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ENHANCED S-BAND BRILLOUIN ERBIUM FIBER LASER WITH ADDITIONAL EDFA

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ABSTRACT

A short wavelength band Brillouin Erbium Fiber Laser (S-band BEFL) with enhanced characteristics using an additional erbium-doped fiber amplifier (EDFA) in the sub-loop of the BEFL system. Compared with the conventional BEFL without the additional EDFA, the enhanced BEFL has improved the number of channels as well as the flatness of the Brillouin Stoke's peak power. By incorporating a double-pass EDFA, a stable output laser comb up to 8 channels was obtained at 1503nm wavelength region with peak power variation for the first three Stokes is reduced from 30.9dB to 5.4dB. The incorporation of additional EDFA also increases the tuning range of the BEFL which the maximum tuning range of 1.8 nm was obtained with the single-pass scheme. The S-band BEFL has constant spacing of 0.09 nm or 11 GHz which has a potential application in dense wavelength division multiplexed system.

INTRODUCTION

Telecommunication industry has witnessed tremendous growth in the demand for capacity over the last few years due to the rapidly growing usage of the Internet and business data transfer. The demand for increased capacity can be met by dense wavelength division multiplexing (DWDM) transmission systems which consist of a large number of wavelength sources spaced at 100, 50 and lately 12.5GHz [1]. Multiwavelength source is an important component in this DWDM system. Recently, a hybrid Brillouin/erbium-doped fiber lasers (BEFL) have been proposed as a densely spaced robust multiwavelength laser source. It combines the nonlinear Brillouin gain and the linear gain in the erbium-doped fiber (EDF) to allow the resonator to be constructed which supports a laser comb with ~11GHz spacing at room temperature.

Most of the multi-wavelength BEFL systems are focused in conventional band (C-band) and long wavelength band (L-band) due to the bandwidth limitation of erbium-doped fiber amplifier (EDFA) [2-3]. Recently, a new S-band amplification technique, which utilizes erbium doped silica fiber with depressed cladding design and 980nm pump laser to generate EDF gain extension effect, has been reported [4]. By using this S-band amplifier, a multiwavelength S-band BEFL system was demonstrated in our earlier paper [5]. In this paper, S-band BEFL with enhanced characteristics is demonstrated by incorporating an additional S-band EDFA in sub loop. The optimum balancing of cavity

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gain profile and Brillouin injection signal has effectively increased the number of Stokes in the new BEFL.

