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Generation of efficient 20 GHz optical combs in a Brillouin-erbium fiber laser

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Abstract

A tunable multiwavelength Brillouin-erbium fiber laser is experimentally demonstrated with a double-Brillouin-frequency spacing. This double-frequency shifter is constructed by incorporating a four-port circulator to isolate and circulate the odd-Stokes signals through the 10 km long non-zero dispersion shifted fiber, which acts as a Brillouin gain medium. The output even-order Stokes signals are amplified in the erbium gain block formed in a ring cavity. Up to 15 lasing lines with a wavelength spacing of 0.173 nm have been achieved at a 980 nm pump power of 50 mW and a Brillouin pump of 3 dB m. The multiwavelength laser source exhibits a 10 nm tuning range from 1552 to 1562 nm with the optical signal-to-noise ratio of the desired output channels at around 34.5 dB.

1. Introduction

Multiwavelength fiber lasers have attracted remarkable interest due to their wide potential applications in dense wavelength division multiplexing (DWDM) networks, optical fiber sensors and microwave photonics [1–4]. To provide gain media in the architecture of multiwavelength fiber lasers, various types of fibers are incorporated such as erbium-doped fiber, bismuth-oxide doped fiber and ytterbium-doped fiber. Typical methods utilizing nonlinear optical effects such as stimulated Brillouin scattering (SBS) [5], four-wave mixing (FWM) [6] and nonlinear polarization rotation (NPR) [7, 8] are employed to achieve a multiwavelength fiber laser at room temperature.

A Brillouin-erbium fiber laser (BEFL), which uses the integration of the hybrid of the nonlinear Brillouin gain and the linear gain of an erbium-doped fiber amplifier (EDFA), has been considered to achieve a multiwavelength fiber laser that is stable at room temperature with narrow equal-spacing and low threshold [9, 10]. However, the practical contribution of a multiwavelength BEFL in the system implementation is limited due to the difficulty of channel demultiplexing from the narrow (~10 GHz) spacing. Hence, attempts have been made to expand the channel spacing between the Brillouin Stokes signals to enhance the demultiplexing process. So far, some bidirectional multiwavelength Brillouin fiber laser architectures have been reported [11, 12]. In these proposed configurations without the erbium gain in the cavity, only four channels were obtained by the 25 km long single mode fiber with 20 GHz frequency spacing.

In this paper, a multiwavelength BEFL is demonstrated with double-Brillouin Stokes-shifted frequency channel spacing. The isolation and circulation of odd-order Brillouin Stokes signals are realized by utilizing a four-port circulator in the fiber laser structure. By incorporating a 10 km long non-zero dispersion shifted fiber (NZ-DSF), 15 output channels with 0.173 nm wavelength spacing are generated and also can be tuned over a 10 nm range (from 1552 to 1562 nm).

2. Experimental setup

Figure 1 shows the experimental architecture of the proposed multiwavelength BEFL that is constructed from a ring cavity and a double-Brillouin-frequency shifter structure. The double-Brillouin-frequency shifter is the main structure, which generates twice the Brillouin frequency (around 20 GHz) down-shifting with every signal injected into the cavity. This ring cavity is constructed by 10 km NZ-DSF as the gain medium and a four-port optical circulator. The used NZ-DSF has a cut-off wavelength of less than 1452 nm manufactured by the Lucent Company and a mode field diameter of 8.5 μm as reported in [12].

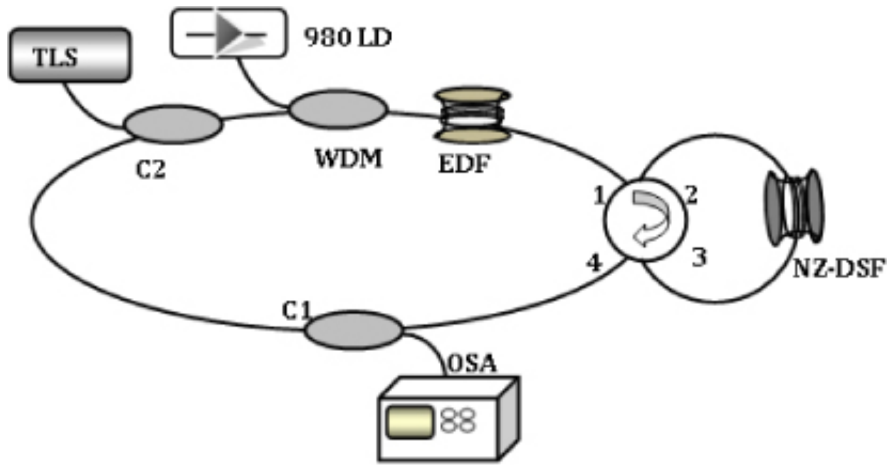

Figure 1. Configuration of the multiwavelength BEFL.

