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Analysis of multi-mode erbium doped fiber laser system

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Rapid development of single-mode and multi-mode laser systems is in line with the current technology of optical communication systems, especially in the Wavelength Division Multiplexing (WDM) system. The design of the laser system was undertaken to investigate the factors that influence the overall performance of the laser system. The construction of erbium doped fibre laser (EDFL) system used erbium as doped material. The focus of this research is to study the characteristics of the multi-mode fibre laser system where two designs are proposed. The simulation was carried out by using OptiSystem software version 7.0. The development of the EDFL system involves several design parameters which includes EDF length, coupling ratio and input pump power. Results show that all design parameters do affect the performance of the system. The multi-mode EDFL system of 10 m EDF length with 90% of coupling ratio and a wavelength of FBG at 1551 nm and 1552 nm are able to generate a maximum output power of 0.0211 mW for two wavelengths-based designs and 0.0238 mW for FWM-based design respectively.

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Keyword: EDFL, Multi-Mode EDFL, OptiSystem

1. Introduction

Optical fibres are now seen as alternative future technology for the internet network to replace cooper wire as a medium of transmission. Fibre optic technology provides unlimited transmission capacity and network performance which is more efficient compared to copper. The principle of optical fibre communications are that the transmission optical wave acts as an information carrier and optical fibre acts as an information transmission line. There are several types of light sources used in communication system such as light emitting diodes (LEDs), laser diodes (LD) and fiber laser (FL). LD and LED do not couple with light efficiently because of the different geometries with the optical fibres. For conditions where the radiation pattern of source does not match with the fibre, it is more efficient if the laser was constructed from a fibre itself [1].

Fibre laser gains more attention and is more attractive than conventional laser due to the coupling efficiency with fibre, reliability and beam quality being high as well as better in management in terms of thermal and narrow linewidth. Due to their various advantages, fibre lasers have been found in many applications especially for wavelength division multiplying (WDM) system, fibre component testing, fibre sensing, spectroscopy and radio over fibre (ROF) [2]. At present, research is more focused on the multi-mode fiber laser system due to address the increasing demand for capacity. Early optical fibre communications systems were typically uni-channel systems, where they were not commercial due to their high cost because more fibres were needed for the transmitter and receiver part. However, the tremendous development of the internet and globalization meet a demand for the capability to transmit large amounts of data quickly and securely over long distances, a capability which could only be fulfilled by optical communications. This increasing demand resulted in the development of Wavelength Division Multiplexing (WDM) technologies, which can increase a single fibre's carrying capacity by a hundred times over [3].

Prior to this work, extensive studies on multi mode fibre laser system which was capable of generating multiple wavelengths simultaneously had been widely carried out by [4] – [13] to accommodate the WDM system which required different lasers for each wavelength transmitted. Various methodologies were introduced to design a laser system by using one or more filters to determine the desired wavelength. Various types of filters can be used such as fiber Bragg grating (FBG), band pass filter, FP etalon and comb filters [4]. In addition, to reduce homogenous broadening of laser beam, several methods were used including single EDF cooling in liquid nitrogen [5], using acousto optic frequency shifter [6], using comb filters or interferometer filter [7], [8] and using Sagnac loop reflector [9]. To increase the stability of the multi-mode EDFL, several techniques have been introduced such as using Sagnac loop filter [10], elliptical core EDF [11], FBG in Sagnac loop interferometer [12] and Single Mode Operation [13].

This paper aims to present the characteristics of multi-mode Erbium Doped Fibre Laser system (EDFL) where two designs are proposed. The OptiSystem software is used as a simulation tool.

2. Methodology

This study includes the development of two multi-mode EDFL system which are based on two designs schematic wavelengths and schematic generation of Four Wave Mixing (FWM). The schematic design for multi-mode EDFL system based on two wavelengths is the modification result of the single-mode EDFL system. This design is able to generate two wavelengths simultaneously. Whereas the schematic design for multi-mode EDFL system which is based on generation of FWM is able to generate multiple wavelengths simultaneously depending on design setting.

The construction of EDFL system is based on two wavelengths involving components which are pump laser, wavelength division multiplexer (WDM), erbium doped fibre (EDF), isolator, output coupler and fibre Bragg grating (FBG) as illustrated in Fig. 1. The results are visualised from an optical spectrum analyzer (OSA), and power meters. The schematic design is developed using software as shown in Fig. 2.

