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BRILLOUIN FIBER LASER WITH SIGNIFICANTLY REDUCED GAIN MEDIUM LENGTH OPERATING IN L-BAND REGION

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Abstract—Brillouin fiber laser (BFL) is demonstrated using a piece of photonic crystal fiber (PCF) in conjunction with a Bismuth-based erbium-doped fiber (Bi-EDF) as the gain media with a simple ring resonator. The proposed BFL operates at wavelength of 1574.08 nm, which is 0.08 nm shifted from the Brillouin pump wavelength with a maximum peak power of 8 dBm. The BFL has a side mode suppression ratio and 3 dB bandwidth of approximately 23 dB and 0.02 nm respectively limited by the optical spectrum analyzer resolution. The BFL is also stable at room temperature and compact due to the use of only 20 m long of PCF and 215 cm long of Bi-EDF.

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1. INTRODUCTION

Stimulated Brillouin scattering (SBS) is a nonlinear effect resulting from the interaction between intense pump light and acoustic waves in a medium and giving rise to backward propagating frequency-shifted light [1]. Although Brillouin generation can be detrimental in coherent optical-communication systems [2], it has been advantageously utilized in the past few years for the many applications such as optical-fiber characterization [3], distributed strain and temperature measurements [4, 5] and narrow-bandwidth amplification [6]. Perhaps the largest interest has arisen from the use of SBS to produce Brillouin fiber laser [7, 8] with applications such as gyroscopes [9].

Photonics crystal fibers (PCFs) are a class of micro-structured fiber which possesses a solid core surrounded by a cladding region that is defined by a fine array of air holes that extend along the full fiber length. Due to the high index difference between silica core and air hole cladding, these PCFs allow much stronger mode confinement, and thereby much higher nonlinearities than that of a conventional single mode fiber (SMF) [10]. This fiber can be used as a nonlinear gain medium to develop a compact BFL. In the previous reports, BFLs have been achieved using more than 70 m long PCF as a gain medium [11, 12].

In this letter, a ring BFL is demonstrated in long-wavelength band (L-band) region using a significantly reduced PCF length. The BFL consists of bi-directionally pumped Bismuth-based erbium-doped fiber (Bi-EDF), which is used to amplify the backward propagating frequency-shifted light as well as to assist in a SBS generation in the ring cavity. The Bi-EDF used has a refractive index higher than 2.2 at 1550 nm and thus nonlinearity of this fiber is 40 times higher than silica-based fiber. Bi-EDF amplifier has the advantage of needing just a few meters for effective amplification in long-wavelength band region. The proposed BFL utilizes this Bi-EDF in the cavity to minimize the total fiber length. The cost of the Bi-EDF is also cheaper than the PCF, which makes the device more compact and affordable.

2. EXPERIMENTAL SET-UP

The experimental setup for the PCF-based BFL is shown in Fig. 1. The ring resonator consists of a circulator, a 20 m long PCF, a 215 cm long Bi-EDF. two 1480 nm pump diodes, two wavelength selective couplers (WSCs), two isolators, a 80/20 output coupler and a polarization controller (PC). The PCF used as a nonlinear gain medium is a polarization maintaining fiber which has a cut-off wavelength of

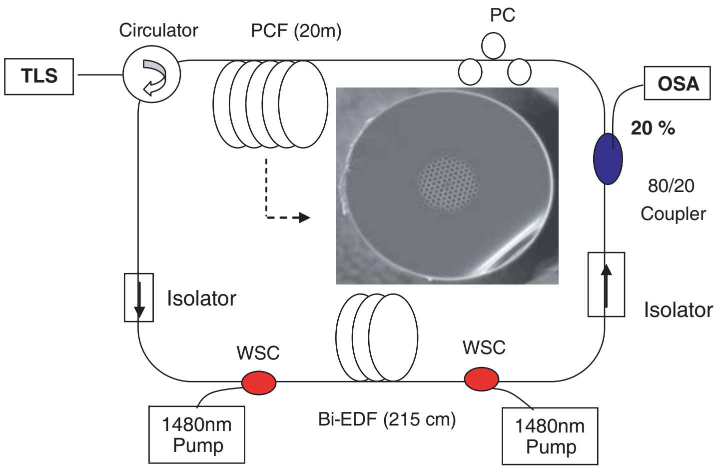

Figure 1. Configuration of the PCF-based BFL.

