The Frequency Gap and SNR Improvement for Self-seeded Multi-wavelength Brillouin-Erbium Fiber Laser

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Abstract— We demonstrate a self-seeded multi-wavelength brillouin-erbium fiber laser with double-brillouin-frequency gap. First, the factor that induces the double frequency gap is investigated. The twice channel gap is induced by the gain difference in different directions. Then, a self-seeded multi-wavelength brillouin-erbium fiber laser with high signal to noise ratio (SNR) is reported. 44 stable output channels (above −25 dBm) with 20 GHz frequency spacing is obtained when the 980 nm pump power is 300 mW.

1. INTRODUCTION

Stimulated Brillouin scattering (SBS) is a nonlinear process in optical fiber resulted from the interaction between a pump wave and an acoustic wave [1]. When a light wave launched into an optical fiber exceeds SBS threshold, a backward stokes wave with a Brillouin frequency shift f_B is generated. SBS in optical fiber has wide application in many fields, such as optical communication [2–4], optical sensor [5, 6], slow and fast light [7–9], optical storage [10], micro-wave photonics [11, 12].

Brillouin-Erbium fiber lasers (BEFL), which integrates the nonlinear gain of single mode fiber and the linear gain of erbium doped fiber, is first demonstrated by G. J. Cowle, et al. [13]. The BEFL has drawn a lot of interest in recent years because of its unique properties-narrow linewidth and high output power [14–16]. Multiwavelength BEFL can be generated by cascaded stimulated brillouin scattering effect [17]. 150 lines are generated by enhanced four wave mixing effect in the cavity [18]. In 2005, Song, et al. reported the self-seeded BEFL that generated 120 lines [19]. A little later, a self-seeded BEFL with 200 lines was report by the same group [20]. The low SNR is one of the main disadvantages of the self-seeded BEFL [18].

The frequency gap of the multiwavelength is equal to the Brillouin frequency shift f_B which depends on the fiber material. For single mode fiber (SMF) based on silica, it is about 10 GHz (~ 0.08 nm) [1]. The narrow frequency gap limits the applications of the multiwavelength BEFL in system implementation. Some researchers are interested in expanding the channel spacing. In reference [21], a BEFL with 10 and 20 GHz frequency gap was reported. The odd-and even-odd Stokes lines are outputting from different arm in the cavity. In reference [22], the multiwavelength BEFL contains two cavities, the multiwavelength comb with 20 GHz frequency gap can be produced in one of the cavities. Recently, Y. G. Shee, et al. reported a multiwavelength BEFL with 20 GHz frequency spacing [23]. A four ports circulator is used to combine two cavities. The light output from the unidirectional cavity has the 20 GHz frequency gap. All the multiwavelength BEFLs above are the traditional BEFLs with the Brillouin pump. To the best knowledge of us, there is no self-seeded BEFL with 20 GHz frequency gap reported.

In this paper, we propose a self-seeded multiwavelength BEFL with 20 GHz frequency gap. The relation between the pump power and the spectra is investigated. The factor that induces the double frequency gap is investigated and proved. 44 output channels with 20 GHz gap are generated when the pump power is 300 mW. The SNR of the multi-wavelength comb is more than 20 dBm.

