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Multiple lasing Brillouin Fiber Laser with the implementation of reflective Fiber Bragg Grating in a ring cavity configuration

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Abstract. A multi-wavelength Brillouin fiber laser with the implementation of reflective fiber Bragg grating is developed. In this ring cavity architecture, the fiber laser system is performed by the stimulated Brillouin scattering effect and four-wave mixing process. An improvement in the number Brillouin Stokes signal and average of the optical signal to noise ratio were generated through the reflection process of fiber Bragg grating. Due to the optimization of output coupling ratio from 10% to 60%, the highest Brillouin Stokes signal of 17 and average optical signal to noise ratio of 14.7 dB were recorded at 60% of the output coupling ratio. The amplified Brillouin pump power of 16.5 dBm at 1550 nm of Brillouin pump wavelength was injected into the laser system. A constant line spacing of 0.08 nm at each of the Brillouin Stokes signals was also recorded.

1 Introduction

Multi-wavelength fiber lasers can be defined as laser sources that emitting light more than one signal or multiple Brillouin Stokes (BS) signals from a main single wavelength light source [1]. The multi-wavelength generation is commonly capable producing an accurate narrow linewidth that made them offered several high potentials in an optical communication system especially in dense wavelength division multiplexing (DWDM) application [2]. As mentioned in a previous paper [2], the operation of DWDM system was manipulated from the extreme growth of multiple signals in order to attain an efficient operation and consequently to make the DWDM system as one of the attractive technology among the researchers. Other notable technologies that applied the multi-wavelength lasers are mostly found in microwave signal processing [3], optical sensors, optical spectroscopy, current monitors, short optical pulses [4] and high capacity optical fiber communication networks [3].

Recently, the requirement for multiwavelength Brillouin fiber laser (MWBFL) is highly desirable for the optical communication system due to its ability to counter the limitations in the multiwavelength Brillouin-Erbium fiber laser (MWBEFL) and multiwavelength Brillouin-Raman fiber laser (MWBRFL). In such a situation, the major drawback of MWBEFL is related to the intrinsic generation of self-lasing cavity modes at the peak of the Erbium-doped fiber (EDF) gain [5] meanwhile a spectrum broadening effect in the MWBRFL cavity is another issue need to be considered [6]. Consequently, these limitations have a major impact on the formation of multi-wavelength generation. In an effort to increase the performance of the laser system, the hybrid MWBFL can counter these problems by allowing a higher coherent light source with narrow downshifted signal through stimulated Brillouin scattering (SBS) effect [7] and thus offer a solution to produce a larger number BS signal.

The direction of MWBFL studied was demonstrated in both linear and ring cavity configurations. Various ring cavity configurations of MWBFL system have been previously reported in [1, 8-9]. In this reported work [1], the ring cavity was successfully produced up to 8 BS signal with 0.08 nm line spacing by a combination of forward and backward output signals. Meanwhile, 0.16 nm of line spacing in between two consecutive odd or even BS signals was attained when the forward and backward direction were discriminated from the laser system. Another invention also proposed by M. R. Nurdik and his team [8]. This ring cavity BFL was mainly constructed by using the same type and length (25 km of SMF-28) of the Brillouin gain medium as previously reported in [1]. The performance of laser system was achieved with 10 BS signals and 7 anti-Stokes signals at a line spacing of 0.088 nm by launching 11.29 dBm BP power at 1510 nm of BP wavelength. Besides, at a BP wavelength of 1550 nm, the limitation of multi-wavelength generation occurred

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when only 5 BS signals were extracted at 50% output coupling ratio.

A linear cavity of BFL with multiple wavelength outputs was also reported in [10]. The optimization of output coupling ratios was varied from 70% to 99% in order to control the amount of light propagation. The effect of 95:5 coupling ratio produced up to 11 BS signals and anti-Stokes signals simultaneously with a line spacing of 0.08 nm. A maximum BP power of 11.7 dBm with 1550 nm BP wavelength was chosen to inject into the laser cavity. In this paper, as compared to our previous configurations [1, 8-10], we successfully reported the increment number of BS signals with an acceptable average optical signal to noise ratio (OSNR) value. The employment of a fiber Bragg grating's (FBG) reflectivity offers a direct impact to produce better lasing performance in a ring cavity. The reflectivity and selective wavelengths of FBG enhance the SBS effect in the Brillouin gain medium to generate a higher nonlinear effect with 17 BS signals and 14.7 dB of average OSNR value. A constant line spacing of 0.08 nm was also observed.

