An Efficient Hybrid Amplifier Configuration for High Output Power

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Abstract
Among all the rare-earth fibre amplifiers, erbium–ytterbium co-doped fibre amplifiers have received great attention during the past few years. In this work an effort has been made to optimize the performance of a hybrid amplifier configuration comprising of an EDFA and EYCDFA in terms of the length of erbium–ytterbium co-doped fibre and the concentration of erbium ions in EYCDFA. The signal power is 10mW, maximum pump power of EYCDFA is 10W, output power obtained is 4.73W with an optimized fibre length of 8-10m. Also a high output power of 19.4W has been obtained with 8-10m of fibre length as the optimum range of operation and concentration of erbium ions as $3\times10^{19}/m^3$ suitable for high gain. The result of range of 8-10m of fibre length is validated using various values of pump powers.

Keywords
Erbium-Ytterbium Co-Doped Fibre Amplifier, EYCDFA, Signal Gain and Noise Figure

I. Introduction

Erbium Doped Fibre Amplifiers (EDFAs) have emerged as a wide application for long-haul fibre communication systems because of highly efficient operation around 1550nm, usage of short length of fibre and delivery of high gain [1]. However, when EDFA is made to work with higher powers the increase in power density inside the fibre damages the fibre. To obtain higher powers, the pump absorption efficiency is needed to be increased. In comparison to EDFA, EYCDFA absorbs higher amount of energy as the ions of Ytterbium absorb most of the pump power because of larger cross sectional area. Also there is cross correlation between the Yb^{+3} and Er^{+3} ions which ensures the transfer of energy from Yb^{+3} to Er^{+3} ions.

Also the incorporation of Yb^{3+} ions facilitates higher Er^{3+} ions concentrations without strong quenching effects [2]. Co-doping the fused-silica fibres with both Erbium and Ytterbium ions led to the coining of the new fibre amplifier popularly known as EYCDFA. There is a wide availability of pumping wavelengths with the co-doping of ytterbium ions i.e. 800-1100nm [3]. Moreover, double-cladding pumping method helps in coupling of more light into the fibre [4]. Due to this a need was felt to study the behavior of EDFA/EYDFA hybrid amplifier configuration. Moreover the gain transients of EDFA require extensive gain flattening techniques whereas EYDFA gives a naturally flattened gain over an extended bandwidth. There are two primary objectives of this work that is to model EDFA/EYCDFA hybrid amplifier for higher output power and gain for a single channel system and to optimize and analyze the performance of the deigned EDFA/EYCDFA hybrid amplifier configuration by studying the effect of fibre length and concentration of Er^{+3} ions.

II. System Model And Assumption

In this paper, the investigation of a high power fibre amplifier has been done. A cascade structure has been employed to get the higher total output power. It comprises of an Erbium-Doped Fibre Amplifier (EDFA) black box as a preamplifier and an erbium/ytterbium co-doped double cladding fibre amplifier (EYCDFA) as a post amplifier. The purpose of using EDFA black box as a preamplifier is that it cuts out the complexities involved in the tailoring the parameters of physical EDFA model [5]. A high output power of 19.4W has been obtained with a good noise figure. The optimum length of 8m-10m has been obtained for the system. The result is validated by analyzing the system at various pump powers.

The EYDFA as the main amplifier with special double cladding configuration has been used which can couple more pump power into the system. The system is given in fig. 1. It is observed that there is an optimal length of the waveguide amplifier (EYCDFA) under a certain pump power and signal power at which the system is able to give an enhanced performance in terms of output power, gain and noise figure. Those suitable parameters of optimum performance have been obtained after analyzing the system performance at large number of possible combinations of parameters. The observations have also been made by varying the concentration of the erbium ions in the coped fibre amplifier. When compared with conventional EDFAs, EYCDFAs can offer significantly higher output powers at a substantially lower cost because the Yb^{3+} ions absorb most of the pump power and cross correlation between adjacent Yb^{3+} and Er^{3+} ions ensures the energy transfer [6]. It has also been inferred that EYCDFA is able to give a naturally flattened gain within 1550-1570nm. The result obtained can be used as an idea to develop a multichannel hybrid amplifier. The work is simulated in the simulation software OptSim 5.2.

