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An Overview of Multi wave length Brillouin-Raman Fiber Laser

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ABSTRACT

This paper presents an overview of most of the articles, which concerned with the generation of multi wave length fiber laser based on hybrid nonlinear Brillouin and Raman gain mediums. We summarize and discuss the previous studies from a scientific point of view; by explained the performance parameters of multiwavelength Brillouin Raman fiber laser (MBRFL). These parameters include threshold power, number of output channels, and flatting of Stokes lines. Before that the basic concepts of these type of lasers are explained. In addition, we described the main performance enhancement techniques that used in MBRFL.

Keywords: **Fiber laser, Brillouin-Raman fiber laser, stimulated Brillouin scattering, Raman scattering.**

1. Introduction

There are basically two ways to increase the total capacity per fiber in dense wavelength division multiplexing (DWDM) technology. The first one is to increase the number of channels by incorporating narrower channel spacing as small as 12.5GHz, and the second technique is to increase the bit rate per channel (Hurh et al., 2005). The first approach is based on a relatively lower bit rate per channel, as compared to the second approach. Thus, leading to the relatively of used low speed electrical circuits a long with no complicated dispersion compensation technique is required. In this context, using the side effects of the nonlinear stimulated Brillouin scattering (SBS) inside the single mode optical fiber to generate the multiwavelength hybrid gain fiber laser (MHGFL) was first demonstrated in 1996 (Cowle and Stepanov, 1996).

There are two generations for MHGFL. The first generation is the multiwavelength Brillouin-Erbium fiber laser (MBEFL) (Cowle and Stepanov 1996; Tang et al. 2011), while the second generation is the multiwavelength Brillouin-Raman fiber lasers (MBRFL) (Min, et al. 2001). Furthermore, Many researchers and specialists were interested in MBRFL with constant channel spacing, because of enormous improvement added by this type of lasers to the MHGFL, such as, special doped fiber is not needed as gain media, wider flatten gain bandwidth by multi-wavelength pumping, wider tunable bandwidth, simpler structure, since the SMF serves both as the source of the cascaded Brillouin lines as well as a gain medium Raman fiber amplifier (RFA), the generation of BSL is higher compared to its counterpart of MBEFL and Stable room-temperature operation because of abstaining from the adverse influence of cavity modes such as in MBEFL (Zamzuri et al., 2006; Zamzuri et al., 2007).

2. Basic Concept

The basic concept of MBRFL is the same of MBEFL in the aspect of combination two gain inside the cavity but the difference here comes from using nonlinear gain represented by RFA instead of using linear Erbium doped fiber (EDF) gain. In other words the MBRFL is the combination between two nonlinear gain media, inside the SMF (Zamzuri et al., 2009; Kamaljit et al., 2010) .

The principle of multiwavelength comb generation can be explained by coupled interaction of three nonlinear scattering processes. As the power of Raman pump (Rp) lasers increase, injected Brillouin pump (BP) power exceed the Brillouin threshold. The feedback for multiple Stokes generation is provided by frequency shifted Brillouin scattering, and frequency un-shifted Rayleigh scattering and Raman gain is provided both for the amplification of the Brillouin and Rayleigh scattered power (Min,, et al., 2001).

The generation of Brillouin Stokes lines (BSL) occurs when the BP reaches the SBS threshold. That BSL is then amplified by Raman amplification as it propagates in the opposite direction to the BP propagation direction. During its propagation, it generates a second-order Brillouin Stokes line propagating in the same direction as the BP. This process continues as long as the particular higher-order Stokes line has a round-trip gain equal to the cavity loss. The round-trip oscillation in the laser cavity is formed by a mirror at each end of the laser structure. These mirrors are used to reflect Stokes lines as well as the residual Rp (Zamzuri et al., 2009).

3. Performance Parameters and Enhancement Techniques

Many specialists and researchers are interested in MBRFL through studying the performance parameters of these lasers. In addition, many of them tried to improve these parameters using a various techniques. This section will discuss these parameters and the techniques proposed to enhance the MBRFL as reported in previous studies.