EXPERIMENT DETAILS

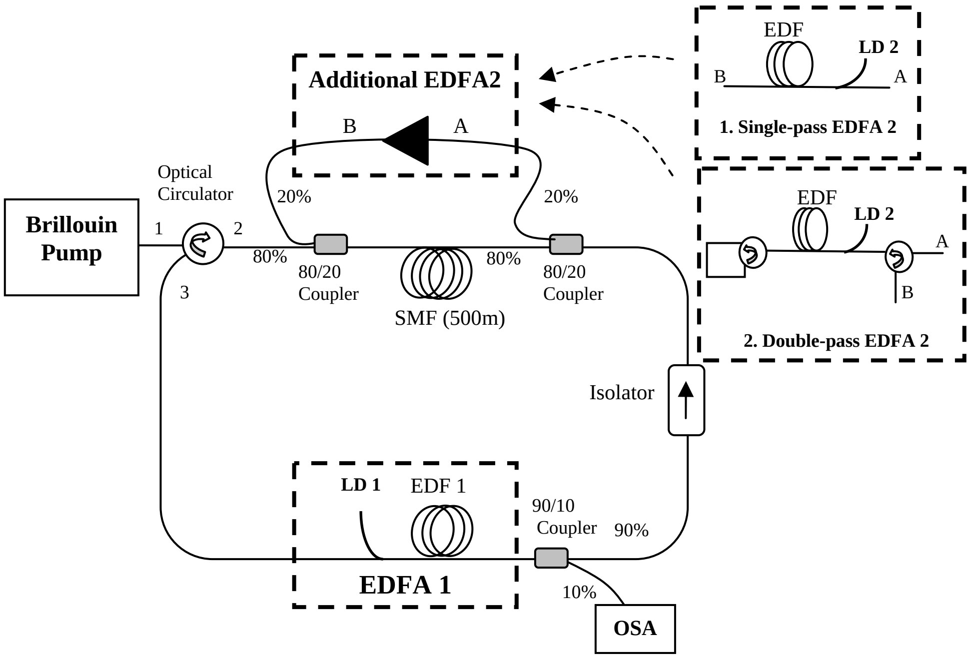

Figure1: Configuration of enhanced S-band BEFL with 2 additional EDFA schemes.

Figure 1 shows the schematic diagram of the S-band BEFL with additional EDFA in sub loop. An optical circulator is used to inject Brillouin pump (BP) into the main cavity and to force unidirectional operation of the laser in the cavity. Two 80/20 optical couplers are incorporated in the resonator and joined in a reverse S arrangement to act as looping arm or sub loop in order to generate multiple stokes signal. EDFA2 is placed in the sub loop to enhance the BEFL's performances. The length of SMF, EDF1 and EDF 2 are fixed at 500 m, 15 m and 15 m, respectively. Both EDFs have a depressed cladding design and peak absorption of 7.6dB/m in the 980nm region. A 90/10 coupler is also included inside the cavity to extract the output. The BEFL performance is investigated for two different EDFA2 schemes: single-pass and double-pass. The double-pass scheme is obtained by incorporation of optical circulator, which port 1 is connected to port 3, at the output end of EDF2 to act as a mirror. The BEFLs performances are also compared with conventional BEFL [5], which is obtained by removing EDFA2.

A narrow linewidth laser from an external cavity tunable laser source (TLS) is used as a BP. The BP signal which closed to the peak gain of the free-running EDFL is injected into the SMF through port 1 to port 2 of an optical circulator in the clockwise direction of the system. This signal will generate a nonlinear Brillouin gain in the counter-clockwise direction at a frequency shifted from the Brillouin pump by the Stokes shift in SMF. The Brillouin gain is then routed into the EDFA1 through port 2 to port 3, to

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generate Stokes at a frequency of approximately 11GHz away from the BP. A portion of the BEFL signal traveling in counter-clockwise direction is then amplified by EDFA2 in the sub loop and re-injected at the other end of the SMF in the clockwise direction to acts as a BP to generate additional frequencies. The output is measured and characterized by an optical spectrum analyzer (OSA) with a resolution of 0.015nm.

RESULTS AND DISCUSSIONS

Figure 2 shows the BEFL output comb against wavelength for various BEFL's schemes. The Brillouin pump power is fixed at 5mW while 980nm pump powers of LD1 and LD2 are fixed at 94mW and 200mW respectively. As shown in the figure, the simultaneous laser lines separated by 0.09nm are generated in all BEFLs schemes. The laser comb generation is attributed to the homogeneous nature of the EDF gain within the limited bandwidth, which enables the multi-line BEFL operation through the combination of traveling-waves generated by EDF and Brillouin gain. Figure 2 also shows that the incorporation of EDFA2 with single-pass scheme increases the number of positive Stokes from 3 to 4 lines. The number of Stokes lines is further increased to 5 lines by incorporation of double-pass scheme. It also can be seen that all BEFL schemes exhibit 3 anti-Stokes lines, which is due to the four-wave mixing and bi-directional transmission in the SMF.