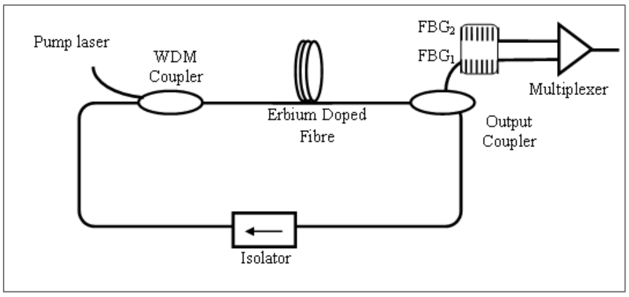

Fig. 1 Schematic design of EDFL system based on two wavelengths

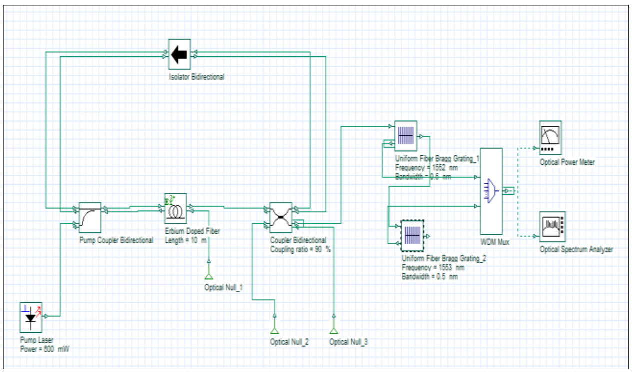

Fig. 2 Schematic design of EDFL system based on two wavelengths using software

The schematic design of EDFL system based on FWM generation as shown in Fig. 3 is a schematic customization of systems based on two wavelength designs. Both FBG is connected after the EDF. This design uses the optimal parameter values as defined in the preceding simulation specification based on FBG wavelength and reflectivity. The EDF length used is also based on the optimum length that has been identified in previous parts. The multiplexer that combines the reflected wavelength of FBG is connected to SMF-28 for non-linear effects of FWM generation. According to [14], the effect of FWM can be generated by using dispersion-shifted fibre (DSF) or conventional single mode fibre (SMF). Considering the cost of a single-mode fiber which is more economical, thus this design was chosen to replace the usage of DSF to SMF-28. A schematic design was developed using the software as shown in Fig. 4.

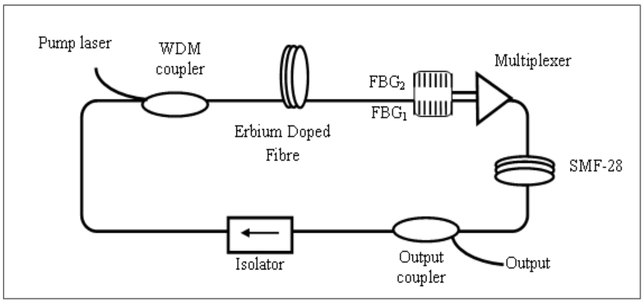

Fig. 3 Schematic design of EDFL system based on generation of four wave mixing (FWM)

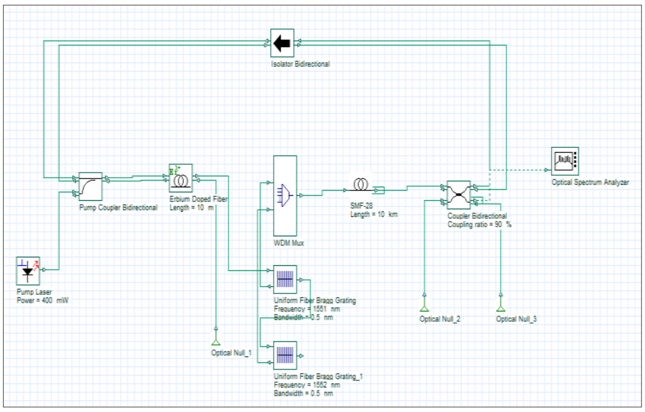

Fig. 4 Schematic design of EDFL system based on generation of four wave mixing (FWM) using software

3. Results and Discussion

The analysis began with a test of system based on two wavelengths followed by FWM generation-based system using the design parameters of the EDF length, the coupling ratio of output coupler and input pump power. In this study, analysis of both systems were carried out using a pump input power of 400mW to generate optimal power output. Analysis of system based on FWM generation involved the usage of optimal parameter values that have been identified in previous parts of system based on two wavelengths.