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This multiwavelength BEFL also consists of a tunable laser source (TLS), two 3 dB couplers, a wavelength division multiplexer (WDM), an erbium-doped fiber (EDF) and a 980 nm laser diode (LD). The gain medium incorporated is an 8 m long EDF with Er^{3+} concentration of 440 ppm. The 980 nm laser diode is coupled to pump EDF through a 980/1550 nm WDM. The portion of oscillating signals inside the loop is extracted from the laser system by using a 3 dB coupler to be monitored. The output spectrum is characterized by the optical spectrum analyzers (OSA) with a resolution of 0.015 nm. The four-port circulator is incorporated to discriminate the even- and odd-order Brillouin lines as well as providing a unidirectional operation laser system. The BP signal is directed at the EDF before entering the NZ-DSF to increase the efficiency of the gain. The first-order Brillouin Stokes signal (BS1) is generated once the BP power exceeds its threshold. The generated BS1 propagates towards port 2 in the opposite direction to BP and it is fed back to the 10 km long NZ-DSF via port 3 to complete a round trip. BS1 oscillates in the cavity in a counter-clockwise direction. The second-order Brillouin Stokes signal (BS2) is produced when BS1 power, behaving as the pump for BS2 signal generation, goes beyond its threshold power. Then it propagates from port 3 towards port 4 in the same direction as BP. Therefore, the four-port circulator discriminates the odd-order and even-order Brillouin Stokes signals to provide a double-frequency shifter laser system. The proposed laser structure enables the circulation of even-order Brillouin Stokes signals in a ring cavity which includes an EDF as amplification gain block. This generated signal then behaves as the next BP to generate higher even-order Stokes lines as the desired output channels. In the same process, higher order BS signals can be generated until the Stokes signal gain is higher than the cavity loss.

3. Results and discussion

Unstable self-lasing cavity modes emerge due to the strong mode competition around the 1555–1560 nm region when the BP signal is not injected into the cavity. Under this condition, the lasing characteristics of EDFL are investigated and recorded. Figure 2 illustrates the self-lasing cavity modes at different pump powers of 10 mW, 50 mW and 120 mW, respectively. The intensity and spectral width of these modes are proportional to the 980 nm pump power.

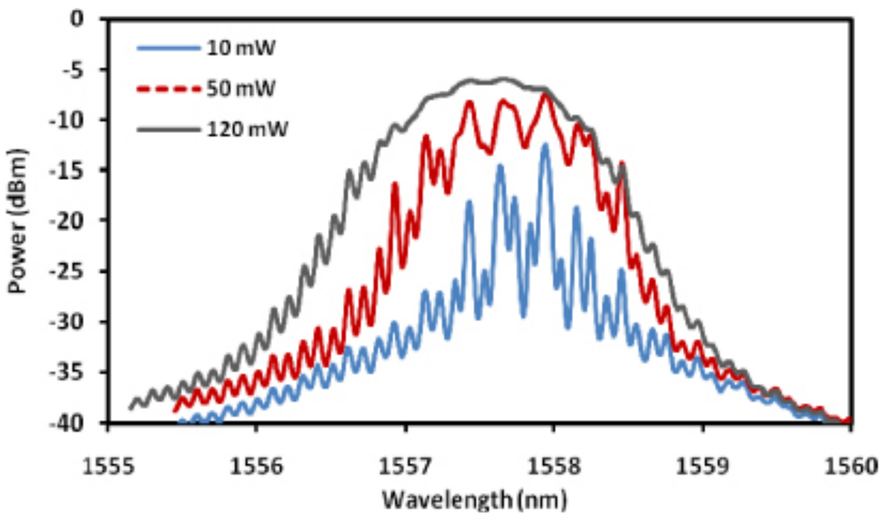

Figure 2. Self-lasing cavity modes versus 980 nm pump power.