2. EXPERIMENTAL AND PRINCIPLES

The experimental setup of the multi-wavelength brillouin-erbium fiber laser is shown in Figure 1. The 50 : 50 coupler is the core component in the ring cavity: port a works as the output port, port b and port d form a ring cavity, port c connects to a Sagnac loop. In the ring cavity there are a 980/1550 wavelength division multiplexing (WDM), 980 nm pump laser, 11 m L-band erbium-doped fiber (EDF), 12 km single mode fiber (SMF). The EDF is produced by OFS, its absorption coefficient at 1530 nm is 28.81 dB/m. The 12 km SMF is produced by Yangtze Optical Fibre and Cable Company. Its mode field diameter at 1550 nm is $9.9 \sim 10.9$ µm and the dispersion at 1550 nm is 18 ps/(ns · km). The Sagnac loop filter consists of a 50 : 50 coupler, 10 cm and 18 cm long PMFs and two polarization controllers. The intensity transfer function of the Sagnac loop filter can be expressed as $T = [\sin\theta \cos(\frac{\pi l \Delta n}{\lambda})]^2$ [24], where θ is the initial polarization angle, l is the length of the PM fiber, and Δn represents the effective refractive index difference between the slow and fast axes of the PMF. In our case, the Sagnac loop filter serves as a reflective filter. A two-section Sagnac loop filter is used in the cavity because it has better performance for gain-flatten of the EDFA [25]. An AQ6370 optical spectrum analyzer (OSA) with resolution of 0.02 nm was used to measure the output spectra of the laser. The mechanism of the laser is shown in reference [19]: when a lasing mode is established, its linewidth is narrowed by the Rayleigh scattering in the SMF, the narrow linewidth mode becomes the pump for the SBS effect in the SMF.

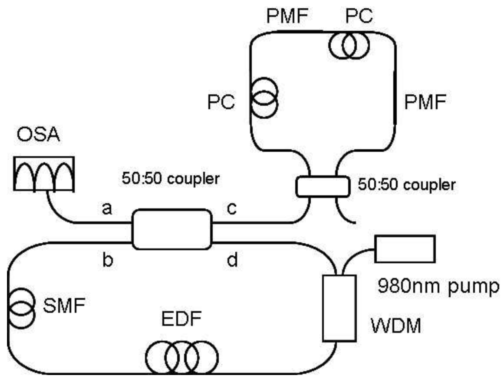

Figure 1: The experimental setup of the multi-wavelength brillouin-erbium fiber laser, EDF: Erbium-doped fiber, OC: optical coupler, OSA: optical spectrum analyzer, SMF: Single mode fiber, PC: polarization controller, PMF: polarization maintaining fiber.

3. RESULTS AND DISCUSSION

In this experiment, the multi-wavelength comb is observed when the power of 980 nm pump laser is above 200 mW. The spectra are shown in Figure 2 when the power varies from 200 mW to 300 mW with the 20 mW interval. When the pump power is less than 240 mW, there appears multi-wavelength comb, but it is not strong enough to suppress the mode competition in the cavity. When the pump power is 260 mW, there appears stable multiwavelength comb. The number of the lines increases with the pump power. In our experiment, the maximum pump power is 300 mW, there are 36 peaks above -20 dBm.

In order to check the frequency gap, the fine spectra from 1597 nm to 1599 nm in Figure 2 at 300 mW pump power are shown in Figure 3. There are 12 peaks in 2 nm. It indicates that the frequency gap between adjacent peaks is 20 GHz.

