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Simple multiwavelength Brillouin–Erbium-doped fiber laser structure based on short SSMF

A.W. Al-alimi [a,b,*], M.H. Yaacob [a,b], A.F. Abas [a,b], M.A. Mahdi [a,b], M.H. Al-Mansoori [c], M. Mokhtar [a,b]

[a] Wireless and Photonic Networks Research Centre, Engineering and Technology Complex, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[b] Photonics and Fiber Optic Systems Laboratory, Department of Computer and Communication Systems Engineering,Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[c] Faculty of Engineering, Sohar University, P.O Box 44, Sohar P.C. 311, Oman

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ABSTRACT

An efficient multiwavelength Brillouin–Erbium fiber laser (BEFL) was developed by improving the feedback mechanism of Brillouin Stokes lines. The BEFL performance in terms of threshold power and wavelengths count was improved by using a new structure of double pass amplification cavity. The new structure utilized the variable optical coupler (VOA) not only as the input and output ports but also to form a fiber loop mirror that reduces the number of optical components, thus, only three optical components were needed. By optimizing the Brillouin and 1480 nm pump power, up to 41 channels and 26 channels were obtained using 0.6 km and 0.3 km long of standard single mode fiber (SSMF), respectively.

1. Introduction

Stimulated Brillouin scattering (SBS) naturally appears due to interaction between an incident light and acoustic waves in a nonlinear medium. The new signal (Brillouin Stokes line) propagates in opposite direction and down shifted from the original signal (Brillouin pump wavelength). The Brillouin wavelength shift depends on the type of fiber materials and structure, which is typically equal to $\lambda_B = 0.09$ nm in standard single mode fiber (SSMF). Therefore, the stimulate Brillouin scattering (SBS) effect can be used to generate multiwavelength laser with wavelength spacing of $V_B = 2nV_a/\lambda_p$, where λ_p is the pump wavelength, V_a is the acoustic velocity, and n is the refractive index [1,2]. However, due to low Brillouin gain, the Brillouin fiber laser is limited to generate low number of wavelengths. To overcome this limitation, an additional linear gain medium is required. In 1996, Cowle and Stepanov combined the Brillouin gain medium and Erbium doped fiber amplifier (EDFA) to enhance the Brillouin gain [3]. Besides compensating the cavity loss, the linear gain of EDF makes a large number of Stokes lines generation possible. The discovery of Brillouin–Erbium fiber laser (BEFL) had opened up a new research dimension for multiwavelength fiber lasers. Such combination of gain mediums has been investigated extensively in various approaches to generate multiwavelength BEFL.

Conventionally, a ring-cavity BEFL can be formed by allowing the laser to resonant in one direction in the cavity [4]. A reverse-S-shaped ring cavity setup was proposed to enhance the internally cascaded multiwavelength operation [4], in which the stimulated Brillouin (SB) lines were feed-backed into the nonlinear gain medium. As a result, the multiwavelength BEFL formed through a cascading process. Also, the number of Stokes lines can be improved by suppressing the out of band amplified spontaneous emission in the BEFL utilizing a tunable band-pass filter in a dual ring cavity [5].

The linear cavity structure was also proposed as another multiwavelength BEFL configuration in which the Brillouin Stokes lines oscillating between the two physical mirrors that are fixed at the both ends of the cavity [6,7]. Due to improvement of the Brillouin Stokes lines feedback mechanism in the linear cavity, up to 18 Stokes lines were generated [8]. Physical mirrors of the linear cavity can be formed by utilizing two circulators, two high reflective mirrors [9], or two 3-dB coupler, or the combination of them. Among the approaches of the linear cavity developments,

* Corresponding author at: Wireless and Photonic Networks Research Centre, Engineering and Technology Complex, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia. Tel.: +60 13 671 90 01.
E-mail address: mogni_66@yahoo.com (A.W. Al-alimi).

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the double pass pre-amplifier technique, in which Brillouin pump amplifies twice before entering the nonlinear gain medium, is the most efficient technique to improve the performance of BEFL [10].

From the previous configurations, by using several kilometers or even longer standard single mode fiber (SSMF), the Brillouin gain threshold is reduced, thus; high number of wavelengths is obtained [8,11]. Higher count of maximum number of generated wavelengths can also be achieved by optimizing EDF pump power, Brillouin pump power and wavelength [8,11–13]. Moreover, the Brillouin threshold and the number of wavelength can be improved by using double pass pre-amplification technique in a linear cavity [10]. However, due to the use of long SSMF, the nonlinear fiber device has been considered as impractical device for laser sources. Therefore, a short length of different fiber with high nonlinearity such as photonic crystal fiber (PCF) has been proposed to replace the inconvenient long SSMF in Brillouin Erbium fiber laser (BEFL) structure [14–18]. However, the performance of multiwavelength BEFL based on PCF is unconvincing as it requires high threshold power and produces low number of outputs channels. This reason prompts us to design a simple structure of multiwavelength BEFL utilizes a short SSMF.

