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Noise figure improvement of a double-pass erbium-doped fiber amplifier by using a HiBi fiber loop mirror as ASE rejecter

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Abstract

In this paper, the noise figure improvement of an erbium-doped fiber amplifier with double-pass configuration is demonstrated. By utilizing a high birefringence fiber loop mirror as the amplified spontaneous emission rejecter, the noise figure of this erbium-doped fiber amplifier (EDFA) greatly decreases compared with that of the EDFA using a conventional 3 dB fiber loop mirror. Moreover, stability observation of the amplifier output spectra ensures its applicability for practical applications.

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Keywords: Erbium-doped fiber amplifier; Noise figure improvement; Double-pass; High birefringence; Fiber loop mirror

1. Introduction

As the natural extension of the conventional band (C-band) erbium-doped fiber amplifier (EDFA), long wavelength band (L-band) EDFA has already been regarded as the most promising candidate for increasing the transmission capacity of wavelength division multiplexing (WDM) system [1]. Nevertheless, since L-band is far away from the gain peak (1530 nm) of silica-based EDF, the gain coefficient in L-band is much lower than that in C-band (approximately by a factor of 1/10) [2]. In recent years, various approaches are reported to solve the above issue [3–7]. Among all those efforts, double-pass configuration is viewed as a good alternative to realize high gain in L-band EDFA. In such scheme, however, the amplified spontaneous emission (ASE) is re-injected into EDF together with signal light, which leads to relatively high noise figure.

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In this paper, a noise figure improved L-band EDFA by utilizing the comb like reflection spectrum of high birefringence (HiBi) fiber loop mirror to inhibit ASE is presented. Experimental results indicate that the noise figure of L-band EDFA based on HiBi fiber loop mirror is much lower than that of double-pass configuration with conventional 3 dB fiber loop reflector. The operation principle and stability of the amplifier output spectra is analyzed and observed, respectively. Moreover, the gain difference for the above two cases has also been investigated.

2. Operation principle

The basic configuration of our novel structure L-band EDFA is shown in Fig. 1. Two 980 nm laser diodes (LD) are used as bi-directional pump sources and about 24.6 m EDF (absorption coefficient: 15.2 dB/m at 979 nm; numerical aperture: 0.22) serves as the gain medium. In our experiment the co-pump and counter-pump power at output port of wavelength division multiplexes are set to 55 and 60.6 mW, respectively. An optical circulator (OC) is placed at the input end with port 2 spliced with the signal port of a wavelength division multiplexer. Meanwhile, a fiber loop mirror locates on the other side of the EDFA to constitute the double-pass configuration. Thus based the above design, the input signal enters port 1 of the OC and the amplified signal will come out from port 3. An optical spectrum analyzer (OSA) is utilized to monitor the output signal.

The principle of HiBi fiber loop mirror can be described as follows in brief. The input light is divided into two counter-propagating beams. After propagating through the birefringence fiber, both of the two beams will separate into fast and slow axis components. They will finally propagate again into the 3 dB coupler and interfere at the output end. Therefore, the reflectivity of the HiBi fiber loop mirror can be described as [8]

$$R(\lambda) = 2K(1-K)[1+\cos\delta\phi(\lambda)], \tag{1}$$

where $R(\lambda)$ is the reflectivity of the fiber loop mirror at a certain wavelength, and K is the coupling ratio of the coupler. $\delta\phi(\lambda)$ is the phase difference between fast and slow axis components, which can be described as the following formula:

$$\delta\phi(\lambda) = 2\pi\Delta n L/\lambda, \tag{2}$$

where Δn is the refraction index difference between the fast and slow axes of birefringence fiber, and L is the length of birefringence fiber. Based on the above analysis, it is obvious the reflection spectrum is comb like and the spectrum period can be written as

$$\Delta\lambda = \frac{\lambda^2}{\Delta n L}. \tag{3}$$

Approximate 5.1 m HiBi fiber with beat length of about 3.1 mm at 1550 nm and Δn of 5×10^{-4} is used to constitute the HiBi fiber loop mirror. Its reflection spectrum is plotted in Fig. 2. The contrast of the reflection spectrum reaches 9.5 dB and its period is about 0.88 nm, basically conforming to our analysis. The major difference between this novel scheme and the conventional double-pass design is that the HiBi fiber loop mirror with periodic reflection spectrum is utilized instead of 3 dB fiber loop mirror. In conventional double-pass configuration, both of the signal and ASE will be reflected back into the EDF by 3 dB fiber loop

