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GAIN CHARACTERISTICS OF SHORT-LENGTH ERBIUM DOPED FIBER AMPLIFIERS AT EXTREME TEMPERATURES

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Mustafa Afif Al-Nuwab

DEDICATION

I would like to dedicate this work to my first teacher, my sisters, my first supporter and role model, my father and my companion throughout the journey. Without you, this dream would never come true and to my sisters who stood with me in order to achieve my dream.

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ABSTRACT

GAIN CHARACTERISTICS OF SHORT-LENGTH ERBIUM DOPED FIBER AMPLIFIERS AT EXTREME TEMPERATURES

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A thesis presented on the Erbium-doped fiber amplifiers (EDFA) which is an amplifier for optical signal used in Telecommunication . In this kind of amplifiers, the core of a silica fiber is doped with Er^{3+} ions. In this study, the gain parameter is affected by temperature for different lengths EDFA is studied as a simulation. Temperatures range was (-200 to +80 °C) for different ion density values in order to simulate harsh conditions, such as the presence of liquid nitrogen , cryogenic. From the results it is concluded that at a range close 0°C the highest gain is recorded . In addition to the important role of concentration of Er^{3+} ions in gain values.

Keywords:EDFA,Temperature,Er^{3+}ons,gain.

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LIST OF ABBREVIATIONS

EDFA	Erbium Doped fiber Amplifier.
YDFA	Ytterbium Doped Fiber Amplifier
C-Band	The conventional Band its range is 1530nm to 1565nm.
L-Band	Long Band
DWDM	Dence Wavelength Division Multiplexing.
WDM-PON	Wave Division Multiplexing – Passive Optical Network

LIST OF SYMBOLS

i_k	The normalized optical intensity
N_t	Local erbium ion density
T	The temperature in Kelvin
k	The Boltzmann constant

1. INTRODUCTION

Erbium doped fiber amplifier (EDFA) is necessary nowadays because of the increasing number of needs. These needs are actually because of the attenuation in signal transmission which results from long distances between the receiving and transmitting parts [1]. The difference in length of the fiber of amplifiers does one of the most crucial effects on this process. Some parameters like pumping power or signal for saturated EDFA help to select the best value of the length of the fiber [2]. The effect of temperature on signal gain has the main role for specifying the design of the systems consisting EDFA, therefore it is necessary to do an investigation about the value of temperature used in that configuration in addition to studying the parts of system and the role of every item which can be helpful to arrange the system properly [3].The gain coefficient is shown below, in terms of ion distributions and optical modes: [3],[4] as expressed in formula 1.1 .

$$g_k\lambda_k = \sigma_e\lambda_k \cdot \int_0^{2\pi} \int_0^{\infty} i_k\,(r,\phi) \cdot n_t(r,\varphi,\mathrm{z})\, r dr d\phi \qquad (1.1)$$

The wavelength value of 1480 nm was more influenced by temperature and if it will be the same setup with 980 nm it will be found that 980 has more effects on the strength of the signal in the standard three level system of Giles and with effects of Rayleigh backscattering system as well [5]. optical amplification process are affected by temperature and that is noticable from the behavior of EDFA properties while starting to change the values of temperature [3], [6].

1.1 GAIN STABILIZATION

Gain and power characteristics of EDFAs is a temperature dependent , and it was discussed and shown that temperature dependence of signal emission and absorption cross-sections have crucial impact on the L-band output power [7]. for stabilizing the gain of EDFA it has to be some tools to do so [8] , regardless of the changing of input power. Until now there is no such perfect technique to block the losses completely especially the variation of gain is different if we add a new band or if delete this band from the main signal. The case of variation is more rapid in case of using a cascaded amplifiers since the signal would be accumulated [9] one of the causes of these defects in signal is the population of the third energy level of erbium ions when using the pump signal at 980nm , where the population inversion process is vary according to the percentage of signal applied to these ions and its probable movements which it is based on Boltzmann probability formula [10].

Spectral hole burning (SHB) is one of the parameters that effects the gain of EDFA [11] ions which exposed to a little different in environments experiencing high random deviation on the emitted and absorbed part in the cross section [12] . Power fluctuations is happening as a reason of adding or subtracting channels from the system this is proportionally with the input power spectrum; therefore, it will make changes on gain of EDFA, these fluctuations will be more severe in case of cascade amplifiers [13] .

