New Technique for High Performance of Double Stage One Linear Cavity Fiber Laser

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Abstract - We report and demonstrate a new Double Stage One Linear Cavity (DSOLC) erbium-doped fiber laser. This study is a characterization and analysis of high performance of new fiber laser based on simulation and experimental results. The two mentioned configurations suppress the Amplified Spontaneous Emission (ASE) and produce a high and stable output power of 22 dBm and 18 dBm at 1560 nm lasing wavelength for the simulated and experimental respectively. The DSOLC produces high output power from 1525 nm to 1565 nm tuning range using an output coupling ratio of 95% and two pumps of 220 mW.

Keywords: Erbium-Doped Fiber Laser, Double Stage Linear Cavity, FBG, and SMSR.

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1. Introduction

The first theoretical prediction of stimulated emission of laser has been proposed by Albert Einstein, where his published paper in 1917 is considered as the foundation of laser physics [1]. The lasers throughout history have had a rich interest and complex development since Theodore Maiman has opened the eyesight of humanity on the laser age in 1960 [2]. In 1961, Elias Snitzer and colleagues constructed and operated the world's first optical fiber laser [3]. Laser developments and applications continue with Erbium-Doped Fiber Lasers (EDFLs) that have received significant attention from researchers for their wide tuning range, single frequency, narrow line-width, side mode suppression ratio (SMSR), high output power, and dense wavelength division multiplexing (DWDM) utilization. The lasing performance of any erbium-doped fiber laser is affected by several factors such as doping concentrations, erbium-ion clustering, pumping wavelength, pumping power, and configuration structure. In this paper, the high performance of DSOLC has been analyzed and investigated based on the measurement of output power and SMSR for both experimentation and simulation. Various configurations have been proposed so far to achieve suitable fiber laser characteristics. The proposed new technique is to achieve high output power, a wide tuning range, and high SMSR. The new technique uses the uniform Fiber Bragg Grating (FBG) for the simulated configuration instead of the circulators and tunable bandpass filter (TBFs) for the experimental configuration.

The output power and SMSR results are deeply depending on the structure [4] and quality level of the design. These design performances can be summarized as the following: lower threshold [5], wider tuning range [6], flat output power, higher power, higher efficiency, higher side mode suppression ratio [5], multiple output wavelengths. Most of the published linear cavity fiber laser papers have low output power and low SMSR compared to what we found in this paper. In the following references, we summarized the results of output power and SMSR of linear cavity laser respectively as follow; -20dBm and 45dB [7], 5dBm and 60dB [8], 12.55 dBm and 40 dB [9], -10 dBm and 47dB [10]. 12.3 dBm and 50 dB [11] and -13 dBm and 45 dB [12]. 40dB and 13.82dBm [13]. From the listed references and their results, it is evident that all the shown papers have recorded low output power and low SMSR compared with the achieved results in this paper which reports high SMSR around 64 dB and high output power of around 22 dBm.

In this paper, we characterize and compare the simulated configuration of DSOLC with the experimental configuration_[14]. The output power from the proposed laser configurations is about 22 dBm at 95 % coupling ratio and 220 mW pump power P1 and P2, the tuning range is from 1525 to 1565 nm for the experimental part due to TBFs limitation.

The proposed paper reports a new DSOLC configuration using a fiber loop-back embedded with tunable filters in a dual-stage one linear cavity technique. Implementing the linear cavity configuration, three circulators and two TBFs are used. Nevertheless, for the simulation, we have used just the mid-way circulator and two FBGs. The double filtering technique is to fulfill the design requirement, it enables the laser configuration to achieve higher stability, high SMSR as well as high output power. As remarked from recorded results the simulated configuration compared to the experimental one shows high output power and low SMSR.

The output power of the DSOLC through the wavelength span is considered very high, unique, and recorded using the simulation for the first time. In contrast with other demonstrated fiber laser techniques as mentioned in the previous references, the laser topology proposed in this paper has some prominent advantages, which make this laser have strong competition ability compared to other techniques in optical sources. Therefore, it is very significant to highlight the advantages and contributions of this new design technique at the level of configuration structure, output power, SMSR, and the replacement effect of CIRs with FBGs on the results.