The Brillouin Stokes peak power for the conventional BEFL reduces rapidly from 1st Stokes to the 3rd Stokes and it is symmetrically with the anti-Stokes. This is due to the insufficient power of the secondary Brillouin pump to generate the next Brillouin Stokes. The optimum balancing of cavity gain profile and Brillouin injection signal plays an important role in achieving multiple wavelength generations to the higher order Stokes line over wide spectral width. Therefore, the optical comb generation can be improved by inserting the additional EDFA2 in the sub loop of the system. This increases the Brillouin injection signal power, which improves the balancing and resulted in a higher number of Stokes lines as well as an improved flatness of the Brillouin Stokes peak power as shown in Figure 2. The power variation between the first 3 Stokes for the enhanced BEFL is obtained at about 17.8dB and 5.4dB for single-pass and double-pass schemes, respectively. It is much lower than the conventional BEFL without EDFA2, which has power variation of about 30.9dB. Refer to our previous work [6], the double-pass EDFA provides a higher gain compared with the single-pass EDFA with gain increment of more than 14dB for pump power above 120mW. Therefore, this BEFL with double-pass scheme for EDFA2 increases the power of the secondary Brillouin pump to generate the additional frequencies with higher peak power. Therefore, a flatter multiwavelength comb is observed with this scheme. The number of lines generated in the BEFL comb is limited to approximately 8 lines because of resonator configuration and the available pump power. This is not an intrinsic limitation, and more available pump power and a lower loss resonator will increase the number of lines.

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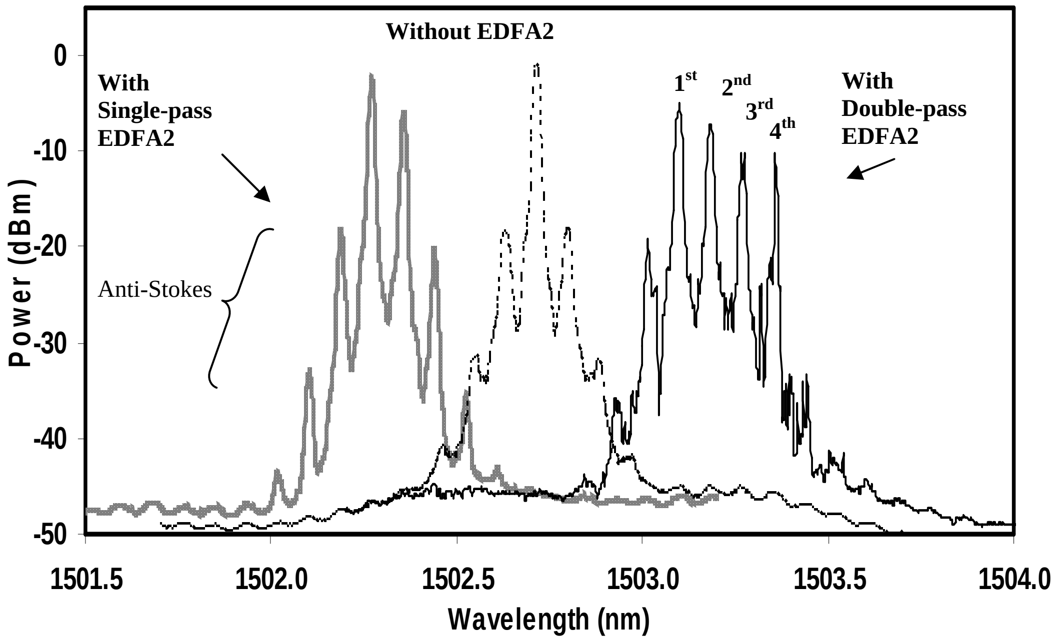

Figure 2: The BEFL output spectra for different BEFL schemes.

The small Brillouin gain necessitates that the wavelength for the operation of the BEFL be close to that at which the EDF laser would operate under free-running condition. There is, however, some wavelength tuning, possibly away from the center of EDF laser wavelength is also acceptable for the BEFL operation. Figure 3 shows the tuning characteristic of the first Stokes for all BEFL systems. The BP, LD1 and LD2 pump powers were fixed at 5mW, 94mW and 200mW respectively. The BP wavelength was tuned near and over the whole spectral range of the free running EDF laser gain region. As shown in the figure, the tuning range is better in the BEFL with an additional EDFA2 compared with in the conventional BEFL with the tuning range for the first Stokes usually is larger than other Stokes. This is because when the wavelength is fall off the gain region of EDF, the Stokes will experience insufficient gain to lase and terminate the process of multiple Stokes generation. The maximum tuning range of 1.8 nm is obtained by incorporation of EDFA2 with single-pass scheme, where the peak power is flat over the wavelength range from 1501.6 to 1503.4 nm. The broad tuning range allows a robust operation of the BEFL as the BP does not need to be accurately wavelength matched, provided that it generates sufficient Brillouin gain. The proposed S-band BEFL has a potential to be used in the future DWDM communication system.