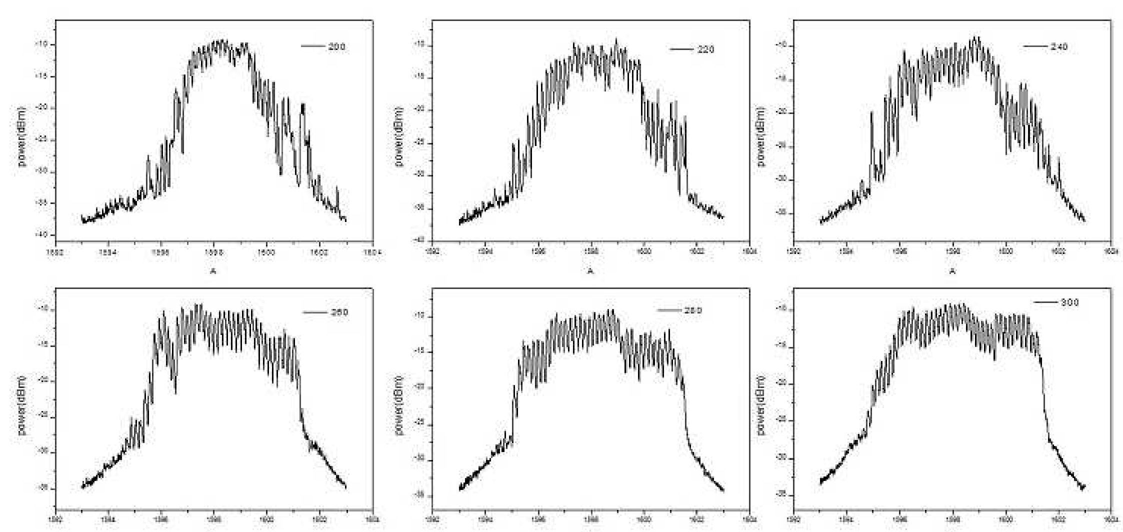

Figure 2: The spectra of multi-wavelength combs when 980 nm pump power varies from 200 mW to 300 mW.

The reason why the frequency gap is 20 GHz is the different paths that the lights at different directions go through. In the cavity, the path of the output light at clockwise direction is the

SMF-port b-port c-port a, the path of the other part light at clockwise direction is the SMF-port b-port d-EDF-the SMF; the path of the output light at anti-clockwise direction is the SMF-EDF-port d-port a, the path of the other part light at anti-clockwise direction is the SMF-EDF-port d-port b-the SMF. In BEFL, the location of the EDFA has big effect on the output characteristics of the laser [26]. Before output, the light at anti-clockwise direction is amplified by the EDFA, but the light at clockwise direction is not. So the output lights at different directions have big power difference, the output spectrum only shows the light from anti-clockwise direction. It induces that the frequency gap becomes 20 GHz.

In the previous results, the light at clockwise direction can't be shown because it is not amplified before output. In order to equalize the power, another EDFA that consists of a 980 nm pump, a WDM and 11 meters long EDF is inserted into the left side of the ring cavity. In the new structure, the light at clockwise direction can be amplified before output. It can compensate the power difference of the light at different direction.

There is stable multiwavelength output when the 980 nm pump power at left side is 130 mW and the 980 nm pump power at right side is 126 mW. Figure 4 shows the output multiwavelength comb. The small figure at the right top in Figure 5 shows the fine spectra at the range from 1601 nm to 1602 nm. There are 12 peaks in 1 nm. It indicates that the frequency gap is 10 GHz. It proves that the reason of double frequency gap is the lack of the amplifier at left side.

From Figure 2 to Figure 4, the SNR of the output is less than 5 dB. It is not good enough for application. In order to improve the SNR, the EDF in the cavity is changed. The new 10-meter-long EDF is produced by Nufern, whose absorption coefficient at 1530 nm is 25.0 ± 2.0 dB/m. The

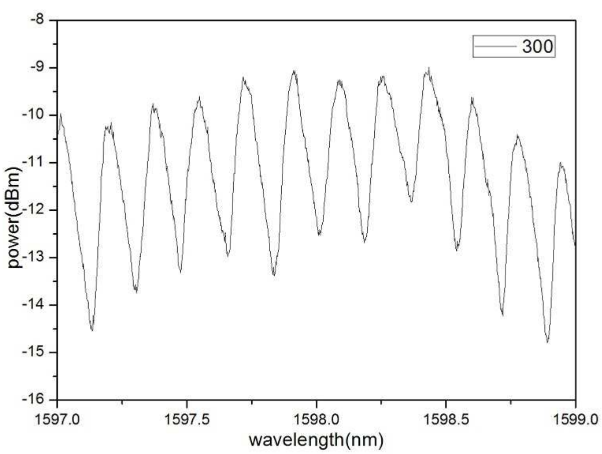

Figure 3: The fine Spectra of multi-wavelength combs when 980 nm pump power fixed at 300 mW.