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The free-running EDF is an essential measurement because it generates unstable modes at low BP power. The mode competition caused by this unstable situation limits the tuning wavelength range of the suggested BEF laser. In order to mitigate this problem, the Stokes lines should be lased at the same resonating free-running EDF laser wavelengths. Therefore, the BP is launched into the laser at the same wavelength as the EDF peak gain to provide an enhanced generation of Brillouin Stokes lasers.

The output spectrum is depicted in figure 3 which shows that the generated Brillouin Stokes is able to suppress the mode competition to generate a stable output at BP and 980 nm pump powers of 3 dB m and 50 mW. Figure 3 shows up to 15 lasing lines of Stokes and anti-Stokes signals with twice the Brillouin-frequency shift spacing at 0.173 nm. The anti-Stokes signals are also generated due to a four-wave mixing process between the injected BP and the generated Stokes lines. It should be noted that all the odd-order Brillouin Stokes lines (shown with the lower peak powers between the desired wavelengths in figure 3) are considered as the Stokes–Rayleigh scattered signals while travelling along the 10 km NZ-DSF.

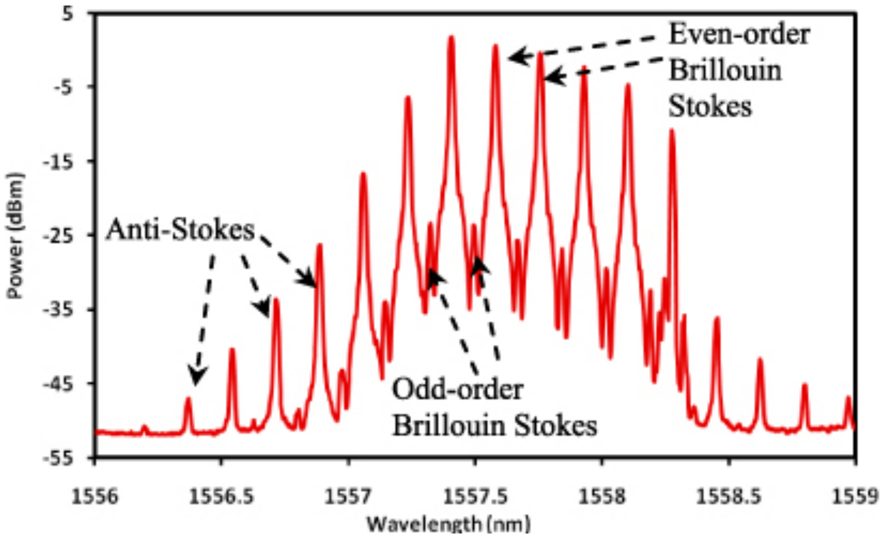

Figure 3. Output spectrum of the multiwavelength BEFL with BP of 3 dB m and 50 mW pump power at 1557.4 nm.

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The performance of the multiwavelength BEFL is investigated for different pump power at 980 nm LD when the BP is fixed at 6 dB m. Figure 4 demonstrates the increase of the peak power of the desired channels with the increase of pump power. When the 980 nm pump power is set at 10 mW, the first channel (second order of Brillouin Stokes signal) rises up from −45 to −7.6 dB m. Further increment in the power to 20 mW leads to the second channel (fourth order of Brillouin Stokes signal) generation. In the same way, the third, fourth and fifth channels grow from −46 dB m to −12.3 dB m, −43 dB m to −13.3 dB m and −44 dB m to −5.7 dB m, at the launched 980 nm pump powers of around 20 mW, 30 mW and 40 mW, respectively. According to the results shown in figure 4, a maximum of six Brillouin Stokes signals are achievable at BP and 980 nm pump powers of 3 dB m and 50 mW, respectively. Therefore, the number of generated lasers is a function of the injected total powers. Since the amount of launched pump power is inadequate to saturate the seventh Stokes signal, so the seventh-order Stokes cannot be provided.

