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Double-pass Raman amplifier for gain enhancement and gain clamping

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A double-pass discrete Raman amplifier (DRA) is demonstrated using a broadband fiber Bragg grating for gain enhancement and gain clamping. With the use of Truewave Reach fiber as a gain medium, maximum on/off gain improvement of 5 dB is achieved in C-band region. However, the proposed double-pass configuration cannot increase the maximum achievable gain in DRA since almost no gain improvement is observed with a piece of 50km long standard single mode fiber. With dispersion compensating fiber as a gain medium, the gain of double-pass DRA is clamped at 19dB for the small input signal. This shows that the double-pass scheme is a promising candidate to perform gain clamping without an optical feedback. The proposed double-pass DRA can also remarkably shorten the fiber length used and reduce the device size of the amplifier.

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1. Introduction

Raman amplifiers have attracted huge attention in recent years as the enabling technology for future long-haul, high-capacity optical communication systems. This is due to the fact that any wavelength within the transparency window of an optical fiber can be amplified by simply adjusting the pump wavelength [1-2]. In typical applications for transmission systems, fiber Raman amplifiers showed superior performance, such as ultra-wide bandwidth, low noise, and suppressed nonlinearities [3]. Discrete Raman amplifiers (DRAs), using dispersion-compensating fiber (DCF) or highly nonlinear fiber (HNLF), have also been shown to have good noise performance [4] and better signal power budget.

Owing to the low Raman conversion efficiency, Raman amplifier requires a significant amount of pump power and a longer interaction of the amplifying medium to achieve enough gain, which results in high cost. Therefore, it is important to enhance the gain efficiency when designing a DRA. The double-pass amplification technique has been utilized in erbium-doped fiber amplifiers (EDFAs) to increase the efficiency of the signal gain [5]. In this structure, the signal light is reflected back into the same amplifying medium by either a broadband reflector or mirror.

In this paper, a double-pass DRA is demonstrated based on a fiber Bragg grating (FBG), which has a flat reflectivity of more than 99% over the wavelength range from 1525 to 1565 nm. Compared with the single-pass Raman amplifier, this double-pass amplifier has been proved to have an obvious gain improvement by the experimental results. Also, the influencing factors such as type and length of gain medium are studied experimentally.

2. Experimental set-up

The configuration of proposed double-pass discrete Raman amplifier (DRA) is shown in Fig. 1. The 1440nm pump laser at 1440nm with the maximum output power of 350mW is employed as a Raman pump and is injected through a wavelength division multiplexer (WDM). A fiber Bragg grating is used as the broadband reflector that has a reflectivity of more than 90% over a wavelength range from 1525nm to 1565nm. A tunable laser source (TLS) with an external cavity is used in conjunction with optical spectrum analyzer (OSA) for the on/off gain measurement of the amplifier. The experiments are carried out for the three types of gain fibers: a standard single-mode fiber (SMF), dispersion compensating fiber (DCF) and Truewave Reach fiber. The DCF and Truewave Reach fibers are a particular convenient Raman gain medium, which has Raman gain efficiency of 5 to 10 times larger than standard SMF.

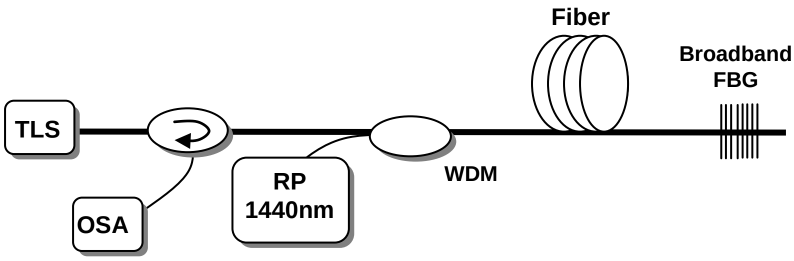

Fig. 1. Configuration of the proposed double-pass DRA.

3. Results and discussion

We first studied the gain performance of double-pass DRA in comparison with the typical single-pass system. In this experiment, the single-pass system is obtained by replacing the FBG with an OSA. In Fig. 2, Raman on/off gain spectra of the DRA using a piece of 7.7km long DCF are plotted for both single- and double-pass systems. The input signal is fixed at 0 dBm. As shown in the figure, Raman gains of the double-pass system at wavelength region from 1525 to 1560nm are increased compared with the typical single-pass amplifier. For instance, the gain enhancement of 5dB is observed at 1540nm. Inset of Fig. 2 shows the gain of the double-pass DRA as a function of input signal power for signal wavelength 1550nm. As shown in the figure, the gain is clamped at 19dB for the small input signal. This is attributed to the double-pass scheme which provides very high gain efficiency with a lower pump power operation. This shows that the double-pass scheme is a promising candidate to perform gain clamping without an optical feedback. It is not practical to apply the all-optical feedback in a DRA, which has a relatively lower gain compared with the typical EDFA.