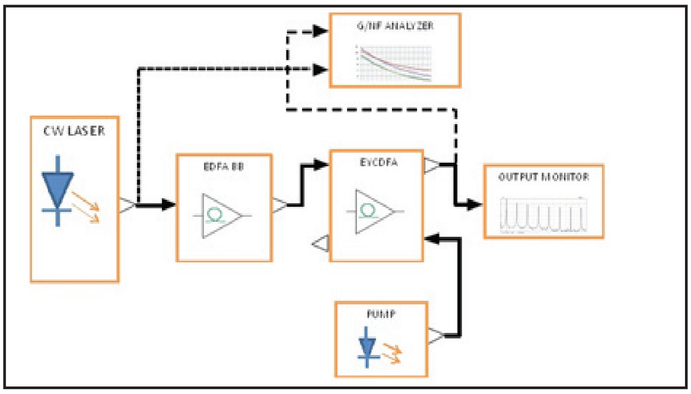

Fig. 1: Schematic of the Hybrid Amplifier Configuration

With an aim to investigate 1550-1570nm high power fibre amplifier with different lengths of gain fibre a two stage hybrid fibre structure was employed. To begin with the optical signal from CW laser at 1550nm having a power of 10mW is given to the input of EDFA black box, which gives a predefined gain of 23db to the optical signal. The saturation power level for EDFA black box is fixed as 50db. The amplified signal is then fed to the Erbium/Ytterbium co doped Fibre Amplifier (EYCDFA). The pumping technique used to pump EYCDFA is counter propagating pumping. This pumping can be used to avoid signal loss at the multiplexer.[7] The pump power of 50W is used at 975nm.The amplified signal from the output of the co-doped fibre amplifier is given to the first input node of the gain/ Noise Figure (NF) analyser. It is also given to the input of the output monitor.

The output from the CW laser is given to the second node of the gain/NF analyser. The parameter settings of the EYDFA are of utter importance in our analysis. The output power of the EDFA is largely dependent on the power of the pumping light source. EYCDFA core diameter, however, ordinarily ranges from a few micrometers to 10 μm at the most, and this restricted cross-section places an inherent limitation on the pumping power that can be coupled. To relax this limitation a double-clad amplifier EYDCFA has been used, in which the signal light propagates in single mode in the core and the pumping light propagates in the first cladding around the core in multimode [8]. The cladding pumped EYCDFA is used to couple more power into the fibre. Since the configuration of the EYCDFA used is double cladding configuration, this makes it possible to use a high pump power [9].

III. Result and Discussion

A. Effect of Fiber Length on Gain and NF of the System

An output power of 19.4W has been obtained with a maximum gain of 34.5db and minimum noise figure of 4.25 db at 50W pump power. The use of double cladding configuration allows the use of multimode laser diodes with high powers as the pumping source. The attainment of high output power signifies a higher pump conversion efficiency. The schematic given in fig. 1 is also being analyzed at various fibre lengths ranging from 1 to 20m at five values of pump powers. The purpose of analyzing the system at various fibre lengths is to obtain the optimal length of operation and an effort to reduce the length of the fibre waveguide taking the issue of fibre latency into consideration.

It can be seen in fig. 2 that the output power of the hybrid amplifier configuration used increases with increase in the fibre length up to the length of 10 m which is 19.4W. After the length of the 10m the system output begins to fall because of insufficient pump power. Also there is an increase in the noise figure of the system after the length of 10m (Fig. 3). There is a lesser variation in the noise figure below the length of 10m i.e., 0.9db. The gain curve obtained in fig. 4 is similar to the output power curve. The gain also decreases after the length of 10m. While looking at the curves in fig. 4(a) very interesting observation can be made that within the fibre length of 8m to 10m, the system provides the highest amount of gain. Also this range gives the range of fibre length for which the system attains a saturation level. Taking the validation of the optimum length of operation to be 8m to 10m into consideration the schematic given in fig. 1 is set up for various pump powers. Also it analyses the behaviour of the hybrid amplifier configuration at different pump powers.

