ASE Reflector-Based Gain-Clamped Erbium-Doped Fiber Amplifier Using an Optical Interleaver

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Abstract—We use a 50-GHz optical interleaver for the reflection of amplified spontaneous emission (ASE) to realize ASE reflector-based gain-clamped erbium-doped fiber amplifiers. The amplifier schemes can secure International Telecommunications Union Telecommunication Standardization Sector grids with 100-GHz channel spacing in the whole conventional band (C-band) for signal amplification gain-clamping characteristics including dynamic ranges lower than −7 dBm are successfully demonstrated.

Index Terms—Optical amplifiers, optical communication, optical fiber amplifiers, optical fiber devices, wavelength-division multiplexing (WDM).

I. INTRODUCTION

Optical amplifiers, especially erbium-doped fiber amplifiers (EDFAs), for wavelength-division-multiplexed (WDM) optical communication networks should be able to manage the gain fluctuation problem of surviving signal channels resulting from dynamic add–drop of other channels. Various schemes based on pump power control, optical feedback, and electronic and optical hybrid schemes have been reported [1]–[6]. Optical feedback schemes based on lasing mechanisms are simple and effective ways to achieve constant gain characteristics regardless of input power changes. However, the surviving channels of the lasing-based gain-clamped EDFAs (GC-EDFAs) still suffer from gain variations which can be separated into dynamic variation due to relaxation oscillation and static one due to spectral hole burning (SHB) [7]. Recently, we reported a novel all-optical gain-clamping scheme based on an amplified spontaneous emission (ASE) reflector using a coarse WDM (CWDM) [8]. The ASE reflector-based GC-EDFA was free from relaxation oscillation since it was not based on a lasing mechanism and can be expected to have less severe SHB-induced static gain variation compared to the lasing-based GC-EDFAs since the reflected ASE power is much lower than the laser power. Its dynamic range, defined by the input signal power corresponding to 1-dB gain suppression from a clamped gain, increased with increasing ASE power reflected [9]. That is the reason why 1530-nm CWDM with a bandwidth of about 16 nm was chosen for the demonstration of the ASE reflector-based gain-clamping scheme. However, due to the CWDM, the GC-EDFA reported was unable to amplify input signals whose wavelengths were within the CWDM bandwidth. In this letter, we use an optical interleaver instead of the CWDM for the ASE reflector-based GC-EDFA in order to expand signal amplification band to the whole conventional band (C-band) wavelength region and discuss its characteristics.

II. EXPERIMENTAL

Fig. 1 shows two schematic diagrams of the GC-EDFA. A 10.5-m-long erbium-doped fiber (EDF) with an absorption coefficient at 1530 nm of 5.5 dB/m was pumped by 70 mW of a 980-nm laser diode for experiments unless otherwise stated. An ASE reflector was composed of a 50-GHz optical interleaver with an insertion loss of about 1.0 dB and a dielectric mirror coated on a fiber end facet with a reflection ratio of about 90%. We fabricated a normal EDFA with no ASE reflector first and then modified it with the ASE reflector not only at the input side to reflect backward ASE like Fig. 1(a) but also at the output side to reflect forward ASE like Fig. 1(b). A brief summary of the gain-clamping principle described in [8] may be that reflected ASE signals act like a power reservoir against input power change as lasing signals do in the conventional lasing-based GC-EDFAs.

Fig. 2 is output spectra of the two GC-EDFA configurations for −10-dBm input signal with a wavelength of 1550.16 nm corresponding to one International Telecommunications Union Telecommunication Standardization Sector (ITU-T) grid. The inset shows details around the signal wavelength. Spectral modulation with 100-GHz spacing due to the 50-GHz interleaver

Manuscript received December 23, 2004; revised April 12, 2005. This work was supported by the Ministry of Information and Communications, Republic of Korea.

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Digital Object Identifier 10.1109/LPT.2005.850890
Fig. 2. Output spectra of the two GC-EDFAs showing the ASE modulation due to the interleaver for an input signal of -10 dBm at 1550.16 nm and an inset showing details around the signal wavelength.

is clearly seen. The input signal coincided with a valley of the modulated ASE in case of the input side ASE reflector (solid line) and with a peak of the modulated ASE in case of the output side one (dotted line). In similar way, other ITU-T grid signals with 100-GHz spacing in C-band can be amplified. Special caution must be paid to measure noise levels at the nearest two valleys or two peaks from each signal wavelength, as indicated by the two arrows in the inset, in order to determine a noise level of each amplified signal by interpolation technique.

Fig. 3 shows gain and noise figure (NF) with respect to input power at a wavelength of 1550.16 nm for the normal EDFA (squares), the GC-EDFAs with the ASE reflector at input side (circles, GC-EDFA-input after this) and output side (triangles, GC-EDFA-output after this). Compared to the normal EDFA, the two GC-EDFAs showed clear gain clamping characteristics with similar clamped gain and dynamic range of about 19 dB and about -7 dBm, respectively. Since the dynamic range is about 5 dB higher than that of the previous GC-EDFA using a 1530-nm CWDM/mirror in [8], the two new GC-EDFAs using an optical interleaver/mirror can more efficiently manage channel add-drop situation in optical communications than the previous one does. Both GC-EDFAs had about 0.4 to 1.2-dB higher NF than the normal EDFA since more inversion was consumed by the reflected ASE power for gain clamping. At input signal powers less than the dynamic range, the GC-EDFA-input has a little bit better NF characteristics compared to the GC-EDFA-output, but on the other hand, a little bit worse dynamic range characteristics. Fig. 4 is wavelength-dependent amplifier characteristics measured at 7 ITU grid wavelengths of 1530.36, 1535.07, 1540.61, 1545.37, 1550.16, 1555, 1559.85 nm for a fixed input power of -22 dBm for the two GC-EDFAs. Compared to the GC-EDFA-output (circles), the GC-EDFA-input (squares) had nearly the same clamped gain values and lower NF by about 1.6–0.6 dB, but on the other hand, lower dynamic range by about 1.5 to 0.5 dB. As wavelength increased, both gain and NF decreased; on the other hand, dynamic range increased. It is obvious from Figs. 2 and 4 that the GC-EDFAs using an optical interleaver/mirror can have an amplifier bandwidth expanded to the whole C-band while the previous schemes using a 1530-nm CWDM/mirror could have only a limited bandwidth longer than 1540 nm within C-band. Additional gain flattening functions, however, should be required due to gain variations within the amplifier bandwidth.
Fig. 5 shows pump-power-dependent amplifier characteristics measured at 1550.16 nm for a fixed input power of $-26$ dBm. For all the measured pump powers, the GC-EDFA-output (circles) had gain and dynamic range a little bit better than, but NF about 0.8 dB worse than the GC-EDFA-input (squares). As pump power increased from 40- to 80-mW, NF increased slightly for the GC-EDFA-output around 4.2 dB and decreased slightly for the GC-EDFA-input around 4.2 dB; on the other hand, gain and dynamic range increased for both amplifiers up to 19 dB and $-7$ dBm, respectively. For pump powers more than 90-mW lasing was usually observed around 1530 nm and, therefore, gain clamping might be dominated not by the ASE reflection but by the lasing. If we want to increase current dynamic range limited to about $-7$ dBm, we should suppress the lasing action up to more intense pump power.

III. CONCLUSION

We demonstrated GC-EDFAs based on an ASE reflector of a 50-GHz optical interleaver and a mirror which has reason-