3.1 Effect of coupling ratio against power output for system based on two wavelengths

Based on the setting of wavelength for FBG 1 which is 1552 nm and FBG 2 which is 1553 nm, and the reflectivity of both FBG at 99%, it appears that most of the maximum output power generated used a coupling ratio of 90% for most EDF lengths except for 5 meters long as in Fig. 5. The maximum power for EDF 5 meters long is the coupling ratio of 80%. This indicates that the optical signal which is amplified by using EDF over 5 meters will experience shrinkage when power is fed too high compared with a longer EDF.

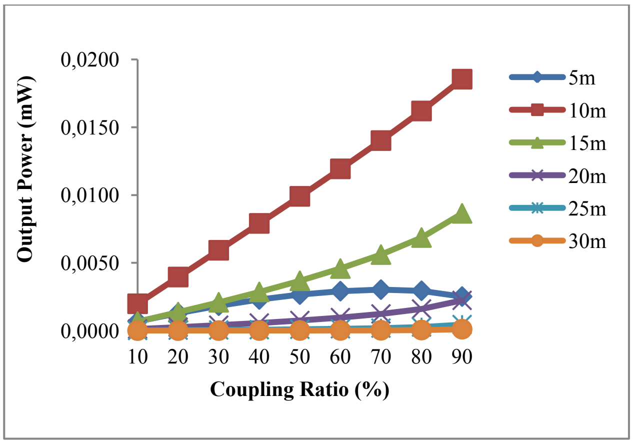

Fig. 5 Effect of coupling ratio for system based on two wavelengths

3.2 Effect of EDF length against power output for system based on two wavelengths

According to the graph in Fig. 6, it can be concluded that the optimum EDF length to generate a maximum power output of the system is 10 meters for all types of coupling ratio studied. This indicates that an EDF more than 15 meters long is not suitable for usage in this design.

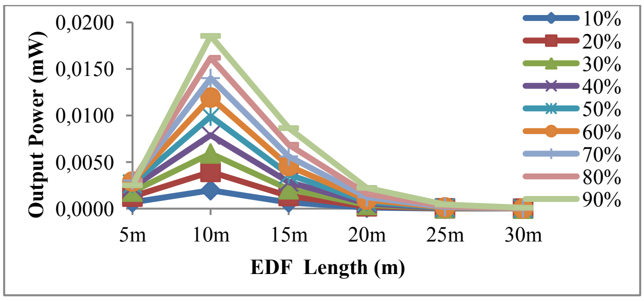

Fig. 6 Effect of EDF length for system based on two wavelengths

3.3 Effect of input power against output signal power for system based on two wavelengths

Using three combinations of wavelength for both FBG of 1550 nm to 1551 nm, 1551 nm to 1552 nm and 1552 nm to 1553 nm, the graph is displayed as in Figure 7. According to the graph, it shows the combination of wavelength 1552 nm 1551 nm is able to generate the highest output signal power compared to other combinations.

Furthermore, the analysis was continued by using a wavelength combination of 1551 nm to 1552 nm for both FBG respectively with different settings of FBG reflectivity. Four reflectivity combinations of both FBG were studied which are 85% to 95%, 87% and 97%, 89% and 99% and 99% to 99%. According to the graph illustrated in Figure 8, it shows a combination of 99% reflectivity for both FBG respectively which has generated the highest output signal power compared to the other three combinations of 0.0211 mW at an input power of 600 mW. This shows that the FBG reflectivity affects the output signal power for this system design which used only the optical signal reflected from the FBG. This condition causes the output power to increase with the FBG reflectivity. The analysis as shown in Fig. 9(a) used the optimal parameter values as described which are an EDF length of 10 meters, the coupling ratio of 90%, the wavelength of 1551 nm for FBG 1 and 1552 nm for FBG 2 nm respectively and reflectivity for both FBG at 99% found FBG 1 generated power higher than the FBG 2. This condition is caused by factors of FBG position where FBG 1 obtains a higher power than the power received by FBG 2. Hence, the value of the reflected power will also be closely associated with this condition which can lead to the power emitted by the FBG positioned advance, being always higher than the power of the next FBG. Therefore, when the energy is increased, reflectivity of the reflected signal will be increased also thereby increasing the output power of the system.