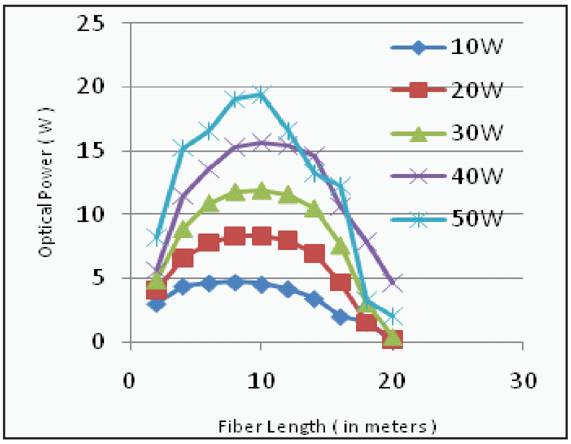

Fig. 2: Variation in Optical Power With Fibre Length

The pump power is being varied from 10W to 50W while varying the length of the EYCDFA from 1 to 20m. The optical power curve obtained for 40W pump power is in agreement with the optical curve obtained for 50W pump power despite the fact the highest amount of output power obtained has reduced to 15.61W as compared to 19.4W with 50W pump power. Similar observations can be made with 30W, 20W and 10W pump powers, that 8-10m of fibre length, is the optimum length of operation with pump powers varying from 10-50W. The curves obtained above (Fig. 2, Fig. 3 and Fig. 4) shows that with 10W pump power, 10mW signal power, 1550nm as the source wavelength, the output power obtained is 4.73W with an optimum length of operation of fibre amplifier as 8-10m [10]. The concentration of the erbium and ytterbium ions is taken in the ratio of 1:3.

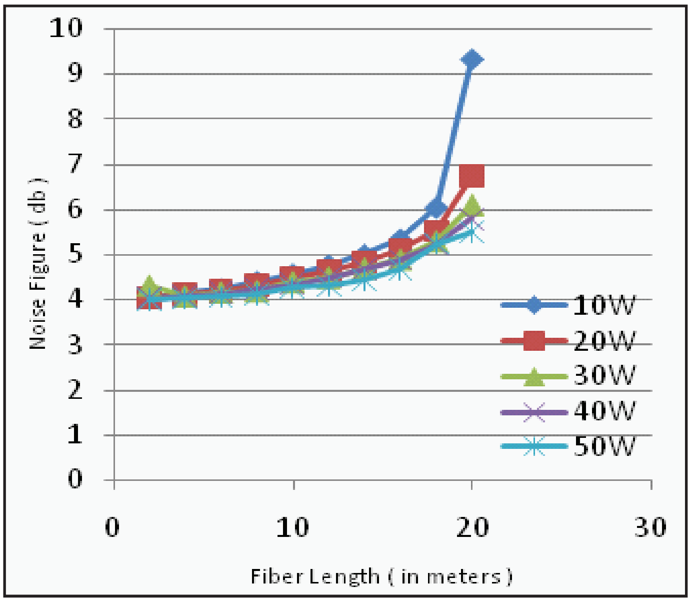

Fig. 3: Variation of Noise Figure with Fibre Length

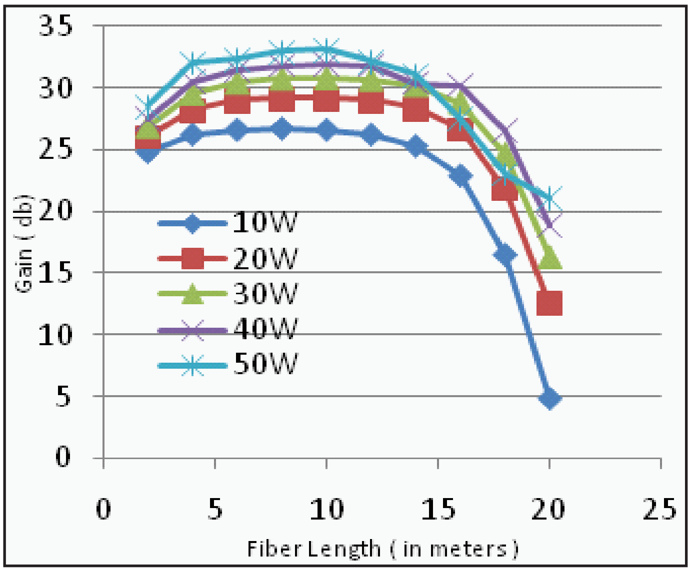

Fig. 4. Variation in gain with Fibre Length

Visualizing the variation in the optical power with EYCDFA length in fig. 2 it can be concluded that under a fixed input power i.e 10mW and a fixed pump power, there is an optimum length of operation which is 8m to 10m in this case. We can see that the output power saturated when the fibre length is about 8m to 10m and would not be increased anymore while lengthening the gain fibre because of insufficient pump power and the signal power loss in the process of transmission. The output power would degrade beyond the optimal length. In a word we can say that under a certain pump and signal powers the amplifier gain has an optimal length.