3.1 Performance Parameters

Performance parameters for any laser can be considered as a measure of efficiency of that system, and determine the qualification of the techniques that be used. Inasmuch as, MBFFL is a complicated contribution between two gains media; Brillouin-Raman gains; the performance parameters determined by optimizing this contribution. In other words, all laser parameters should be measured at optimum case, for instance, the two gains media should be adjusted to give optimum output. In addition, the main performance parameters of the MBRFL are represented by number of Stokes lines, threshold lasing power, flatting of the BSL, and optical signal to noise ratio. The publications that illustrate the main performance parameters of MBRFL in the last decade will be reviewed in this section.

The number of Stokes lines that generated using hybrid gain cavity is the essence of the emergence of the MBEFL, and MBRFL. The MBRFL was marked by a vast number of Stokes of up to 798 (Min, et al. 2001), and a wide bandwidth of laser can be used as pumping source (1488-1550 nm), with high power up to several hundred mW (Liu et al., 2008). In this context the threshold lasing power, can be defined as a require BP power to generate the first Stokes line in MBRFL. Usually, the best configuration has low threshold power and high number of Stokes lines.

The flatting BSL is a term given to equal amplitude cascaded Brillouin operation of the comb generator. The balance between three scattering processes (Brillion, Rayleigh and Raman) in MBRFL leads to a flattened comb generation (Min, et al. 2001). Thus, in order to have a reasonable flat-amplitude Stokes lines, BP wavelength must be located closer to the Raman peak gain region. The optimization of the BP power and wavelength has great influence in determining the uniformity of the Stokes lines amplitude. The flat-amplitude bandwidth is also governed by the number of Rp wavelength used in the laser structure (Zamzuri et al. 2007). Optical signal to noise ratio (OSNR) is the measure of the signal power to noise power ratio in an optical channel. OSNR is important because it suggests a degree of impairment when the optical signal is carried by an optical transmission system that includes optical amplifiers. The first appearance of the MBRFL was in 2001 by Min et al.. They employed a simple, but novel use of Raman amplification and other nonlinear processes within the fiber medium. Up to 798 lines of Brillouin Stokes generation with high stability and excellent flatness have been realized from a single fiber section by employing a single-pass configuration (Min, et al. 2001).

Zamzuri et al. (2006), demonstrated a multiple-wavelength Brillouin comb laser with cooperative Rayleigh scattering that uses Raman amplification in dispersion-compensating fiber. The laser resonator is a linear cavity formed by reflector at each end of the dispersion-compensating fiber to improve the reflectivity of the Brillouin Stokes comb. Multiple Brillouin Stokes generation has been improved in terms of optical signal-to-noise ratio and power-level fluctuation between neighboring channels. Furthermore, the linewidth of the Brillouin Stokes is uniform within the laser output bandwidth. In addition, (Zamzuri et al. 2007), reported a flat-amplitude bandwidth of 30.7 nm from 1527.32 to 1558.02 nm when Rp wavelengths were set to 1435 and 1450 nm. Up to 357 uniform Brillouin Stokes lines with 0.086 nm spacing was generated across the wavelength range. The average signal-to-noise ratio of 17 dB was obtained for all the Brillouin Stokes lines.

Liu et al. (2008), demonstrated a Stable room-temperature multi-wavelength lasing oscillations with more than 30 lasing lines and wavelength spacing of 0.076 nm were obtained with only 250mW Rp power and a section of high nonlinear fiber with a length of 1.5 km. In the same year, they used a simple technique for achieving wavelength tunable and amplitude equilibrium dual-wavelength fiber laser source based on a dual-pass Raman Brillouin amplification configuration.

