efficiently the gain. When the laser-cavity loss is 23dB, the gain is clamped at 18dB and the dynamic gain clamped range is 30dB from –40dBm to –10dBm and the NF is about 5.5dB. Intergrading all the above advantages, such a GC-EDFA maybe very suitable for the application in high-capacity DWDM system.

Acknowledge: This work was supported by the Science and Technology Committee of Shanghai Municipal (Contract number: 012261016, 022261003), China.

REFERENCES

[1] G. Luo, J. L. Zyskind, Y. Sun, A. K. Srivastava, J. W. Sulhoff, C. Wolf, and M. A. Ali, IEEE Photon. Technol. Lett. 9 (1997) 1346.
[2] L. L. Yi, L. Zhan, Q. H. Ye, X. Hu, and Y. X. Xia, IEEE Photon. Technol. Lett. 15 (2003) 1695.
[3] M. Cai, X. Liu, J. Cui, P. Tang, D. Liu, J. Peng, IEEE Photon. Technol. Lett. Vol. 9 (1997) 1093.
[4] Shih Hsu, Tsair-Chun Liang, Yung-Kuang Chen, Opt. Commun. 196 (2001) 149.
[5] Bing Xia, Dominik Pudo, and Lawrence R. Chen, IEEE Photon. Technol. Lett. 15 (2003) 519.
[6] J. Bryce, G. Yoffe, Y. Zhao and R. Minasian, Electron. Lett. 34 (1998) 1680.
[7] S. W. Harun, P.Poopalan, and H.Ahmad, IEEE Photon. Technol. Lett. 14 (2002) 296.
[8] L. L. Yi, L. Zhan, J. H. Ji, Q. H. Ye, and Y. X. Xia, IEEE Photon. Technol. Lett. 16 (2004) 1005.
[9] Zexuan Qiang, Xiang Wu, Sailing He, Zukang Lu, Opt. Commun. 224 (2003) 73.