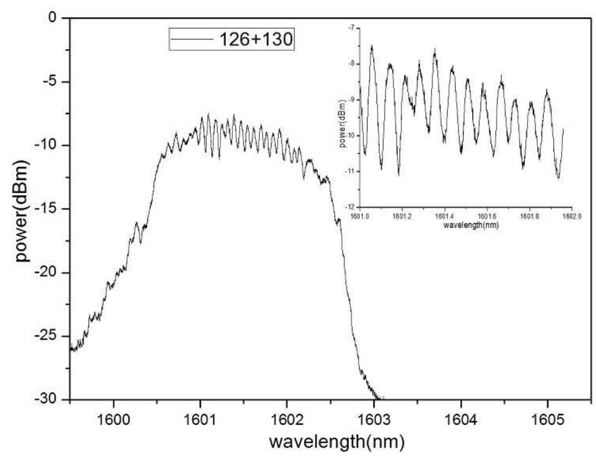

Figure 4: The spectra of the laser with two amplifiers.

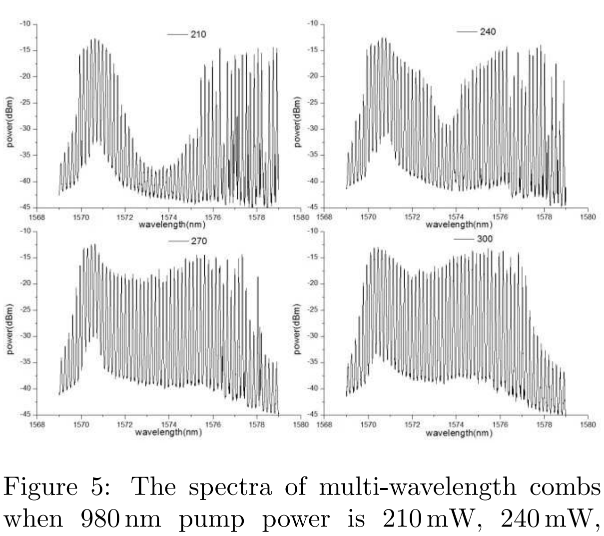

Figure 5: The spectra of multi-wavelength combs when 980 nm pump power is 210 mW, 240 mW, 270 mW, 300 mW.

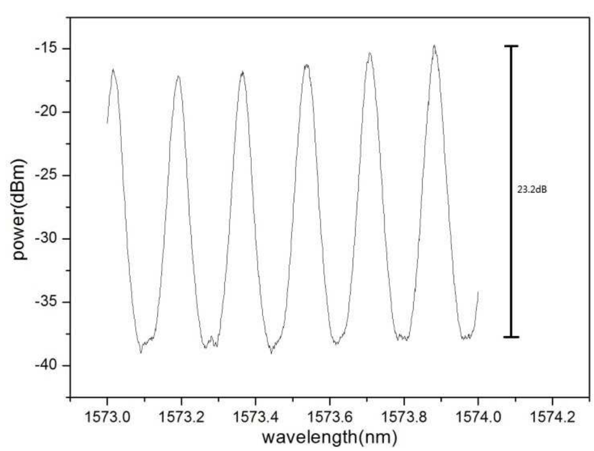

Figure 6: The fine spectra from 1573 nm to 1574 nm when the pump power is 300 mW.

relationship between the multi-wavelength comb and the power of 980 nm pump laser is shown in Figure 5. The power varies from 210 mW to 300 mW with the 30 mW interval. When pump power is 300 mW, there are 44 peaks above −25 dBm.

In order to check the SNR of the multi-wavelength comb, the fine spectra from 1573 nm to 1574 nm in Figure 5 at 300 mW pump power are shown in Figure 6. There are 6 peaks. The biggest SNR is 23.2 dB. The SNR of the lines in figure 6 is more than 20 dB.

4. CONCLUSION

We have successfully demonstrated a self-seeded multi-wavelength brillouin-erbium fiber laser with double frequency gap. The influence of the pump power on the multiwavelength output is investigated. The reason of the double-frequency-gap is the gain difference in different directions. When the amplifier is balanced in both sides of the SMF, the frequency gap becomes normal. At the same time, the method to improve the SNR of the multiwavelength comb is reported. The multi-wavelength comb with 44 double-brillouin-frequency stokes lines is obtained when the pump power is 300 mW. The multiwavelenghth BEFL can be used for potential applications in DWDM and optical sensor systems.

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