To the best of the authors' knowledge, this is the first reported paper that shows high output power, high SMSR, and an investigated analysis of compared simulation and experimental results of DSOLC. In addition, the simulated and experimental results are considered unique and very high compared to the published results either at the output power or at the Side Mode Suppression Ratio (SMSR).

2. Experimental, Simulation and discussion of results

The experimental setup is shown in Figure 1 (a). It consists of three circulators, CIR1 and CIR2 with three ports and midway CIR with four ports. CIR1 and CIR2 are used as loop-back mirrors connected to a tunable bandpass filter (TBF) for the double suppression of the ASE inside the two stages cavity. The arrangement allows the insertion of the output coupler at one of the fiber loop-back mirrors. The TBF is mechanically tuned with a pass-band of 1nm, insertion loss of around 1.5 dB at the center wavelength, and a tuning range limited to 40 nm, from 1525 nm to 1565 nm.

It is worth mentioning the existed difficulty during the experimental practice due to the adjustment of the two TBFs in the same wavelength to suppress the ASE efficiently during the tuning span. The tuning process is used to fix the lasing wavelength, stabilize the output power, control the shape of the spectrum and minimize the insertion loss. The DSOLC consists of two portions in the configuration, the first EDF1 is 10m in length and the second EDF2 is 15m in length with an Er^{3+}ion concentration of 440 ppm. The EDF is pumped by two 980 nm laser diodes pumps. Each pump can provide a maximum power of 220 mW. A fused coupler (CP) with a 95% coupling ratio is placed after the TBF in one of the fiber loop mirrors to act as the laser output power. All connections are fusion spliced to minimize the back-reflection and achieve low loss inside the cavity and high output power. An optical spectrum analyzer (OSA) with 0.1 nm resolution is connected to the coupler to measure and record the output spectra.

The stimulated emission will be produced within the two EDFs influenced by the pumps. The DSOLC structure creates the laser inside the linear cavity, the signal will propagate through the two EDFs passing through the two TBFs and the two circulators. The laser inside the DSOLC propagates through the mid-way CIR of four ports passing two different ways, the first way passes from port 3 to port 4, then from port 1 to port 2 through EDF1, the second way, pass from port 2 to port 3 through EDF2. In the end, the laser inside the cavity passes through TBF2 and from coupler (C)P) to OSA. The total DSOLC insertion loss of the setup without EDF is 9 dB three circulators (six passes through) and two TBFs (two passes through).

Figure 1 (b) shows the proposed simulated configuration using Optisystem. The same characteristics of the optical components are used for the two configurations of DSOLC such as; same EDF length, same erbium ion concentration, same pumping power, and same wavelength. The changes are the replacement of the two circulators CIR1 and CIR2 and the two TBFs of the experimental configuration with two FBGs for the simulated configuration. The Optisystem is used for the simulation where the insertion loss is minimized due to the utilization of a new technique.

