Gain-Clamped Erbium-Doped Fiber-Ring Lasing Amplifier With Low Noise Figure by Using an Interleaver

L. L. Yi, L. Zhan, Q. H. Ye, X. Hu, and Y. X. Xia

***Abstract*—A novel all-optical gain-clamped erbium-doped fiber-ring lasing amplifier (GC-EDFRLA) has been demonstrated, in which the odd port of a 100/200-G interleaver was used to form a fiber-ring cavity to produce lasing oscillation for locking the gain and its even port was employed to export the amplified signals. In such a way, the problem existing in the conventional GC-EDFRLA is solved. The signal can be exported separately without the lasing power while the noise figure (NF) is very low. Finally, the GC-EDFRLA with a low NF of 4.2 dB was achieved.**

***Index Terms*—Erbium-doped fiber amplifier (EDFA), gain clamping, interleaver.**

I. INTRODUCTION

WITH THE explosive growth of the optical communications, it is more and more necessary to emphasize the importance of amplifiers for not only long-haul systems, but also for metro applications. Especially, erbium-doped fiber amplifiers (EDFAs) play a milestone role on the growth of the dense wavelength-division-multiplexing (DWDM) systems. For such systems, gain clamping, also called gain-dynamic equalization, is an important characteristic of EDFAs, which ensures that the performances of EDFAs are independent of the input power of signals and the number of used channels in DWDM systems.

Up until now, different methods for gain clamping have been demonstrated, such as all-optical gain locking using double-pass super fluorescence [1], fast pump control in a two-stage EDFA [2] by detecting the powers of input signals, and gain-clamped (GC) EDFA using stimulated Brillouin scattering [3]. Also, the gain clamping in EDFAs can be achieved using an optical ring to establish lasing oscillation by feed backing a portion of amplified spontaneous emission (ASE) [4]–[6]. There are two kinds of gain-clamping schemes with an optical feedback ring: One is the cotraveling structure, in which the lasing power travels along the same direction as the signal. It has a lower noise figure (NF), but cannot distinguish the signal from the lasing power [5]. The other is the counter-traveling structure, in which the lasing power travels in the opposite direction as the signals. Although it can export the signal separately, it is subjected to high NF [5], [6]. Hence, the low NF and the output signals without lasing power cannot be satisfied simultaneously in the conventional GC erbium-doped fiber-ring lasing amplifiers (GC-EDFRLA).

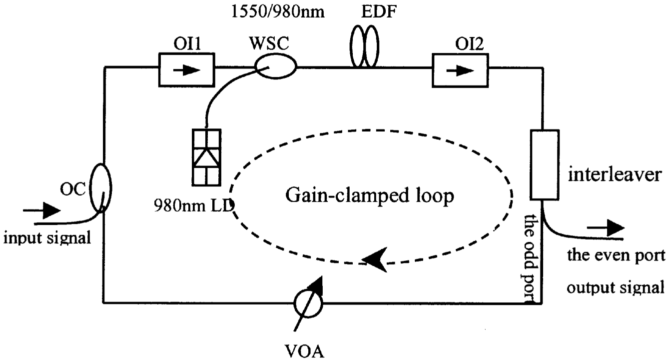

Fig. 1. Experimental setup of the GC-EDFRLA with an interleaver.

In this letter, a novel all-optical GC-EDFRLA with an interleaver has been demonstrated to solve the problems existing in the conventional GC-EDFRLA. In our design, the odd-channel output port of interleaver was connected into a ring cavity to establish lasing oscillation for gain clamping while the even output port was employed as signal output port of the EDFA. In such a structure, the signal travels along the same direction as the lasing power so that the NF is lower than that of the counter-traveling case. As their wavelengths are different from each other, the amplified signals are exported separately without the lasing power. Furthermore, the interleaver plays the role of a filter, which filters partial ASE power and lasing power from the output signal and then leads to a quite low NF. Finally, a GC-EDFRLA with a low NF of 4.2 dB was demonstrated.

II. EXPERIMENT

The schematic diagram of our novel all-optical GC-EDFRLA is shown in Fig. 1. A 90 : 10 optical coupler (OC) input 90% signal power into the fiber-ring cavity. Two isolators (OI1 and OI2) were used to propagate the signal and the lasing power along a single direction. A 1550/980-nm wavelength selective coupler coupled 90-mW laser from a 980-nm laser diode as co-propagating pump into the erbium-doped fiber (EDF). The interleaver is such a filter that can separate DWDM signal channels into two groups with twice the wavelength spacing, and let the even-channel signal group and the odd group export separately in the different ports. Here, a 100/200-GHz interleaver

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Manuscript received February 26, 2003; revised July 11, 2003. This work was supported by the Science and Technology Committee of Shanghai Municipal, China under Contract 012261016 and Contract 022261003.