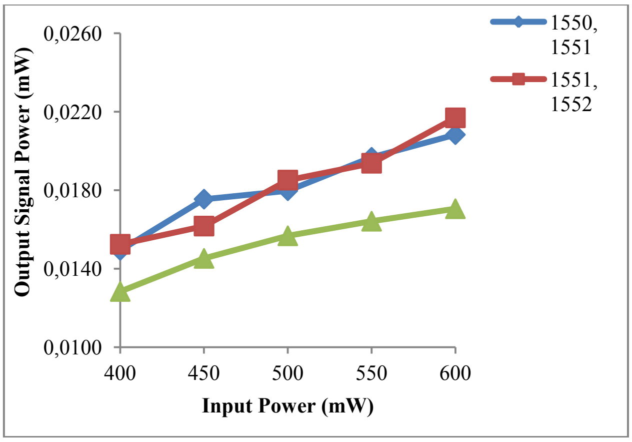

Fig. 7 Effect of different wavelength combinations for input power of system based on two wavelengths

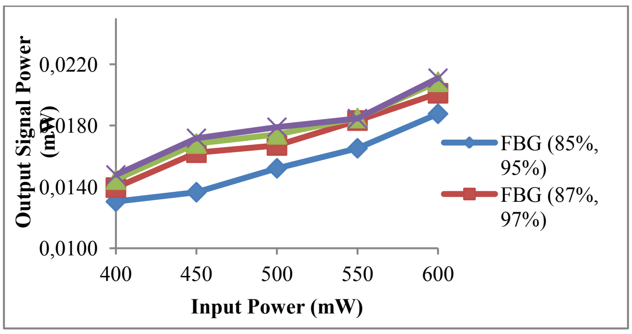

Fig. 8 Effect of different reflectivity combinations for input power of system based on two wavelengths

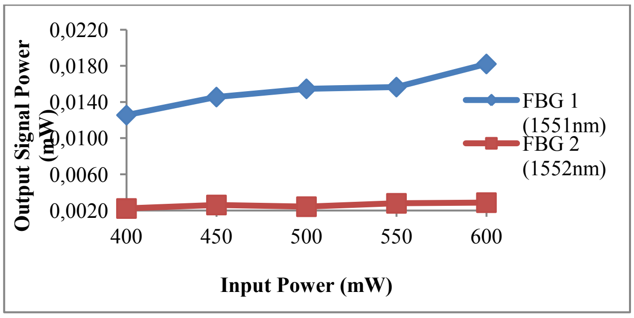

Fig. 9(a) Effect of FBG 1 and FBG 2 position for input power of system based on two wavelengths

3.4 Effect of SMF-28 length against output signal power based on generation of FWM

The graph illustrated in Fig. 9(b) shows a reduction in output signal power in occurance with the increasing length of SMF-28. This shows that there is a loss of power along the fibre used although the study carried out by [14] used a 5 km single fibre. Due to system design differences, this led to single fibre along 5 km being inappropriate to be applied in this study. Thus, a single fibre was used for the next analysis which was only 2 km to ensure optimized FWM generation occurs.

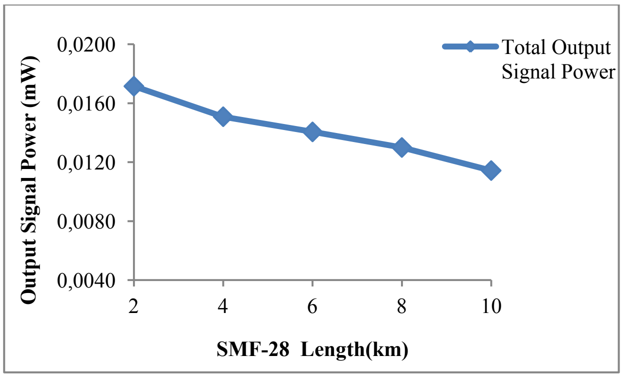

Fig. 9(b) Effect of SMF-28 length for system based on generation of FWM

3.5 Effect of input power against output signal power for both systems

This analysis was done based on the use of optimal values for all parameters that have specified the length of the EDF, ratio and output coupling FBG specifications as well as long single-mode fiber SMF-28 that have been identified. From Figure 10, the output power was found to increase with an increasing input power of 0.0238 mW at 600 mW input power. This shows that the optical light intensity increased with increasing input power. According to [15], the efficiency of FWM generation depends on the input pump power. Therefore, the increase of pump power into the cavity stimulated the FWM effect and it is directly proportional to the intensity of the optical light [16].