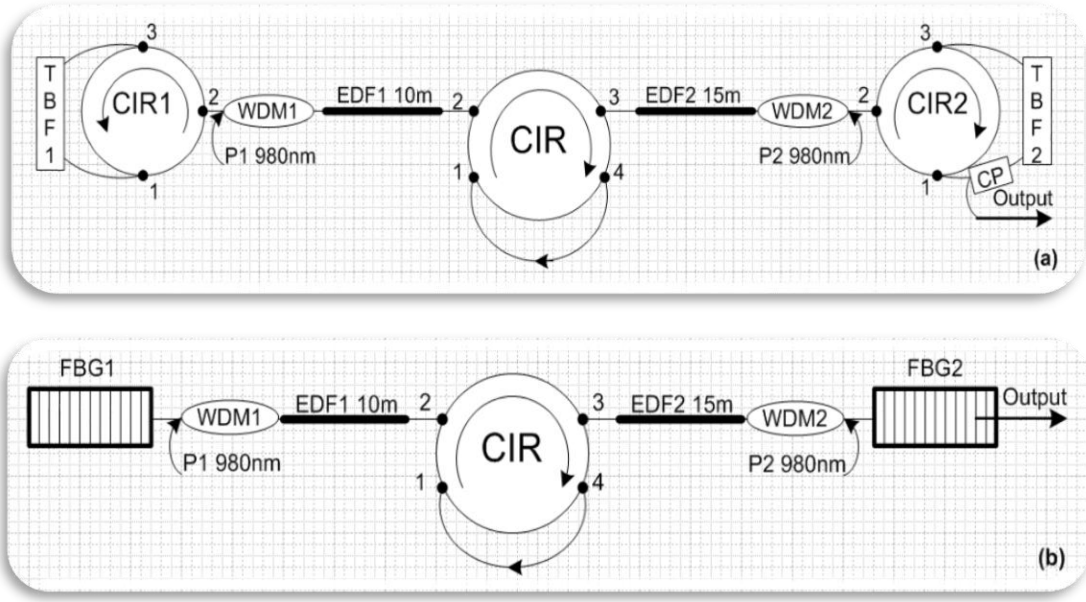

Figure 1: Double stage one linear cavity erbium-doped fiber laser design of (a) experimental configuration and (b) simulated configuration.

A fixed output coupler ratio for both experimental and simulation of 95% is used to characterize the output power versus the pumping power. The first pump power P1 was varied from 10 mW to 220 mW by the increment of 10 mW, the second pump power P2 was varied from 50 mW to 220 mW by the increment of 50 mW. The results of output power taken against pumping power are shown in figure 2. The measurements of output power and SMSR are recorded by OSA. Experimental results are indicated by clear markers and simulation results are indicated by shaded markers. When P02 is fixed at 50, 100, 150, and 220 mW, the pump P1 is raised similarly by an increment of 10 mW until it reaches 220 mW.

The lasing output power is directly proportional to pumping power as illustrated in figure 2. The highest output power reaches 18 dBm in the experiment configuration and about 22 dBm in the simulation one. Figure 2 shows that all the results of the simulation are higher compared to the experimental, this maybe is due to the replacement of two circulators and two TBFs by two FBGs for the simulation which reduce the loss inside the cavity, reduce the back reflection and increase the output power.

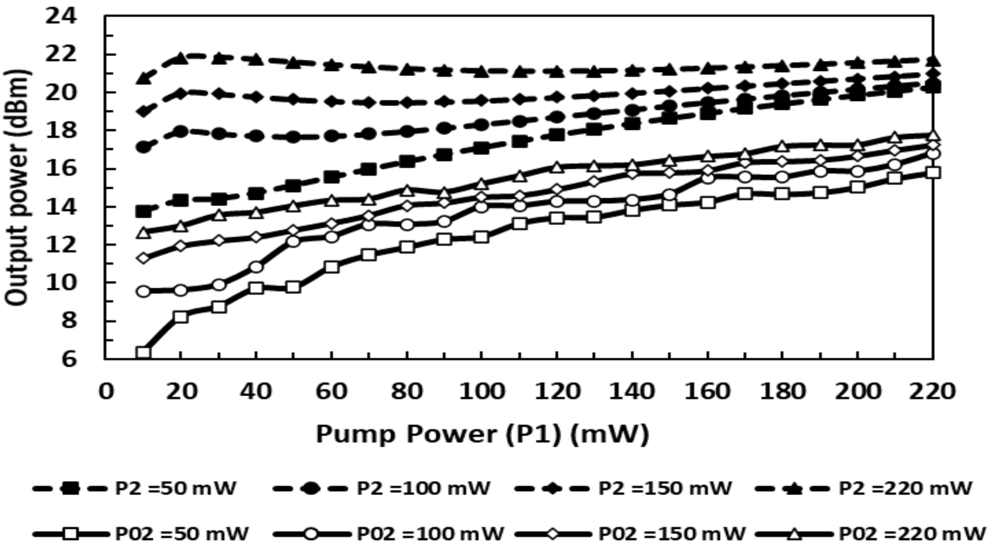

Figure 2: Experimental (clear) and simulated (shaded) lasing output power versus pumping power at 1560 nm wavelength.

It is worth and very important to mention that, all the output power of the simulation results are higher compared to the experimental one. All the recorded simulated results at all the pumping power are above the experimental results with a gap varying between 9 dB and 4 dB. The achieved results need to be verified experimentally by using variable FBGs to simplify the recording of results.