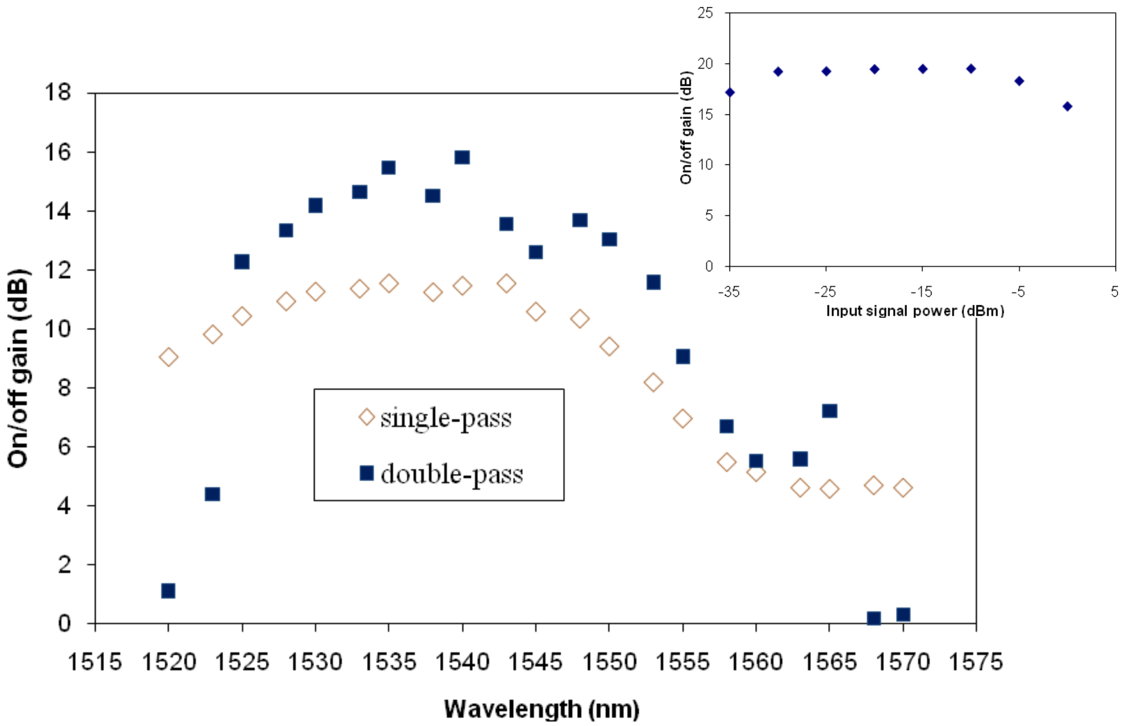

Fig. 2 On-off gain spectrum for both single-pass and double-pass DRA. Inset shows the gain as a function input signal power for the proposed double-pass DRA.

Fig. 3 shows the on/off gain enhancement against the signal wavelength of the proposed DRA with different types of gain medium. In this experiment, the pump power is fixed at the maximum value of 350mW. As shown in the figure, the highest gain of about 5dB is obtained with 10km long Truewave fiber. The gain enhancement is attributed to the double propagating of the signal in the gain medium which doubles the effective length of the amplifier. With the use of a 25km long standard SMF, the gain improvement is achieved within the range of 1 to 3dB in C-band region. However, almost no gain improvement is observed with a longer length of the SMF (50km). This shows that the double-pass scheme can only shorten the optimum length of the DRA by increases the effective length, but cannot increase the maximum achievable gain, which is also depended on the Raman pump power. The fluctuating of gain improvement value in 1525 to 1565nm region in all DRAs tested is due to the use of broadband FBG, which has a wavelength dependent loss. This varies the cavity loss spectrum and resulted in a fluctuation of the gain spectrum of the double-pass DFA. These results show that the proposed double-pass DRA can remarkably shorten the fiber length and reduce the device size of the amplifier as well as performing the gain clamping without an optical feedback.

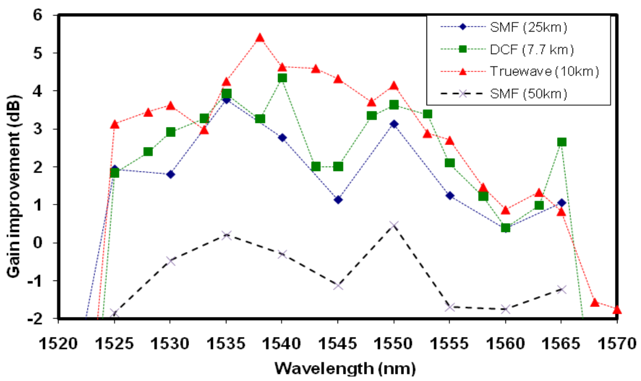

Fig. 3. Gain improvement against the input signal wavelengths with different gain media.

4. Conclusions

Gain enhancement and gain clamping characteristics are demonstrated by the double-pass DRA. This amplifier employs a broadband FBG as a reflector to allow double-propagation of the signal in the gain medium. Gain enhancement up to 5dB is obtained by the use of Truewave Reach fiber as a gain medium. However, the proposed double-pass configuration cannot increase the maximum achievable gain in DRA since almost no gain improvement is observed with a piece of 50km long standard SMF. The gain of double-pass DRA is also clamped at 19dB for the small input signal. This shows that the double-pass scheme is a promising candidate to perform gain clamping without an optical feedback. The proposed double-pass scheme can also remarkably shorten the gain medium required for the amplifier.

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