2 Experimental Setup

The architecture of ring cavity MWBFL with the implementation of a reflective FBG is illustrated in Fig. 1. It consists of an external tunable laser source (TLS), a unit of erbium-doped fiber amplifier (EDFA), 8 km of single mode fiber (SMF) that acts as a Brillouin gain medium, 3-port of optical circulator, 2x2 optical coupler and 3 dB bandwidth of 5 nm FBG with 70% reflectivity is used as another fiber loop mirror. Based on the FBG's properties, it only reflected the 5 nm wavelengths back at the centre wavelength of 1550 nm, while others wavelengths would be filtered and eliminated from the laser system.

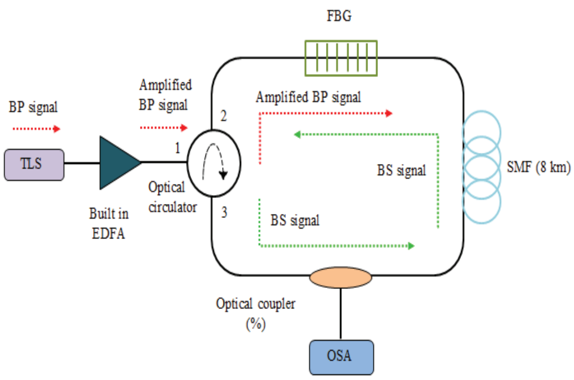

Fig. 1. The proposed ring cavity MWBFL system with the implementation of a reflective FBG.

In this experiment, the main nonlinear phenomenon called as SBS effect initiated in the SMF once the intensity of Brillouin pump (BP) signal is sufficient enough to excite the atoms. Without sufficient high BP power from the external TLS, the BP signals would be absorbed by the EDFA instead of being amplified by it. After being amplified, the high BP signals oscillated into the port-2 via port-1 of the optical circulator. From port-2 of the optical circulator, the amplified BP signals propagated directly into the FBG in order to remove the unwanted wavelengths according to the FBG's properties. About 30% of amplified BP signals continued to transmit into the SMF while another 70% of amplified BP signals reflected in the opposite direction.

In the SMF, the SBS effect only generated when the Brillouin threshold condition is achieved. The first downshifted BS signal would propagate in the opposite direction of amplified BP signals and enter the FBG for the reflection process. Later, the first BS signal oscillated to the optical circulator and circulated back into the FBG and SMF to complete clockwise and anti-clockwise light propagation. This propagation continues until the power of subsequent BS signals is high enough to overcome the Brillouin threshold power. In other words, the first BS signal acts as a BP power to generate the second BS signal, and this propagation continues as long as the Brillouin gain is equal or greater than the cavity loss. This MWBFL system has a line spacing of approximately 0.08 nm which depends on the type of optical fiber (SMF). The output BS signal is extracted from the optical coupler form 10% to 60% and is monitored by using an optical spectrum analyzer (OSA) with 0.02 nm resolution bandwidth.

3 Results and Discussion

The corresponding optical spectrum of FBG's reflection profile was investigated as shown in Fig. 2. The 3 dB bandwidth of 5 nm is utilized in order to enhance the signal quality by having 70% of reflectivity. The improvement of light intensity generated within 1547 nm to 1553 nm. There is a stop band of wavelengths in which filtered certain wavelengths from propagated into the Bragg grating. Thus, only desired wavelengths that fulfilled the Bragg's condition are strongly back-reflected.