B. Effect of Concentration on Gain and NF of the System

The concentration of erbium doped ions in the co-doped fibre is varied and gain and noise figure spectra have been obtained. The pump power is fixed at 50W. The source wavelength used is 1550nm. The length of the fibre is 10m.Amplification in an EYDFA occurs through the mechanism of stimulated emission where the signal from the pump excites Er^{3+} ions to the upper energy state while the information signal stimulates transition of the excited Er^{3+} ions to the lower energy state, resulting radiation of photon with the same energy and wavelength the input signal.
The increase in concentration of the Er ions directly influences up conversion efficiency as it determines the transfer of energy from the ytterbium ion to erbium ions. It can be seen in fig. 5 there is an increase in gain as the concentration of Er^{3+} ions is increased. The concentration of the erbium ions is varied from $1\times10^{19}/m^3$ to $3\times10^{19}/m^3$. A gain of 32.7db is obtained at the concentration of $3\times10^{19}/m^3$. So it can be said using the ratio Er:Yr ions as 1:3 and 50W pump power good results can be obtained. The noise figure also increases with increase in the concentration of the erbium ions. But the variation the noise figure is just 0.4db.So a higher concentration of Er^{+3} ions can give a higher gain with lesser increase in the noise figure (Fig. 6).

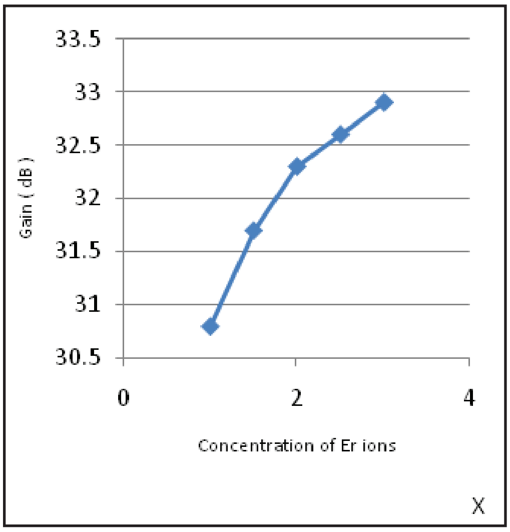

Fig. 5: Gain vs Concentration of Er ions

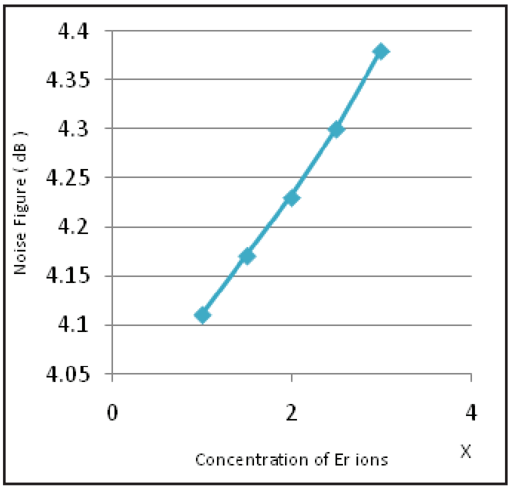

Fig. 6. Noise Figure vs Concentration of Er Ions

IV. Conclusion

So far it can be deduced that there is an increase in optical output power as there is an increase in the fibre length. There are two physical reasons in the variation of the signal power with the fibre length. The first reason is that the signal power increases linearly with the fibre according to linear gain regime. The pump power should be enough to keep the variation in the power in the linear regime. At a fixed pump power and a fixed input signal there is an optimal length in which the output power gets saturated. The optimal length obtained in this case is 8m to 10m. Also beyond this optimal length the output of the system begins to fall. With the use of this configuration a flat gain spectrum can also be obtained by tuning the CW laser to various wavelengths as it can be seen in Fig. 1. Also with increase in the erbium doping density a high gain can be obtained, though there is also an increase in the noise figure of the system but the increase in noise figure i.e 0.4db is far less than increase in the gain of the setup which is upto 3db when the concentration is reached as high as $3\times10^{19}/m^3$.
So as the end approaches one has three things in mind firstly a hybrid amplifier configuration comprising of EDFA/EYCDFA is suitable for the attainment of high gain, secondly using 8-10m of fibre length gives optimum performance, thirdly the EYCDFA is capable of providing a flat gain within 20nm bandwidth and at last ratio of 1:3 for Er:Yr ions is suitable for enhanced performance at 10m fibre length. This entire analysis can lead to the idea of development of a high gain WDM system using a hybrid amplifier and employing the optimized parameters obtained in the above work in the system.

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