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Characteristics of the single-wavelength ring cavity Brillouin fiber laser operated in L-band region

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ABSTRACT

We experimentally demonstrated the characteristics of a single-wavelength Brillouin fiber laser that operated in the L-band region. The 4 km of a single mode fiber plays a significant role as a nonlinear gain medium to generate stimulated Brillouin scattering effect and causes the frequency shift with ~0.08 nm spacing. At a pump power of 350 mW, a Brillouin pump wavelength of 1580 nm and 50% of output coupling ratio, the Brillouin threshold power at 6.3 mW is obtained. The highest average Brillouin Stokes power of 4.07 mW has been produced at 10 mW of Brillouin pump power at 50% of output coupling ratio. The tuning range of 30 nm is recorded without any unwanted oscillating modes appeared from 1570 nm to 1600 nm. The 70% of the output coupling ratio is found to produce flattened output for BS power and signal to noise ratio. The highest value for optical signal to noise ratio is recorded at 41.36 dB, with 50% of output coupling ratio and at 1600 nm of Brillouin pump wavelength.

1. Introduction

Ever since stimulated Brillouin scattering (SBS) effect is discovered, it has become a major research due to its light wave effect on the optical systems. The backward signal propagation is produced by the SBS effect. SBS is a nonlinear effect subsequent from the interaction between intense pump light and acoustic waves in a gain medium. From the interaction, the backward propagating frequency-shifted light and Rayleigh scattering are generated, and inelastic scattering process shifted the frequency downward [1]. Raman scattering and Brillouin scattering are categorized as inelastic scattering of a photon by molecules and large scale, low-frequency phonons respectively that result in changes of energy [2]. The pump and Stokes waves intervention have a tendency to raise the amplitude of the acoustic waves; then the interaction with the pump is emphasized by the Stokes wave. This condition can cause exponential growth and recreate the Stokes wave [2].

SBS are frequently applied in laser amplifiers and oscillators to increase the quality of the laser beam and to shorten the laser pulse width. A single mode fiber (SMF) which plays an important role as a gain medium, has been used as a standard to produce the SBS effect in many research. A laser signal, known as a Brillouin fiber laser (BFL), can be generated from the

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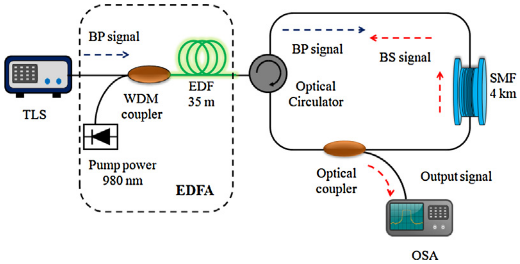

Fig. 1. Single wavelength BFL structure that operated in the L-band region.

Brillouin Stokes (BS) effect as a seed signal by using nonlinear Brillouin gain in an optical fiber. In the gain medium, electrostriction works as both; the mechanism leading to a third-order nonlinear optical response and as a coupling mechanism that leads to SBS effect [3,4]. The interaction between intense pump light and acoustic waves in a fiber caused the SBS effect. This nonlinear effect leads to backward propagating frequency-shifted light [5].

For several years, research on BFL has developed a myriad of techniques in order to enhance their characteristics, such as ultra-narrow linewidth [6], tuning range [7], low threshold power [8] and low noise [9]. Two techniques of single-wavelength BFL, utilizing a ring-cavity, has been experimentally demonstrated in [10]. Both experimental setups consist of 25 km long SMF as the gain medium. In this experiment, the output spectrum for the conventional BFL and the proposed BFL structure are compared. From the results, the BS signal power of −0.5 dBm is found, which is 5.7 dBm higher compared with the conventional structure. A ring-cavity BFL by using similar structure and components as proposed in [10] is demonstrated in [11]. A polarization controller (PC) is employed in this structure to adjust the polarization of the pump and the BS signals. Through this experimental work, 3.6 mW of Brillouin threshold power is obtained with 50% of output coupling ratio. At the injected pump power of 40 mW, the BS signal with a signal power of 22 mW is obtained. The performance of ring cavity BFL with the effect of output coupling ratio is reported in [7]. As stated, the investigation of different output coupling ratios performance has been carried out. The output BS power of 7.3 mW and threshold power of 0.9 mW respectively, is obtained by using 90% of output coupling ratio. However, the optical signal to noise ratio (OSNR) and the flatness of BS signal powers are not discussed explicitly in this paper. A compact single wavelength BFL is demonstrated by inserting a Bismuth-based Erbium-doped fiber (Bi-EDF) and photonic crystal fiber (PCF) into the fiber resonator [12]. However, this structure only focusses on 1574 nm and known as a single wavelength Brillouin-Erbium fiber laser (BEFL). However, this structure suffers from the presence of unwanted oscillating modes at peak wavelength around 1574 nm. Furthermore, BFL structure reported in [7,10–12] are focused on C-band region of the optical communication window.

A simple tunable L-band multiwavelength Brillouin-Erbium fiber laser (MWBEFL) utilizes a short passive erbium doped fiber (PEDF) as an absorber medium is reported in [13]. At 100 mW of 1480 nm pump power and 4 mW of Brillouin pump (BP) power, a wide tuning range of 24.4 nm has been achieved. High threshold power of 33 mW of first-order Brillouin Stokes is generated from a dual cavity MWBEFL laser in L-band region [14]. Meanwhile, the threshold value of 15.9 mW is used to generated first order BS signal from L-band MWBEFL that utilizing a double-pass Brillouin pump preamplified technique [15]. However, reported paper in [8] and [13–15] only focused on the multi-wavelength generation of BEFL and operated on L-band region of the optical communication window.

Furthermore, the selection of band also plays an important role in the communication system. Nowadays, C-band region has extensively had been used for numerous applications. C-band region has been exploited by many industries, particularly for communication, and remote sensing. Thus, the C-band region is almost occupied. However, owing to the overcrowding and susceptibility of the nonlinear effect, the addition of L-band region wavelength is extremely desirable [8]. L-band region are preferred mainly because of its low attenuation [16], its ability to expand single wavelength and its dense wavelength division multiplexing (DWDM) which allowed multiple signals to share a single fiber [16]. The usage of the L-band region is still new. Thus the region is not crowded, and various features of research can be done and utilized.

In this paper, we report the experimental demonstration the of a single-wavelength ring cavity BFL structure that operated in L-band region. A short SMF length of 4 km is used as a gain medium. The characteristic of single-wavelength ring cavity BFL structure based on amplified spontaneous emission (ASE), threshold, output BS power and OSNR are studied. A lowest Brillouin threshold power around 6.3 mW is produced at 1580 nm of BP wavelength and 50% of output coupling ratio. The flat amplitude of BS signal and OSNR are achieved at 70% of output coupling ratio, respectively. At 50% of output coupling ratio, higher average OSNR about 37.12 dB is recorded. Meanwhile, at 50% of output coupling ratio, higher average BS peak power value about 4.07 mW is recorded.

1.1. Experimental setup

Fig. 1 shows the structure of L-Band single-wavelength ring cavity Brillouin fiber laser (BFL) which consists of tuneable laser sources (TLS), EDFA, an optical circulator, 4 km long of single mode fiber (SMF), an optical coupler and optical spectrum analyzer (OSA). The EDFA components consist of 35 m long of Erbium doped fiber (EDF), wavelength division multiplexing