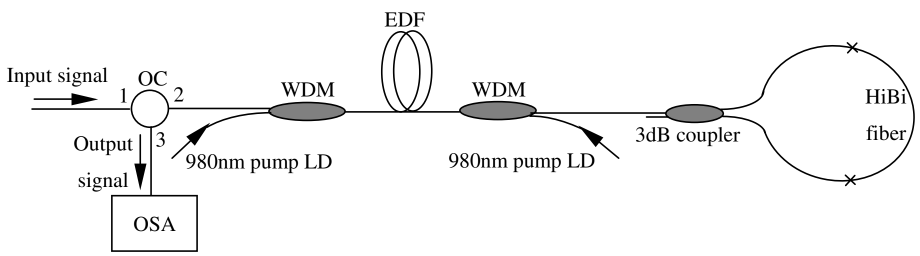

Fig. 1. Experimental setup of the noise figure improved EDFA based on ASE rejection technique.

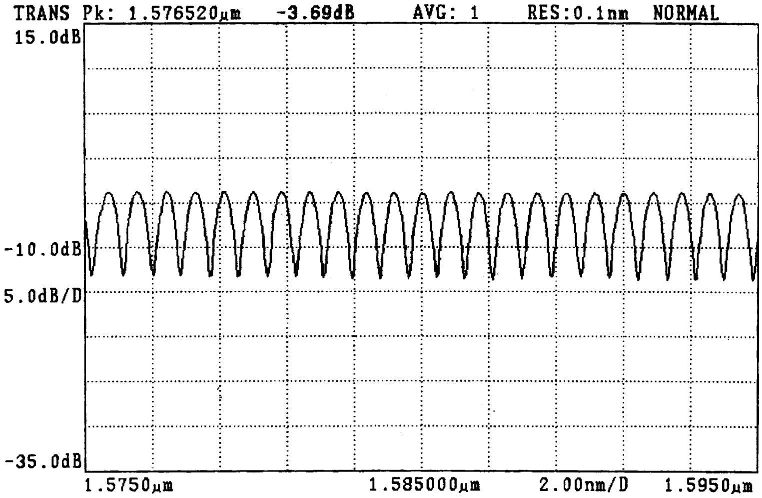

Fig. 2. Reflection spectrum of the HiBi fiber loop mirror.

mirror, which increases output ASE at the input end of L-band EDFA. The high level of ASE at the input side of EDF reduces the population inversion and degrades noise figure. In our experiment, signals are selected at the wavelength with maximum reflectivity on the reflection spectrum of HiBi fiber loop mirror. In this case, ASE generated from the EDF is attenuated by the fiber loop mirror and then will be reflected into EDF for a second time. Thus, the ASE distribution along the EDF is changed to reduce ASE at the signal input end of EDF, which increases the population inversion and improves the noise figure.

3. Experimental results and discussion

Fig. 3 shows the gain (shaded) and noise figure (clear) for ten sampled signals. The square and diamond symbols represent the characteristics of new double-pass and conventional double-pass L-band EDFA, respectively. From this figure, it is apparent that noise figure of our novel structure EDFA is much lower than that of the conventional one. The noise figure of L-band EDFA with conventional configuration is inevitably higher because strong ASE induced by double propagation will deteriorate the population inversion level at input side of EDF. In contrast, the HiBi fiber loop mirror with comb like reflection spectrum is actually utilized to suppress the forward ASE, which gives rise to the noise figure improvement. Compared with that of the conventional one, the noise figure of the new double-pass L-band EDFA is about 3.7 dB lower in average. Throughout 1580.84 and 1588.48 nm, the noise figure of our novel configuration is reduced by 2.06–5.33 dB for the ten sampled signal wavelength. Fig. 4 shows the gain measurement spectra of a typical signal at 1584.22 nm with input power of ~ -30 dB. The lower and upper spectra in this figure represent the input signal and amplified output signal, respectively. The noise figure at 1584.22 nm is 5.78 dB and its gain reaches 23.68 dB. We can see that there are some ripples in the spectrum of amplified signal, indicating that the reflection spectrum of this HiBi fiber loop mirror has large loss only at ASE wavelength and has much less loss at signal wavelength. The reduction of ASE will bring about less consumption of population in the upper energy, which will improve the noise figure to a large extent.