The authors are with the National Laboratory on Fiber Optic Communication Networks and Advanced Optical Communication Systems, Institute of Optics and Photonics, Shanghai Jiao Tong University, Shanghai 200030, China (e-mail: lizhan@sjtu.edu.cn).

Digital Object Identifier 10.1109/LPT.2003.819714

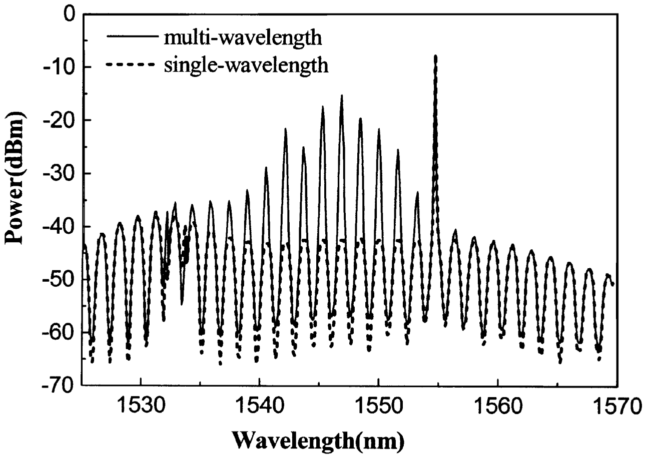

Fig. 2. Optical output spectra of the amplified signals for single-wavelength input and multiwavelength input.

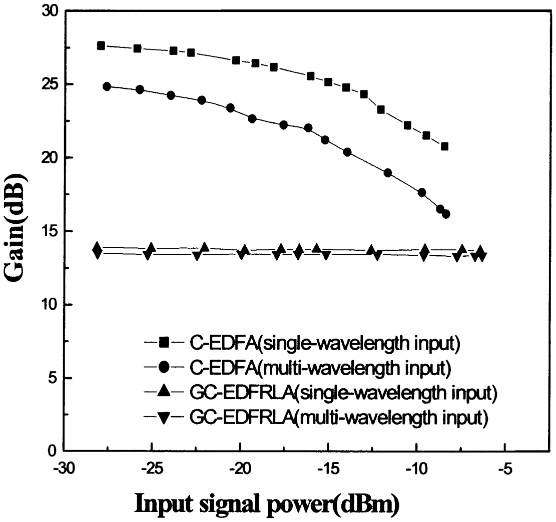

Fig. 3. Gain variation with input signal power for single-wavelength input and multiwavelength input in the C-EDFA and the GC-EDFRLA.

was used to filter the continuous ASE from EDF into two reverse-shape spectrums with 1.6-nm wavelength spacing. The ASE output from the odd-channel port was fed back into the fiber-ring cavity through the 10 : 90 OC to establish the lasing oscillation, and the amplified signals were exported from the even-channel port. Due to the filtering of the interleaver, only the signals with the even-channel wavelengths can be amplified. To control the clamped gain, a variable optical attenuator (VOA) was applied to change the cavity loss. Finally, an EXFO optical spectrum analyzer was used to measure the spectrum, gain, and NF.

In measurement, a tunable laser with a VOA was employed as the single-wavelength signal source. In order to compare the gain-clamping characteristics between the single-channel input and multichannel input, a highly stabilized semiconductor laser with multiwavelength output, which accord with the output wavelengths of the even port of the interleaver, was applied as multiwavelength signal source. Finally, both the tunable laser and the multiwavelength semiconductor laser were coupled into the input port of our EDFA by using a 50 : 50 coupler.

III. RESULTS AND DISCUSSION

Fig. 2 shows the output spectra of the amplified signals from the even port of interleaver, in which the solid line and the dashed line represents the optical spectrum when the multiwavelength input and single-wavelength input, respectively. The spectrum of the multiwavelength laser is similar to the solid line without the peak at 1554.97 nm in Fig. 2, and its total output power was −14.12 dBm. In measurement, we tuned the output wavelength of the tunable laser at 1554.97 nm and kept −20-dBm power at 1554.97 nm to input into EDFA. The single-wavelength amplified signal was measured after closing the multiwavelength laser source. When the input power was −20 dBm at 1554.97 nm and the ring cavity loss was 16 dB, the output power at 1554.97 nm was measured with a value of −7.60 dBm for multiwavelength input and −7.30 dBm for single-wavelength input. Fig. 2 shows intuitively that the power difference at the same 1554.97 nm between two input cases can be negligible. This result also indicates that the gain was clamped at about 12.6 dB when the cavity loss was 16 dB.