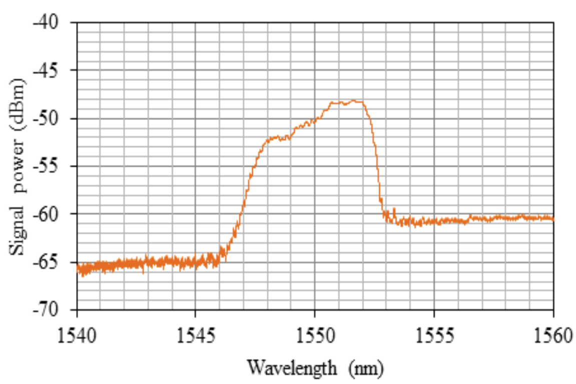

Fig. 2. The optical spectrum of FBG's reflection profile.

As the input light of 15.5 dBm with a broad spectrum was propagated along the core of the optical fiber, there was only 1547 nm to 1553 nm that back-reflected light at maximum reflectance at Bragg wavelength, λ_B.

Meanwhile, the transmitted light would eliminate from the spectrum due to Bragg's condition. It should be noted that the light propagation in the FBG was not only occurred in the back-reflected direction but also occurred in the forward direction.

Next, the effect of amplified BP power on the generation of multi-wavelength was investigated as depicted in Fig. 3. In this investigation, the amplified BP power is considered as the input signal after being amplified by the EDFA. The amplified BP power was varied from 12.0 dBm to 16.5 dBm whereas the BP wavelength was fixed at 1550 nm and 60% of the output coupling ratio was used to extract the output signal. Referring to Fig. 3, the number of BS signals increases as the amplified BP power gradually increases. This condition can be explained as the EDFA provides high Brillouin gain for initiating the maximum SBS effect. Due to the increment of the amplified BP power, the SBS effect generates efficiently to produce the downshifted BS signal in the opposite direction and thus more multi-wavelength generation was observed.

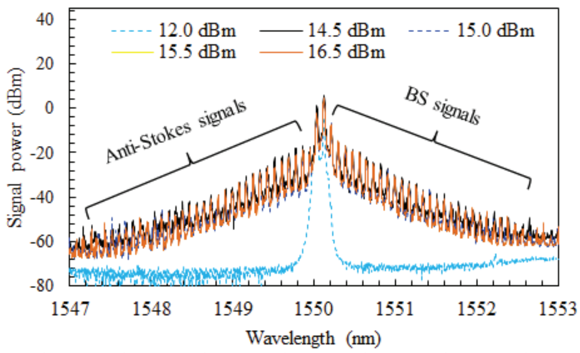

Fig. 3. Output spectra for different amplified BP powers at 1550 nm of BP wavelength by utilized 60% of the output coupling ratio.

At 12.0 dBm of amplified BP power, the optical spectrum indicates only 1 BS signal because of low injected input power. The BS signal generated once the Brillouin threshold power is satisfied [11]. In this case, at 12.0 dBm of amplified BP power, the laser system is considered as around Brillouin threshold condition. When the amplified BP power was increased further, it was found that the generation of multi-wavelength was started to generate with 8 BS signals at 14.5 dBm. It was noticed that the amount of power at each of the BS signals were dropped due to low Brillouin gain. By increasing the amplified BP powers from 15.0 dBm to 16.5 dBm, more multi-wavelength were generated. The most generated BS signals of 17 were found at maximum amplified BP power of 16.5 dBm. Besides that, it was also noticed that the anti-Stokes signals were generated at the left side of the optical spectra for 14.5 dBm to 16.5 dBm. The formation of anti-Stokes signal happened based on the interaction of multiple four-wave mixing (FWM) process. The unidirectional propagation in the laser system produced the anti-Stokes signal where the BS signal interacts with a pump beam to create other new signals (anti-Stokes signal). The number of anti-Stokes signals is lower compared to BS signals because the FWM process depends on the BS signals. The anti-Stokes signals increases as the BS signals increases.