A room-temperature dual-wavelength lasing oscillations with average channel power of more than 1 mW and signal-to-noise ratio of more than 30 dB were obtained with only 250 mW Rp power over a wide tuning range of ~35 nm from 1545.090 nm to 1580.078 nm. Meanwhile, (Shirazi et al. 2008), the effects of backward, forward, and bidirectional Raman pumping schemes on stimulated Brillouin scattering (SBS) in linear cavity was investigated. Surprisingly, it was revealed that the SBS threshold reduction depends strongly and solely on Raman gain and it is independent of the Raman pumping schemes. In addition, the effect of Raman amplification on SBS was more effective at the SBS threshold, especially in the bidirectional and forward schemes.

The generation of multiple Brillouin Stokes lines assisted by Rayleigh scattering in Raman fiber laser was reported by (Zamzuri et al. 2010). The linear cavity was utilized to take advantage of the Rayleigh scattering effect, and it also produces two strong spectral peaks at 1555 and 1565 nm. Under a strong pumping condition, the Rayleigh backscatters contribute to the oscillation efficiency, which increases the Brillouin Stokes lines intensity between these two wavelength ranges. The multiple Stokes lines get stronger by suppressing the buildup of free-running longitudinal modes in the laser structure. After that, (Liu et al. 2010), a tunable laser whose power is 3dBm was used as Brillouin pump, a three-wavelength fiber Raman laser was used as Raman pump, and 25km single mode fiber was employed as both Brillouin and Raman gain media. The backward cascaded SBS of 178 even orders was observed with tuning range up to 29.72 nm.

Ahmad et al. (2011), an S-band Brillouin–Raman Fiber Laser (BRFL) was demonstrated utilizing a dispersion compensating fiber (DCF) as the non-linear gain medium in a linear cavity configuration and amplified by two 1425 nm, 380 mW pumped RFA's. A Brillouin pump signal of 1515 nm at 12 dBm in power was injected into the setup that generated Stokes lines via the SBS process. Up to 32 Stokes lines with a flat peak output power of −18 dBm was generated. In the same year, (Al-Mansoori et al., 2011), proposed a simple Brillouin-Raman multichannel fiber laser with supportive Rayleigh scattering in a linear cavity without employing any feedback mirrors at the end of cavity. Brillouin and the consequences of Rayleigh scattering work as virtual mirrors. A section of large effective area fiber was employed in addition to a section of dispersion compensating fiber to enhance the optical signal-to-noise ratio of multi-channel Brillouin-Raman comb fiber laser. A flat comb fiber laser with 37 nm bandwidth from 1539 to 1576 nm built-in 460 Stokes lines with 0.08 nm spacing was produced.

3.2 Enhancement Techniques

Different enhancement techniques have been proposed and used to improve the performance parameters of MBRFL. The MBRFL is a Brillouin fiber laser (BFL) with Raman amplification, thus, the technique that has been used to enhance the Raman amplifier almost improved the output channel in BRFL (Lou, et al. 2004); (Zamzuri et al. 2007); (Shirazi, et al. 2008). These include the use of several pumps of different wavelengths and pump directions techniques.

3.2.1 Multiwavelength Raman Pump Source Technique

Multiple-pump Raman amplifiers make use of the fact that the Raman gain exists at any wavelength as long as the pump wavelength is suitably chosen. Thus, even though the gain spectrum of a single pump is not very wide and is flat only over a few nanometers, it can be broadened and flattened considerably by using several pumps of different wavelengths. Superposition of several such spectra can produce relatively constant gain over a wide spectral region when pump wavelengths and power levels are chosen judiciously (Headley and Agrawal 2005).

3.2.2 Raman Pump Direction Technique

In MBRFL there are three configurations for Raman pump, (forward, backward, and bidirectional pump). The SBS threshold reduction depends strongly and solely on Raman gain and it is independent of the Raman pumping schemes. In addition, the effect of Raman amplification on SBS was more effective at the SBS threshold, especially in the bidirectional and forward schemes (Shirazi, et al. 2008).

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