1000 nm, zero dispersion wavelength of 1040 nm, nonlinear coefficient of 11 $(\text{W}\cdot\text{km})^{-1}$ and a mode field diameter of 4.0 µm. The Bi-EDF used has an erbium concentration of 3,200 ppm with a cut-off wavelength of 1440 nm and a pump absorption rate of 130 dB/m at 1480 nm. The Bi-EDF is pumped bi-directionally using two 1480 nm lasers. Optical isolators are used to block the Brillouin pump (BP) from oscillating in the cavity and also to ensure a unidirectional operation of the BFL. An external cavity tunable-laser source (TLS) with a linewidth of approximately 20 MHz and a maximum power of 7 dBm is used as the BP. PC is used to control the birefringence of the ring cavity so that the power of the generated laser can be controlled.

The BP is injected into the ring cavity and then PCF via the circulator to generate the backward propagating Stokes light at opposite direction. However, since the PCF length is not sufficient enough, the back-scattered light due to Rayleigh scattering is relatively higher than the Stokes light. Both back-scattered pump and the Stokes lights are amplified by the bi-directionally pumped Bi-EDF and oscillate in the ring cavity to generate dual-wavelength laser. However, the nonlinear gain by both PCF and Bi-EDF only amplifies the Stokes light and thus the Stokes light is more dominant and laser is generated at the Stokes wavelength. The spacing between the BP and the BFL is obtained at approximately 10 GHz, which is equivalent to the Stokes shift in the SMF. The output of the linear cavity BEFL is tapped from the 80/20 coupler and characterized by an optical spectrum analyzer (OSA) with a resolution of 0.015 nm.

3. RESULT AND DISCUSSION

The operating wavelength of the BFL is determined by the bi-directionally pumped Bi-EDF gain spectrum which covers the L-band region from 1560 to 1600 nm as well as the cavity loss. The Bi-EDFA amplifier has a small signal gain of more than 30 dB at 1570 nm region. Fig. 2 shows the free-running spectrum of the BFL (without BP) at the total 1480 nm pump power of 270 mW. As shown in the figure, a peak wavelength is generated at around 1574.5 nm due to the difference between Bi-EDF's gain and cavity loss is largest in this region. The free-running BFL also exhibits a peak power of approximately −6 dBm with 20 dB bandwidth of approximately 1 nm. The chosen BFL operating wavelength must be within or close to the bandwidth of the free running BFL. Therefore, the BP is set within this region in this experiment.

Figure 3 compares the BP and output spectrum of the proposed ring BFL. The pump power for each 1480 nm laser diode and BP is fixed at 135 mW and 6 dBm, respectively. The BP wavelength is optimized at 1574.0 nm which is within the lasing bandwidth of the free running BFL (without the BP). The BFL is achieved at 1574.08 nm with the peak power of 8 dBm and the 3 dB bandwidth of approximately 0.02 nm, limited by the OSA resolution. The side mode suppression ratio, which is defined as the power difference between the BFL's peak with the second highest peak is obtained at approximately 23 dB as shown in Fig. 3. The side modes are mainly resulted from anti-Stokes and additional Stokes of the BFL, which arises due to four-wave mixing effect in the ring cavity. In the BFL, the BP also acts

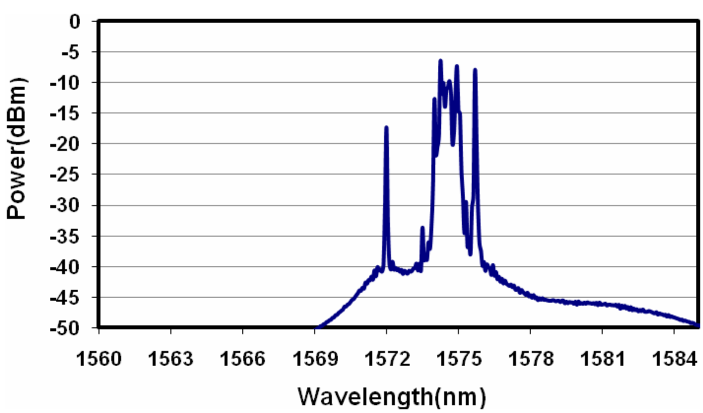

Figure 2. Free-running spectrum of the BFL.