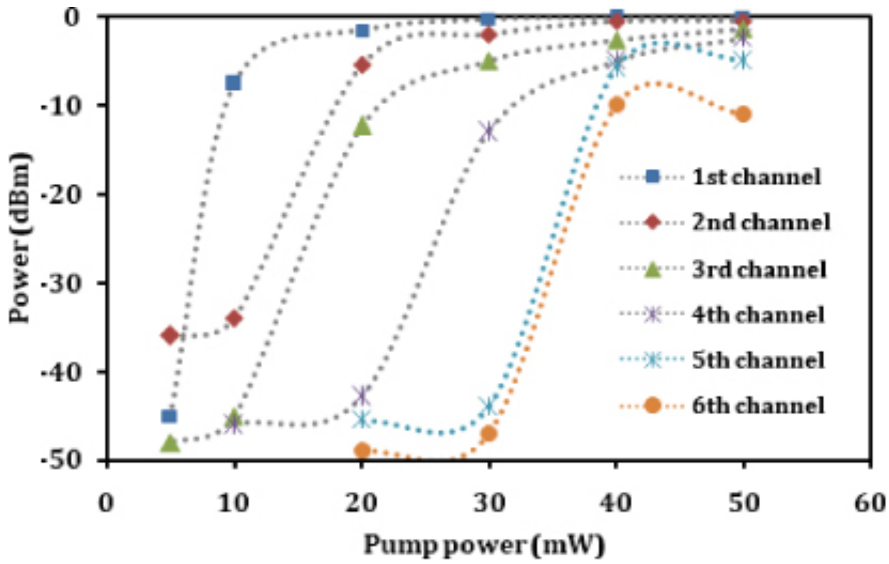

Figure 4. Variation of output channels' peak power with 980 nm pump power at BP power of 3 dB m.

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The capability of the wavelength tuning range is a key parameter of a tunable multiwavelength BEFL which is limited by self-lasing cavity modes. Figure 5 illustrates the output spectra of the tunable BEFL at some selected BP wavelength corresponding to the BP power of 3 dB m and 980 nm pump power of 50 mW. Up to 15 Stokes and anti-Stokes lines are generated that can be tuned from 1552 to 1562 nm, as shown in figure 5. The measured tuning range for the proposed configuration at the same BP power and with the lower pump power of 30 mW is obtained at around 21 nm (1546–1567 nm) which is higher than that of 50 mW pump power. This is attributed to the tuning range of BEFL decreasing with the increment of the 980 nm pump power due to the stronger mode competition between the self-lasing cavity modes and Brillouin Stokes signals.

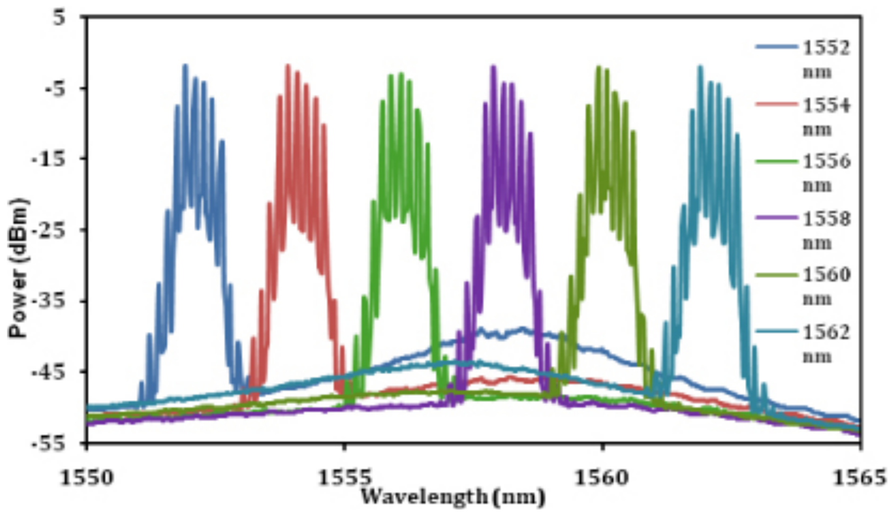

Figure 5. Tuning range spectra of multiwavelength BEFL at BP power of 3 dB m and 980 nm pump power of 50 mW.

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The optical signal-to-noise ratio (OSNR) of the generated channels is also studied with the injected BP power of 3 dB m for different 980 nm pump power. The OSNR analysis is performed by comparing the peak power of the generated desired channel and the highest noise floor level. For 980 pump powers of 50 mW, 80 mW and 115 mW, the OSNR are obtained around 34.5, 16.5 and 6.5 dB, respectively. As can be observed in figure 6, the OSNR starts to decrease at a higher 980 nm pump power and has a larger value at low power of 50 mW. In this power, BP power is almost adequate to suppress the amplified spontaneous emission (ASE) generated by EDF gain to provide a better achievement of OSNR. However, the BP power is unable to compete with the laser cavity modes at higher ASE from the EDF amplifier which reduces the OSNR quality.