The relationship of number BS signal with different amplified BP powers by utilizing 8 km of SMF is illustrated in Fig. 4. In this study, the BS signal experienced a flat trend before having a dramatic growth for all proposed output coupling ratios. At amplified BP powers of 12.0 dBm to 13.5 dBm, only 1 BS signal was recorded for all case output coupling ratios. At amplified BP power of 14.0 dBm to 16.5 dBm, the number BS signals were dramatically increased. This observation has resulted because of the higher Brillouin gain property accumulated higher SBS effect. This effective Brillouin gain medium provides maximum light intensities to lase the MWBFL system. Thus, this oscillated light resulted in the increment of the generated BS signals. The highest BS signal of 17 was recorded at 16.5 dBm of amplified BP power. In terms of output coupling ratio factor, the BS signals improved as the coupling ratios were increased. This also corresponds to the higher output coupling ratio influenced the increment of cavity loss. Therefore, the oscillating energy experienced inside the ring cavity becomes lesser. As a result, the lowest number BS signal of 4 was found at 10% output coupling ratio with 16.5 dBm of amplified BP power. Meanwhile, the highest number BS signal of 17 was attained at 60% optimum coupling ratio by launching 16.5 dBm of amplified BP power.

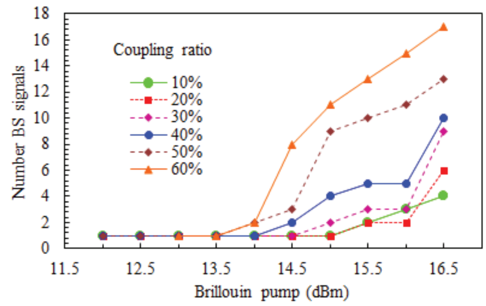

Fig. 4. Number BS signals as a function of amplified BP powers at 1550 nm of BP wavelength.

Fig. 5 depicts the average of OSNR with different amplified BP powers. Due to the effect of additional FBG's reflection, the average of OSNR gradually increases as the increment of amplified BP powers and output coupling ratios. The sufficient amount of amplified BP power that shared at each of the BS signals was the main factor that affected this abrupt change. At high amplified BP power, the laser system provided a high Brillouin gain which results in increasing of the OSNR. Therefore, high amplified BP power was required to supply the input power to reduce the noise level of the MWBFL system in which led to increases of OSNR. Moreover, the higher average OSNR is also owing to the implementation of additional FBG in which enhances the signal quality by having a reflection process. In this experiment, the average of OSNR was measured by comparing the peak power at each of the BS signals to the highest noise floor level of the signal [12]. The deduction of both signals is defined as the OSNR. Since the MWBFL system produced a multi-wavelength generation, the OSNR for each of the BS signals was calculated and then divided into the total number BS signals in order to calculate the average OSNR. Overall, the lowest average of OSNR was obtained around 11.1 dB for 12.0 dBm of amplified BP power at 10% of the output coupling ratio. Meanwhile, a higher average of OSNR about 14.7 dB was achieved for 16.5 dBm of amplified BP power and 60% of the output coupling ratio.

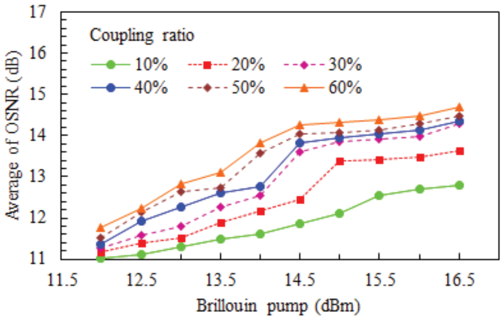

Fig. 5. Average of OSNR with different amplified BP powers for all cases output coupling ratios.

4 Summary

We have successfully demonstrated a ring cavity MWBFL system with the implementation of a reflective FBG that can be used at 1550 nm in the optical communication window. At amplified BP power of 16.5 dBm with a corresponding 60% of the output coupling ratio, 17 BS signals and 14.7 dB average of OSNR were generated by the combination process of multiple SBS and FWM effect. The output BS signals were constantly separated by 0.08 nm. The implementation of FBG inside the ring cavity can effectively be used in the laser system especially in the Brillouin fiber laser to increase the number BS signals. Moreover, due to the reflection process of FBG, an acceptable average of OSNR was recorded which could be used for several potential applications in the optical communication. For future work, a high reflection of FBG can be utilized to improve the average OSNR in order to meet the requirements of high capacity optical communication networks.

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