Brillouin fiber laser with Raman amplification

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A single-wavelength Brillouin fibre laser (BFL) is demonstrated at 1550nm region using Raman amplification in single mode fiber. The BFL operates at 1550.09nm, which is up-shifted by 0.08nm from the Brillouin pump with a peak power of -26.2 dBm and a side mode suppression ratio (SMSR) of more than 12 dB. The threshold power for Brillouin pump and Raman pump is obtained at around 5~6dBm and 250mW, respectively for the case of 70~90% of the pump powers is injected into the SMF. The generated BFL has narrow linewidth and many potential applications such as in optical communication and sensors.

(Received September 1, 2008; accepted September 26, 2008)

Keywords: Brillouin fiber laser, Raman amplification, SBS, SRS

1. Introduction

Raman and Brillouin scattering are inelastic processes in which part of the optical wave power is absorbed by the transmission medium while the remaining energy is reemitted as a wave (Stokes wave) with a down-shifted frequency called a Stokes shift. The growth of Brillouin and Raman Stokes waves is governed by the Brillouin-gain g_B and the Raman-gain g_R. For silica fibers, the peak values of g_B and g_R are about $g_B = 6 \times 10^{-11}$m/W and $g_R = 7 \times 10^{-14}$m/W and occur for the Brillouin and Raman Stokes shifts by about 13 THz and 10 GHz, respectively [1]. Although stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) can be detrimental in coherent optical communication systems [2] they do serve many useful applications, in particular the realization of very narrow linewidth Brillouin fiber lasers (BFL) and Raman amplifier.

BFLs have been thoroughly investigated throughout the years due to their potential applications in optical communications and sensors [3-5]. In this letter, BFL is demonstrated under a new approach using a Raman gain. With the use of SRS in a single-mode fiber (SMF), a Brillouin Stokes is amplified to generate a BFL. The performance of the BFL is investigated under a different ratio of coupler, which determines the amount of injected pumps powers and resonator cavity loss. Raman amplification in the Brillouin generating fiber has several advantages over erbium-doped fiber amplifiers (EDFAs) as well as unamplified systems. First, the lasing threshold is lower because Raman amplification can provide higher gain and simultaneously eliminate the need for a separate amplifier. Secondly, the laser configuration can be used for a much wider range of wavelengths than the bandwidth of an EDFA. Finally, this configuration does not put strict high-output power and narrow linewidth requirements on the Brillouin pump and requires only a high-powered Raman pump, which is readily and commercially available.

2. Experimental set-up

A configuration of the BFL is shown in Fig. 1, which consists of a hybrid component of isolator wavelength division multiplexer (IWDM), couplers and a 25 km long SMF as a nonlinear gain medium. The SMF has a cut-off wavelength of 1161 nm, zero dispersion wavelength of 1315 nm and a mode field diameter of 9.36 μm. The BFL is pumped by an external cavity tunable laser source (TLS) with a linewidth of approximately 20 MHz and a maximum power of approximately 8 dBm. Two laser diodes are used as a Raman pump module with a maximum combined pump power of 350 mW and operating at wavelength of 1440nm. A 1440/1550 nm IWDM is used to inject a Brillouin pump (BP) and Raman pump into the SMF.

The injected BP generates backward propagating Brillouin Stokes, which is amplified by the Raman gain and oscillates in the loop of couplers to generate a BFL. An optical isolator is inserted inside the loop to block the Raman pump and BP from oscillating in the loop. By using a single fiber for Raman amplification and Brillouin Stokes generation, we are simultaneously amplifying the BP and Brillouin signal in this cavity. This allows longer lengths of fiber to be used while maintaining a more distributed intra-cavity power level so as to reduce the limiting effects of pump depletion. A 10% output coupler is used to extract BFL output, which is characterized using an optical spectrum analyzer (OSA).