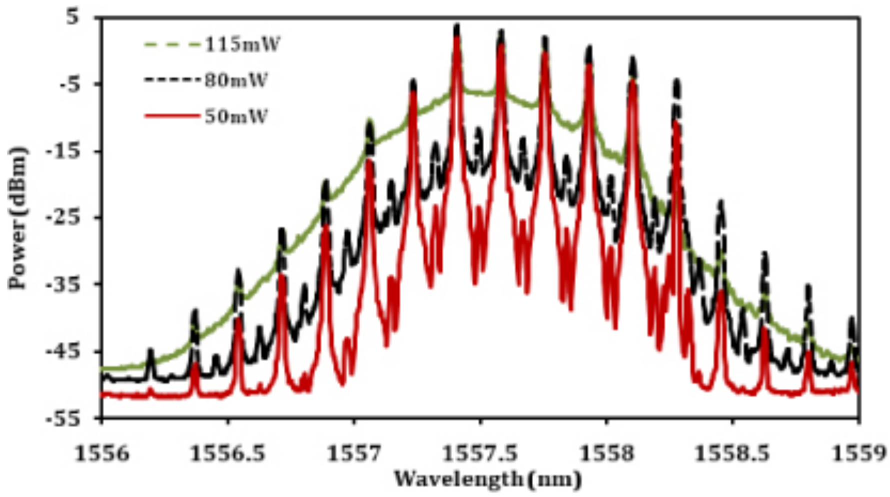

Figure 6. Output spectra of multiwavelength BEFL against 980 nm pump power.

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4. Conclusion

We have successfully demonstrated a multiwavelength Brillouin-erbium fiber laser that provides channels with double-Brillouin wavelength spacing of 0.173 nm (~20 GHz). A four-port circulator provides the isolating and circulating of odd-order Brillouin Stokes signals through the 10 km long non-zero dispersion shifted fiber as a Brillouin gain medium in the ring cavity. The generated even-order Stokes lines in this configuration are amplified by propagating within the erbium-doped fiber in a ring cavity. In this configuration, up to 15 channels are generated with 0.173 nm wavelength spacing and over 10 nm tuning range from 1552 to 1562 nm. The evaluated optical signal-to-noise ratio of the desired output channels is around 34.5 dB. With this wider channel spacing, it is possible to open up the possibilities of employing multiwavelength Brillouin-erbium fiber lasers in diverse applications.

References

[1]
Chen D, Sun B and Wei Y 2010 Laser Phys. ***20*** *1733* CrossRef
[2]
Fu J, Chen D, Sun B and Gao S 2010 Laser Phys. ***20*** *1907* CrossRef
[3]
Hambali N, Mahdi M, Al-Mansoori M, Saripan M, Abas A and Ajiya M 2010 Laser Phys. ***20*** *1618* CrossRef
[4]
Shee Y, Mahdi M, Al-Mansoori M, Ismail A, Hambali N, Zamzuri A, Mohamad R and Yaakob S 2009 Laser Phys. ***19*** *2194* CrossRef
[5]
Li Y, Liu Y, Xu J, Tai B and Wang Z 2010 Laser Phys. ***20*** *528* CrossRef
[6]
Sun H, Liu X, Wang L, Li X and Mao D 2010 Laser Phys. ***20*** *1994* CrossRef
[7]
Yang X and Yang C 2009 Laser Phys. ***19*** *2106* CrossRef
[8]
Luo A, Luo Z and Xu W 2011 Laser Phys. ***21*** *395* CrossRef
[9]
Abd Rahman Z, Al-Mansoori M, Hitam S, Abas A, Abu Bakar M and Mahdi M 2009 Laser Phys. ***19*** *2110* CrossRef
[10]
Mohd Nasir M, Yusoff Z, Al-Mansoori M, Abdul Rashid H and Choudhury P 2009 Laser Phys. ***19*** *2027* CrossRef
[11]
Shirazi M R, Biglary M, Harun S W, Thambiratnam K and Ahmad H 2008 J. Opt. A: Pure Appl. Opt. ***10*** *055101* IOPscience
[12]
Parvizi R, Ali N, Harun S, Moghavvemi M, Arof H and Ahmad H 2011 Laser Phys. ***21*** *205* CrossRef

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