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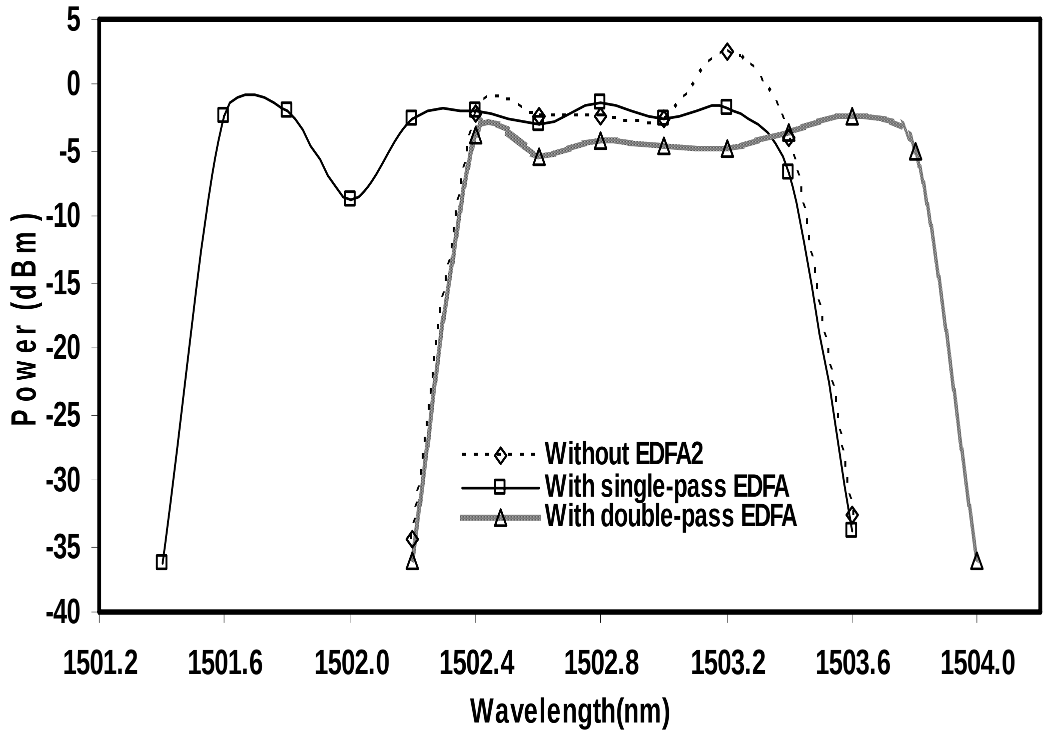

Figure 3: Tuning characteristics for different BEFL schemes.

CONCLUSION

An enhanced S-band BEFL is obtained with additional EDFA2 at the sub-loop of the laser system. Compared with the conventional S-band BEFL, the enhanced BEFL has improved the number of channels as well as the flatness of the Brillouin Stoke's peak power. A stable output laser comb up with 8 channels and the power variation for the first three Stokes of less than 5.4 dB was obtained by incorporation of EDFA2 with double-pass scheme. The proposed BEFL has also allowed a robust operation which a broad tuning range of approximately 1.8 nm was achieved for the BEFL with the single-pass scheme. The BEFL has constant spacing of 0.09 nm or 11 GHz and operates at 1500 nm region. The S-band BEFL has potential application for future DWDM communication system in S-band incorporating external modulator.

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