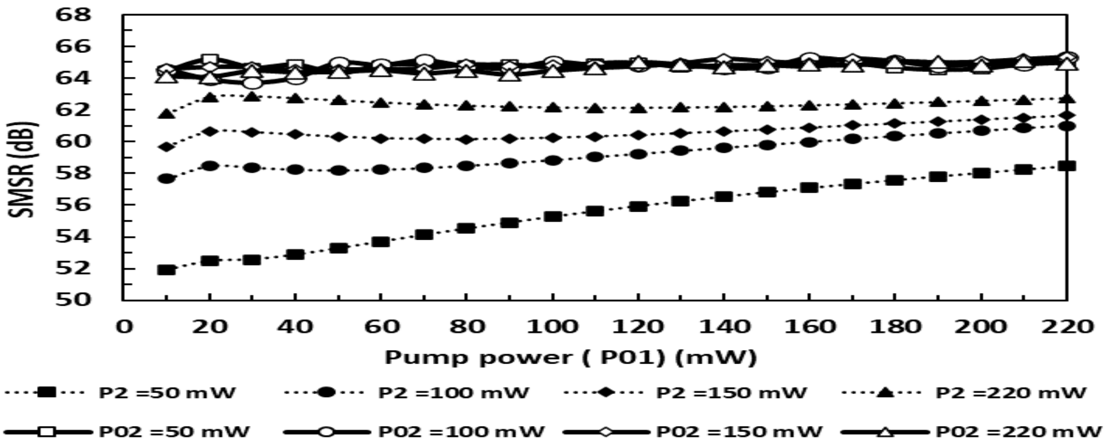

Figure 3: Experimental (clear) and simulated (shaded) SMSR versus pumping power at 1560 nm wavelength.

Figure 3 shows the SMSR of both experimental and simulation versus pumping power. The results are obtained at different pumping powers and fixed wavelength of 1560 nm with 95 % coupling ratio. The recorded results show higher experimental SMSR compared to the simulated one. At all the pumping powers of the experiment, the results show flat SMSR from 64.11 to 64.93 dBm, while the simulation results have higher gaps at different pumping powers. This gap difference in simulation results of output power maybe is due to high-quality ASE suppression for the two TBFs compared with the two FBGs.

To investigate the behavioral trends of the output power versus the tuning wavelength from 1525 nm to 1565 nm the simulated configuration is used. The output power is an important parameter for the DSOLC characterizations. Figure 4 shows the results of the output power versus the wavelength at different coupling ratios. The lasing wavelength is swept from 1525 to 1565 nm with an increment of 5 nm at 220 mW pump power. The output power of the simulated configuration versus the coupling ratio is flat at 22 dBm output power for all the wavelengths span of 40 nm. Nevertheless, for the coupling ratios less than 60% the output power is quasi flat for the recorded span.

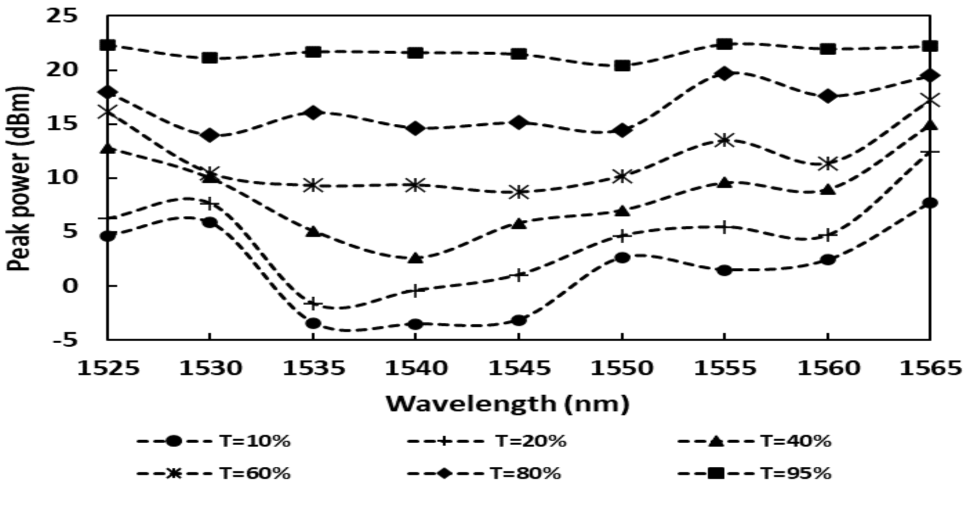

Figure 4: Simulated output power versus lasing wavelengths at different coupling ratios.