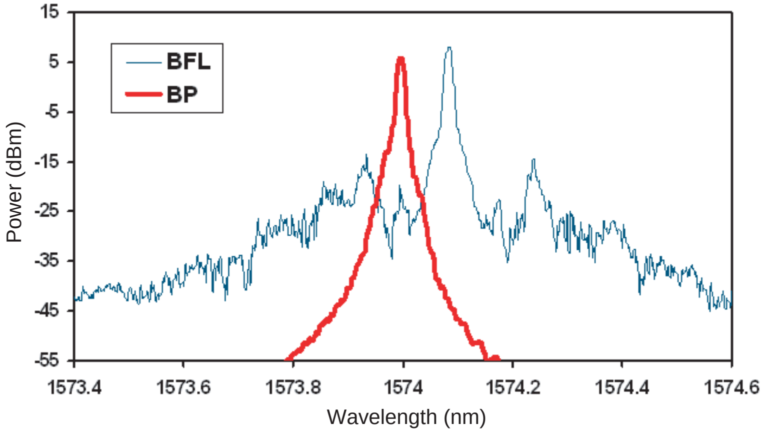

Figure 3. The input BP and BFL output spectra of the BFL.

as a wavelength locker, which allows lasing at BP wavelength and suppresses other modes. Therefore, the peak output power of the BFL is higher compared to the free-running laser of Fig. 2.

Figures 4(a) and 4(b) show the peak power of the BFL against the total input 1480 nm pump power and BP pump power, respectively. In the experiment, the BP and 1480 nm pump powers are fixed at 6 dBm and 135 mW, respectively. As shown in Fig. 4(a), the BFL starts to lase at 1480 nm pump power of 95 mW. Below this power, the erbium gain is very low and cannot sufficiently compensate for the loss inside the laser cavity and thus no Stokes is observed. The peak power increases as the 1480 nm pump power increases which is attributed to the increment of the erbium gain with pump power. On the other hand, the BP power threshold of the BFL is obtained at 2 dBm as shown in Fig. 4(b). After the threshold power, the output power of the BFL increases with the BP power. However, the BFL power starts to saturate at BP power of 5 dBm as shown in Fig. 4(b). This is attributed to the Brillouin gain, which is a significantly smaller than the erbium gain. Therefore, the peak power is normally depended on the 1480 nm pump power and the BP is used to lock the BFL operating wavelength. The output of the BFL is observed to be stable at room temperature with only minor fluctuations observed coinciding with large temperature variances. The BFL has a relatively very narrow linewidth which is useful for sensor applications.

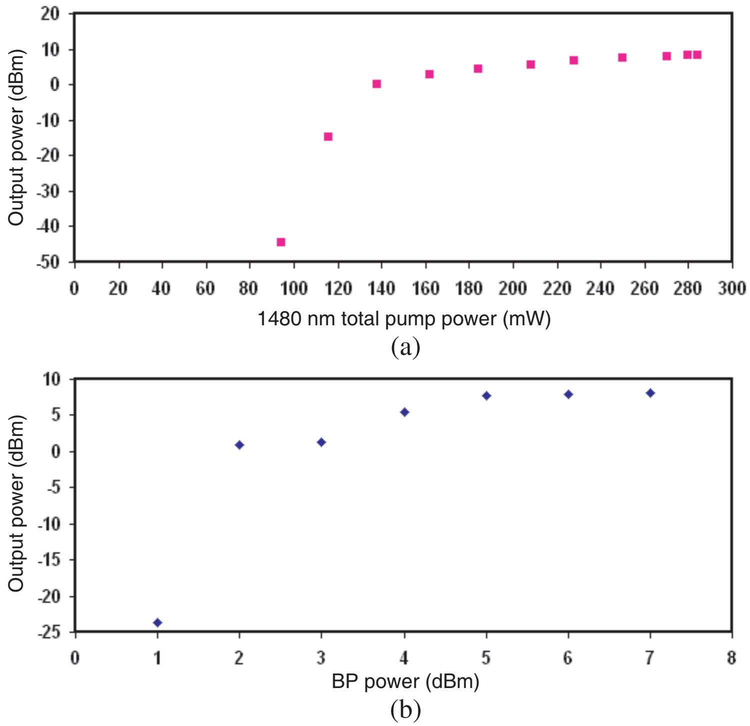

Figure 4. The peak power against the 1480 nm pump and BP powers. (a) 1480 nm pump, (b) BP.

4. CONCLUSION

A compact BFL is proposed and demonstrated using a piece of 20 m long PCF and 215 cm long Bi-EDF as gain media. The BFL operates at 1574.08 nm with peak power is obtained at 8 dBm when the total 1480 nm pump and BP powers are fixed at 270 mW and 6 dBm, respectively. The BFL shows a side mode suppression ratio of 23 dB and 3 dB bandwidth of 0.02 nm limited by the OSA resolution.

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