To indicate the GC characteristic of EDFA under different input powers, we show that the gain varies with input signal power in Fig. 3 for single-wavelength input and multiwavelength input. In Fig. 3, the results of the conventional EDFA (C-EDFA) were measured when disconnecting the fiber ring. In the experiment, we chose the light at 1546.92 nm as the consulted wavelength, since the power at this wavelength is the strongest in the output spectrum of the highly stabilized laser. In Fig. 3, the above two curves show that the gain varies with the input signal power in the C-EDFA for the single-wavelength input and multiwavelength input, respectively. It is obvious that the gain decreases with the increase of the input signal power and the gain reduces by about 3 dB due to adding channels by the multiwavelength laser. Hence, the C-EDFA obviously cannot support WDM system, which requires adding or dropping the channel does not change the gain of the existing channels. The below two curves show that the gain in the new GC-EDFRLA varies with the input signal power for the two input cases. When the cavity loss was kept at 18 dB, the gains were clamped at 13.8 and 13.4 dB for these two cases, respectively. Their gain variations were less than 0.2 dB, when the input power changed from −30 to −5 dBm. The 0.4-dB gain difference between two input cases was possibly caused by the measurement error and the connection loss of two light sources.

Fig. 4 shows that the gain and NF at 1546.92 nm varies with input signal power for the different cavity losses. In the C-EDFA, regarded as the GC-EDFRLA with the infinite cavity loss (without fiber ring), the gain and NF under small signal input are about 28 and 6.4 dB, respectively, but both of them degrade with the input signal power increasing. Corresponding to the cavity losses of 24 and 18 dB, the gains in our GC-EDFRLA are, respectively, clamped at 17.8 and 14.0 dB in the range of input signal power from −32 to −10 dBm. Here, the gain-clamping results from the fixed average population inversion provided by the lasing mechanism. Therefore, the gain and the GC dynamic range are related with the cavity

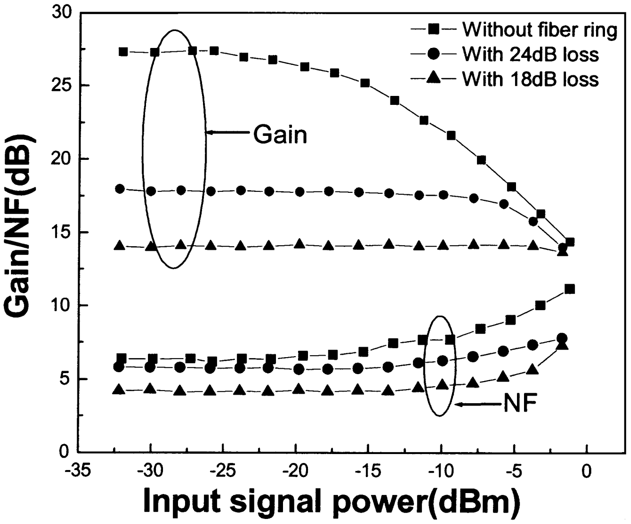

Fig. 4. Gain and NF at 1546.92 nm versus input signal power for the different cavity-losses.

loss. As shown in Fig. 4, the gain becomes smaller with the decreasing of the cavity loss while the GC range of input power turns to be longer.

It should be pointed out that the novel GC-EDFRLA is superior to the conventional GC-EDFRLA as the amplified signal can be exported separately without the lasing power and the NF is very low. Certainly, one reason is that the signal cotravels with the lasing power, which makes the NF less than that in the counter-traveling case [5]. From Fig. 4, the NFs within the GC range were 6.4, 5.8, and 4.2 dB, respectively, corresponding to the cavity loss at infinite, 24 and 18 dB. The NFs of the GC-EDFRLA are lower than that without the ring cavity, because the lasing power compresses the ASE strongly and the operation point of the amplifier fell in the dip region of the original noise profile [5]. The less the cavity loss is, the stronger lasing power will compress the ASE generation. Meanwhile, the interleaver also plays the role to filter the lasing power from the output signal, and as a result, a quite low NF is obtained. Nevertheless, the low NF is based on the expense of the gain because the stronger lasing power leads to a reduction on the gain. To confirm the lasing effect on the gain locking, we also incorporated a 90 : 10 coupler after the odd port of the interleaver to observe the lasing generation. When the small signal input, the unstable dual-wavelength lasing at ~1560 nm was observed. When the input power exceeded the GC range of input power (~ −10 dBm), the lasing oscillation vanished.

In the experiment, a 100/200-G interleaver was used to form the fiber-ring cavity for gain clamping, and the design can only be used in 200-GHz spacing DWDM system. If using 25/50- or 50/100-GHz interleaver, such a way can also be used in 50- or 100-GHz spacing DWDM system.

IV. CONCLUSION

A novel all-optical GC-EDFRLA to solve the problems existing in the conventional GC-EDFRLA was demonstrated. In such an EDFA, the signal travels along the same direction as the lasing power and is exported separately without the lasing power by using an interleaver. A low NF can be achieved because of the cotraveling condition and the use of the interleaver, as the lasing oscillation strongly compresses the ASE power and the lasing power can be filtered from the signal output by the interleaver. Finally, a low NF of 4.2 dB was demonstrated for an 18-dB cavity loss. This low NF GC-EDFRLA may be very useful in DWDM systems, which requires the gain is independent of the number of used channels and the power of the input signals.

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