From Fig. 3, however, we can see that the gain of new double-pass EDFA is averagely 1.3 dB lower than that of the conventional one. This slight gain decrease can be explained by the following discussion about reflection loss of these two types of fiber loop mirrors. The reflection spectrum of conventional 3 dB fiber loop mirror is illustrated in Fig. 5. It is conspicuous that the reflectivity of

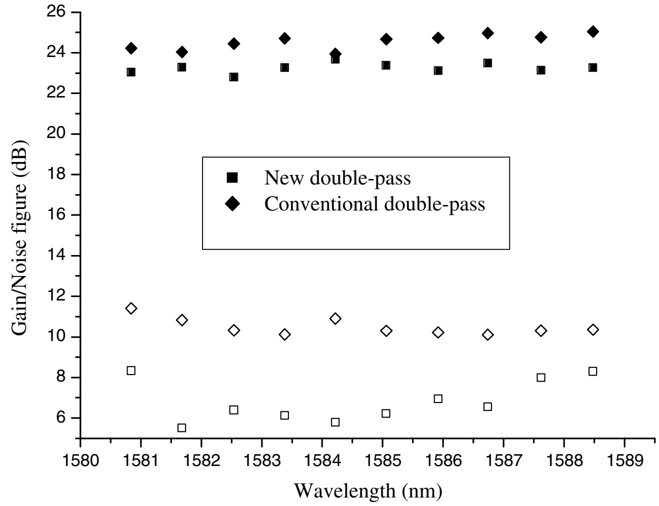

Fig. 3. Gain (shaded) and noise figure (clear) as functions of input signal wavelength.

3 dB fiber loop mirror nearly keeps constant over a broadband wavelength region and its reflection loss is 1.18 dB. It should be notable that we have used an L-band optical circulator to obtain the reflection spectra of these fiber loop mirrors and the loss between port 2 and port 3 of this circulator is 0.76 dB. Therefore, the extra loss being taken into account, the reflection loss of 3 dB fiber loop mirror is about 0.42 dB. In like manner, the HiBi fiber loop mirror has a reflection loss of 2.93 dB. That is to say the loss of the HiBi fiber loop mirror reflection spectrum is a bit more than that of conventional 3 dB fiber loop mirror, which is major explanation for the minor gain decrease in the new double-pass EDFA. The higher reflection loss of HiBi fiber loop mirror is caused by the large splicing loss between polarization maintaining fiber and single-mode fiber. By optimizing the splicing technique, the gain decrease induced by reflection loss of HiBi fiber loop mirror will be further reduced.

We have also experimentally studied the stability of the amplifier output spectra. Fig. 6 represents 16 times repeated scans of the dou-

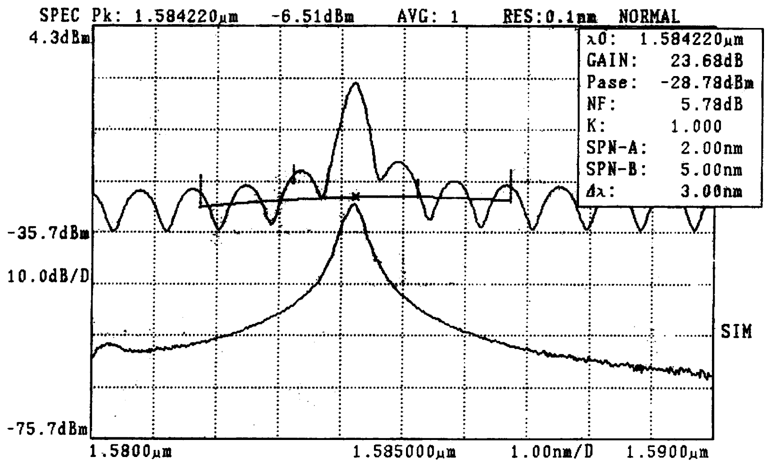

Fig. 4. Typical gain measurement spectra with input signal power of −30 dBm.

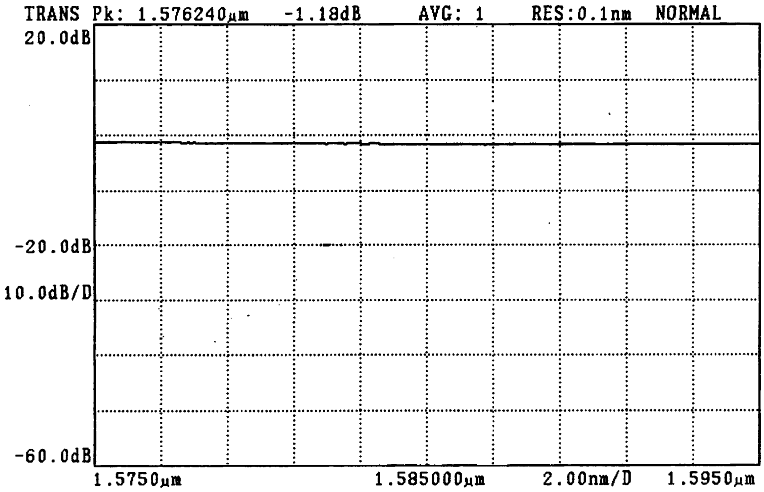

Fig. 5. Reflection spectrum of conventional 3 dB fiber loop mirror.