In this paper, the performance of multiwavelength BEFL based on short SSMF that is installed in a new linear cavity is experimentally demonstrated. A variable optical coupler was used as a fiber loop mirror and as input and output ports. SSMF was installed in different places with respect to the EDF to form two configurations: configuration A in which 0.6 km long of SSMF was placed between erbium doped fiber amplifier (EDFA) and circulator 2 (C2), and configuration B in which the optical fiber was located between EDFA and the variable output coupler (VOC). Each BEFL configuration has different amplification mechanism, and their basic characteristics such as threshold power, Stokes lines number, and self lasing cavity modes were investigated. It was found that the configuration with double pass amplification process has better performance as compared to the single pass amplification cavity. Note that in this experiment, no investigation were conducted on the effect of polarization state on the BEFL performance, which will be the subject of the future work.

2. Experiment setup

The proposed linear cavity configuration is shown in Fig. 1. First, at this stage, we ignore the SSMF at point B. A 1480 nm pump power was used to activate the linear gain medium, while a wavelength selective coupler (WSC) was used to combine the 1480 nm pump wavelength and the 1550 nm signals. The EDFA block consists of 10 m long EDF with an absorption coefficient of 5 dB/m at 1530 nm that was used as a linear gain medium, 1480 nm pump power, and WSC. Two circulators were used: one as high reflective mirror in which the forward laser is feedback to the cavity while the second circulator (C2) was used as input and output port as well. A variable optical coupler (VOC) was used to

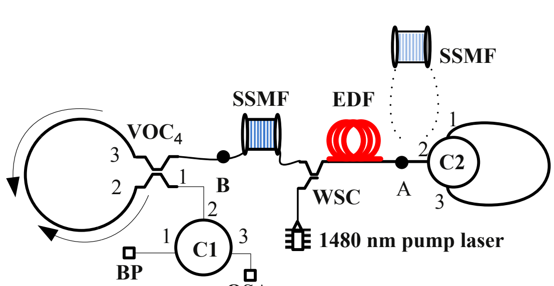

Fig. 1. Experimental setup.

reflect back a portion of the laser power to the cavity and to transmit the second portion of the laser power to the output port through port 3 of circulator 1 (C1). In this experiment, the output coupling ratio of VOC is optimized to get the highest number of wavelength. It is found that the splitting ratio of 40/60% is the best ratio which reflects approximately half of the laser power to the cavity and guides the second half to the output port via port1 of C1as depicted in Fig. 1. The linear cavity of the multiwavelength BEFL was formed by two fiber loop mirrors; C2 and VOC, which were fused at both ends of the cavity. A SSMF was used to act as a nonlinear gain medium. Due to the low Brillouin gain coefficient in silica which equals to 4×10^{-11} m/W, several kilometers of optical fiber or EDF pump with output power of several hundred milliwatts are required to overcome Brillouin threshold power [19]. Therefore, the length of the laser cavity, which is about 5 m excluding length of SSMF and EDF, is neglected. The source of Brillouin pump power was formed by utilizing an external tunable laser source (TLS), which provides a maximum power of 8 dBm and a tunability of 100 nm from 1520 nm to 1620 nm.

In this experiment, the Brillouin pump power was injected into port 1 of the C1 and transmitted into the SSMF through port 4 of VOC. The output spectrum of the laser was taken from port 3 of C1 to an optical spectrum analyzer (OSA) with resolution bandwidth of 0.01 nm. The Stimulate Brillouin scattering (SBS) mechanism for configuration A can be described as follows: a portion of the BP power is transmitted to the cavity through port 4 of VOC. Then, the BP wavelength is amplified by EDFA block before injected into the SSMF. The first Brillouin Stokes line is created when Brillouin pump power exceeds the threshold condition of Brillouin Stokes line. The first Brillouin Stokes line is down-shifted and propagated in the opposite direction of the BP wavelength. The first Stokes line is amplified by EDFA block and a portion of its power is transmitted to the output port through port 1 of VOC while the other part is reflected back to the cavity through port 4 of VOC. The reflected Stokes line is amplified by EDFA and serves as a BP for the next order Stokes lines generation. This process is repeated again and again until the total gain in the laser cavity, which is provided by Brillouin gain medium and EDFA, is lower than the cavity loss. The Brillouin Stokes lines are formed between C2 and VOC when the power intensity of the Stokes lines overcomes the cavity loss. The Brillouin Stokes lines generation in configuration B will be discussed in the following section.

3. Results and discussion

Fig. 2 depicts the output spectrum of the two configurations with 0.6 km long fiber and EDF pump power of 30 mW while the BP power was switched off. The self lasing cavity modes of the two configurations, which is the EDF peak gain, was observed by using

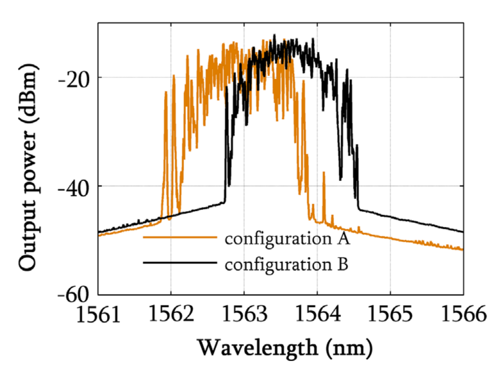

Fig. 2. Self lasing cavity modes of configuration A and B at 30 mW of EDF pump power.