Figure 5(a) illustrates the optical spectra of the output power of the simulated configuration and experimented configuration in figure 5 (b). The pumps are fixed at 220 mW and the coupling ratio at 95% for both experimental and simulation. The OSA records the spectra at 1560 nm wavelength. The two spectra show the maximum recorded output power of 21.71 dBm for simulation and 18.01 dBm for experimental.

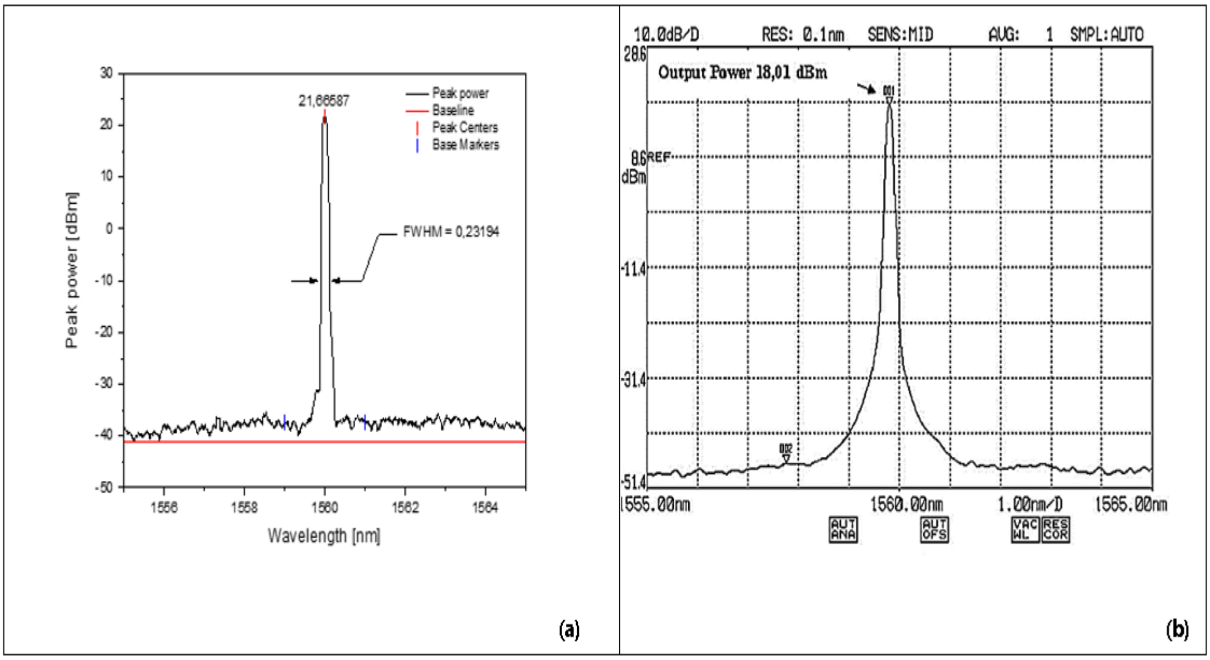

Figure 5: Output spectra of the proposed laser configuration at 1560 nm (a) simulation, (b) experiment.

3. Conclusion

A novel double stage one linear cavity Erbium-doped fiber laser configurations have been constructed, demonstrated, and analyzed based on experimental and simulated results. This new technique of simulated architecture achieves a high output power of 22 dBm and a high SMSR of 64 dB through the 40nm lasing span. The DSOLC shows technical novelty, high output power, high SMSR, wide tuning range, and standard optical spectra. Efficient noise suppression is successfully demonstrated by utilizing TBFs and FBGs. The proposed two configurations show an evident harmonization of results between experiment and simulation. The output power of the DSOLC through the wavelength span is considered high, unique, and recorded for the first time.

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