ble-pass amplifier output spectra based on HiBi fiber loop mirror and the interval between every scan is 2 min. It is apparent that the novel design has highly stable output performance. Fig. 7 shows the output spectrum of the conventional amplifier based on 3 dB fiber loop mirror. Compared with that of the conventional design, the output spectrum of our novel amplifier based on HiBi fiber loop mirror is periodic, which plays an important role in the noise figure reduction. It should be noted that due to the limitation of our signal light source, we have only measured the typical wavelengths in the L-band. However, when it comes to longer wavelength region, the noise figure will still be obviously reduced because the HiBi fiber loop mirror also acts as the ASE rejecter in other wavelength regions. In Fig. 6, we can find that throughout the long wavelength band, the intensity of output spectrum is higher at the signal wavelengths and relatively lower at the ASE wavelengths. From Fig. 7, in contrast, the output spectrum is not modulated by the HiBi fiber loop mirror. Therefore, the ASE wavelengths will be amplified simultaneously with the signal ones, leading to higher noise figure.

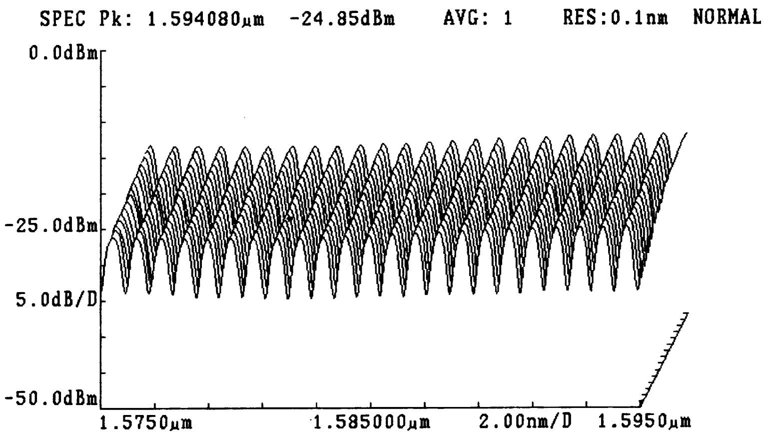

Fig. 6. 16-times repeated scans of the double-pass amplifier output spectra based on HiBi fiber loop mirror.

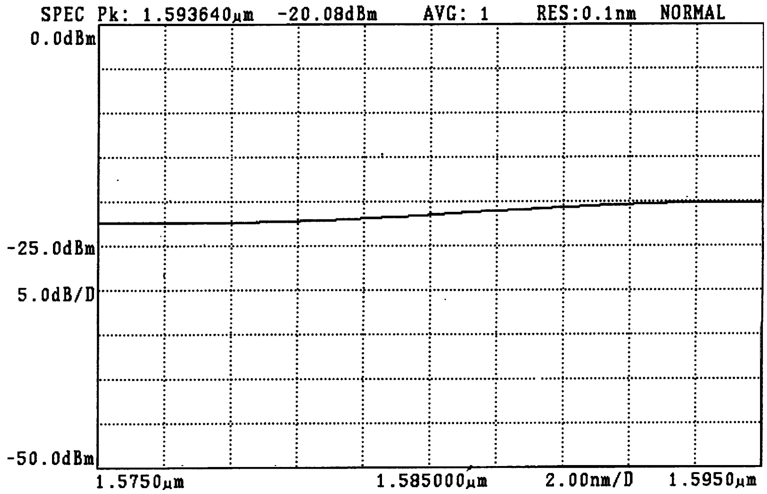

Fig. 7. Output spectrum of the conventional double-pass amplifier based on 3 dB fiber loop mirror.

4. Conclusion

In conclusion, a noise figure improved double-pass L-band EDFA is demonstrated and its operation principle has been analyzed in detail. In utilization of a HiBi fiber loop mirror to suppress ASE, the population inversion level at input side of EDF is promoted, which contributes much to the improvement of noise figure. Experimental observation shows that the output spectra of the double-pass amplifier based on HiBi fiber loop mirror is highly stable, meanwhile, by adjusting the length of high birefringence fiber, the period of its reflection spectrum can be set to 0.8 or 0.4 nm as recommended by the International Telecommunication Union for wavelength usage in wavelength division multiplexing or dense wavelength division multiplexing systems. The good stability and flexibility of HiBi fiber loop mirror ensures its feasibility for potential use in the future applications.

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