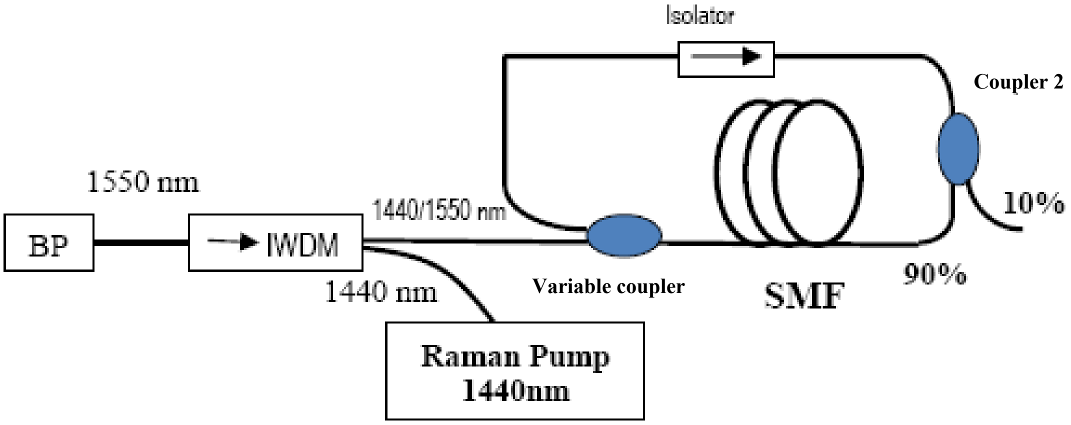

Fig. 1. Configuration of the proposed BFL.

3. Results and discussion

Fig. 2 compares the BFL output spectrum at different coupler ratios, which the port with higher power is connected to the IWDM. The BP and Raman pumps powers are fixed at 8 dBm and 350mW, respectively. If the total gain obtained due to SBS and SRS is equal to or higher than the cavity loss, a laser oscillation can be formed in the loop. As shown in Fig. 2, the BFL is generated with all couplers used except for 50%. The laser cannot be generated with the 50% (3dB) coupler because of the high loss. This reduces the BP and Raman pump powers that reach the SMF. The highest peak is obtained with a 80% coupler, which allow a sufficient BP and Raman pump powers to reach SMF to generate and amplify the Brillouin Stokes. The 80% coupler also provides the highest total gain in the loop. A single-wavelength Stokes is obtained at wavelength of 1550.09nm with a peak power of -26.2 dBm and a side mode suppression ratio (SMSR) of more than 12 dB with the BP and 1440nm pump powers of 8dBm and 350mW, respectively. The spacing between the BP and Stokes line is 0.08nm, as measured by an optical spectrum analyser with 0.015 nm resolution. Anti-Stokes line is also generated through four wave mixing between the BP and Stokes line as shown in Fig. 2.

Fig. 3 shows the output Brillouin Stokes peak power against the input signal BP power, with a 1440 nm Raman pump in various coupler ratios. In the experiment, the Raman pump power is fixed at 350mW. Before the Brillouin Stokes starts to increase quickly at SBS threshold power, the output power of the SBS increases in accordance with the increase of the BP power. The BFL threshold power is obtained at around 5~6dBm for the coupler ratio between 70~90% coupler. The combination of Brillouin and Raman gains is higher than the cavity loss at these coupling ratios so that the BFL has been generated and increases with the BP power as the threshold power reached. With a 3dB coupler, only a spontaneous Brillouin scattering is observed which increases in accordance with the increase of the BP power as shown in Fig. 3. The BFL cannot be obtained due to the injected BP power into SMF is below the SBS threshold power.

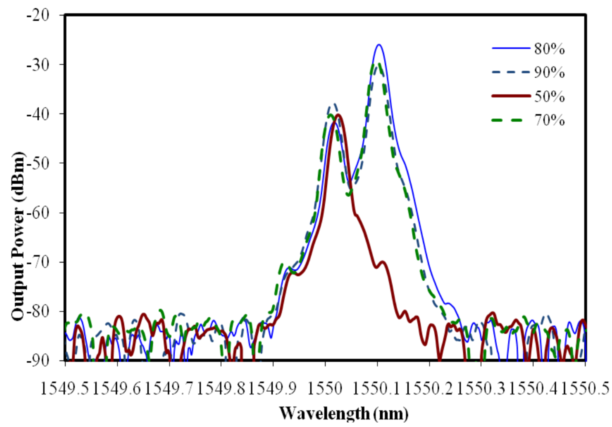

Fig. 2. The BFL output spectrum for different coupling ratiosfor the "variable coupler".