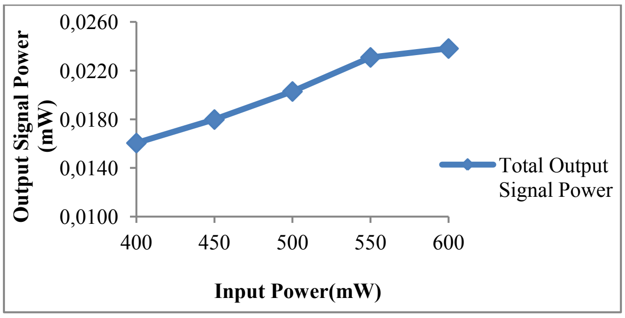

Fig. 10 Effect of Input Power for System

Based on Generation of FWM Fig. 11 shows the stability of the wavelength generated from FWM phenomenon. From the graph, it portrays that the emitted wavelength is stable on each input power and it also proved that FBG 1 and FBG 2 works well in terms of reflecting the optical signal specifications. In addition, the waves generated from FWM (1550 nm and 1553 nm) also performed well in the value of signal wavelength which was determined based on the distance of 1 nm..

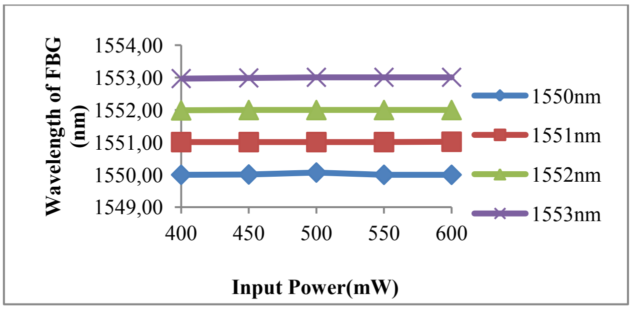

Fig. 11 Wavelength of FBG for system based on generation of FWM

The comparison of both multi-mode EDFL system designs are based on two wavelengths, schematic and schematic generation of Four Wave Mixing (FWM) as illustrated in Fig. 12. Design 1 indicates the system based on two wavelengths while Design 2 indicates the system based on generation of FWM. According to the graph, it shows that design 2 generates more output power of 0.0238 mW compared with design 1 which generated power of 0.0211 mW at the same input power of 600 mW. This condition is probably caused by different settings between both designs where reflecting signals from both FBG in design 2 is more efficient. For instance, design 2 also produced the additional wavelength generated from FWM phenomenon. As a conclusion, multi-mode EDFL system based on FWM produced better performance of output signal power generation compared with the system based on two wavelengths.

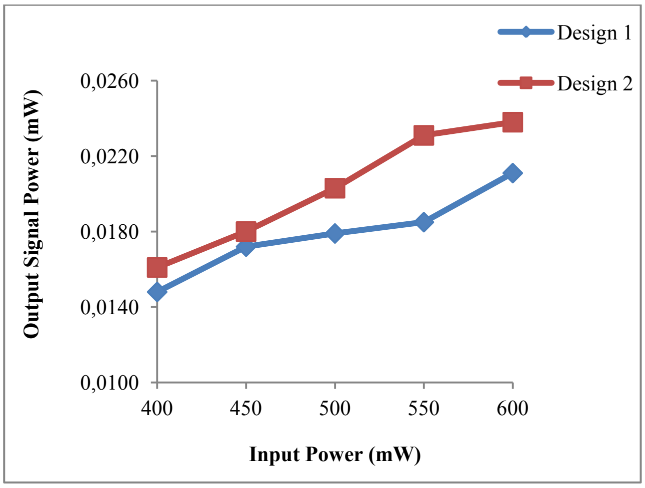

Fig. 12 Effect of input power for system based on two wavelengths and system based on generation of FWM

4. Conclussion

Throughout this research, the analysis found that all the design parameters affected the performance of two multi-mode EDFL system designs which were based on two wavelengths: schematic and schematic generation of Four Wave Mixing (FWM) schematic. The multi-mode EDFL system of 10 m EDF length with 90% of coupling ratio and wavelength of FBG at 1551 nm and 1552 nm are able to generate a maximum output power of 0.0211 mW for two wavelengths-based design and 0.0238 mW for FWM-based design respectively. It can be concluded that the system based on FWM produced better performance of output signal power generation compared to the system based on two wavelengths.

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