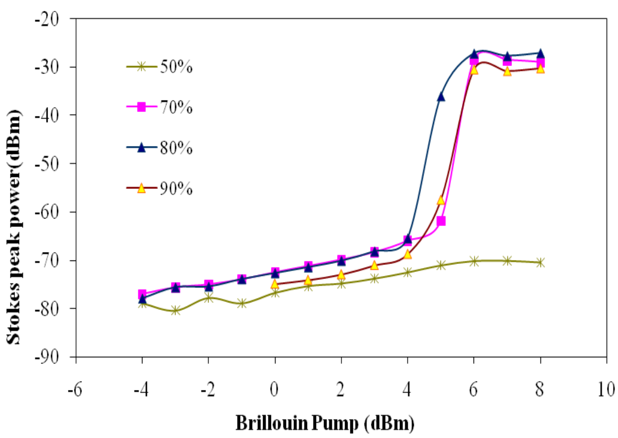

Fig. 3. The Brillouin Stokes peak power against BP power for different coupling ratios.

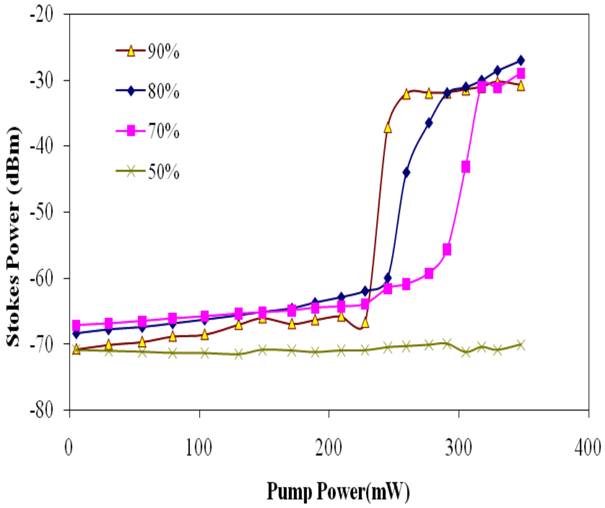

Fig. 4. The Brillouin Stokes peak power against Raman pump power for different coupling ratios.

Fig. 4 shows the output Brillouin Stokes peak power against the input signal Raman pump power for various coupler ratios. In the experiment, the BP power is fixed at the maximum power of 8 dBm. Without Raman pumping, a Brillouin pump produces only a very weak spontaneous Brillouin scattering signal. As the Raman pump power increases, the power of the signal also increases before it starts to increase quickly at a certain pump power (around 250mW) except for the system with 50% (3dB) coupler. The threshold pump power reduces with the increase of the coupling ratio, which increases the actual Raman pump that reached the SMF region. The 1440nm pump power will generate Raman gain at 1550nm region, which is used to amplify the Brillouin scattering signal and assists in BFL generation. The BFL has a very narrow linewidth and low technical noise which makes it suitable for sensing applications. The BFL is also able to operate at any wavelength within the Raman gain bandwidth. Furthermore, the BFL can be made compact with the use of highly non-linear fibers such as holey fibers and Bismuth-oxide fibers for the generation of SBS instead of SMF.

4. Conclusions

We have demonstrated a single-wavelength Brillouin fibre laser enhanced by Raman amplification. The BFL is obtained at wavelength of 1550.09nm with a peak power of -26.2 dBm and a side mode suppression ratio (SMSR) of more than 12 dB with the BP and 1440nm pump powers of 8dBm and 350mW, respectively. The spacing between the BP and the Stokes is measured to be approximately 0.08 nm. The threshold power for BP and Raman pump is obtained at around 5~6dBm and 250mW, respectively for the coupler ratio between 70~90% coupler. The BFL cannot be achieved using a 3dB coupler.

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