1.2 CASCADED EDFAs

At shorter wavelengths specifically, the effects of temperature variations are more intensive on the gain of EDFA, In cascaded Erbium Doped Fiber , more fluctuations will be by differences of temperature [14], more variations in gain and noise is happening when using the pump wavelength of 1480nm while using pump wavelength 980nm will produce a signal which is more stable and less affected by temperature or cascaded EDFAs [15] [16].

1.3 NECESSITY OF EDFA

1.3.1 Heat Influence On Multi-Channel EDFA

The important role of Erbium Doped Fiber as amplifier made it a necessity nowadays to know high capacity long- haul wavelength division multiplexing (WDM) at a time when the transmission band of the signal is very fast to be consumed , the last developments tend to use long wavelength amplifier [17] , Flatted and wide gain window can be supported by more than 80’s nm when mixing it with conventional EDFA . Thermal environment on multichannel gain of EDFA has not been researched intensively regardless of how well-designed and gain flattened the optical amplification is , especially in case of EDFA . Although there is some few investigation about this issue . it still limited for single mode fiber [18] [19] . the accumulated effects of cascade method which it will be more problematic when it comes to losses in signal , and these researches are missing this cascaded effects made it a hidden problem , another reason for the lack of these researches is due to the needs of temperature variations in environment during experiments.

1.3.2 EDFA Temperature Dependence

The effect of pump laser wavelength change on the temperature dependence of EDFA was studied and the important result was the temperature dependent gain variation of EDFA is lower for 980 nm pump wavelength [20]. Other reports include the study of the variation of the gain flattening of EDFA [21], theoretical approach to the propagation equation for EDFAs pumped at 1480 nm [22] and the numerical approach to the temperature impact [23]. The lower temperature limit of these studies are not less than -20 ^{o}C except the latest which covers −40 ^{o}C, where the highest temperature was 80 ^{o}C.Therefore, to the best of our knowledge, there are no research, which covers a broad temperature range with different ion concentrations, such as starting from severly cold temperatures such as -200 ^{o}C. These very low temperatures describe the cryogenic systems, which might have many applications in medicine, energy, chemistry, experimental applied physics as well as quantum computing and cryogenic computing [24], [25].

Cryogenic fiber studies include cryogenic fiber optic assemblies for spaceflight environments [26], investigation of five different fiber optic sensors at cryogenic temperatures [27] and validation of a novel fiber optic strain gauge in a cryogenic condition [28]. Therefore, the simulation and characterization of EDFA over a wide temperature range is of interest and can be beneficial for technological uses.The aim is to find the optimum gain using temperature effects with fiber length, where the considered spectral range is C-band. It was reached through practical study of the influence of temperature on the EDFA fiber, pumped by means of the LD working at 980 nm for the WDM-PON system. [29], [30].

1.3.3 Temperature Effects on YDFA AND EDFA

The study of simulation properties of the EDFA and YDFA identified the achievement of the output power for different temperatures from positive to negative values. It was discovered that both the types of amplifiers increase the power in the spectrum with the increasing power from the pump source at the maximum level of the amplification zone. Along with the increasing temperature, the EDFA decreased its power and the YDFA output spectrum was independent on the temperature. [31].The EDFA temperature dependence of the EDFA amplifier can be a relatively fundamental problem in telecommunications, as the gain of the amplifier changes based on temeprature change. If the amplifier is deployed in the DWDM operation when a few dozens of channels amplify at the same time, it is very inconvenient that the gain changes on individual channels. Therefore, it is necessery that the whole amplification system is actively cooled and kept at a constant temperature [32-34].

As it was already mentioned, the Erbium has its energy levels subdivided into vibrational levels. The difference in occupancy of these levels is the reason for the thermal instability of the Erbium-doped fibers. The occupancy of these levels in the thermodynamic equilibirum is based on the Boltzmann’s law. [33].As it was already mentioned, the Erbium has its energy levels subdivided into vibrational levels. The difference in occupancy of these levels is the reason for the thermal instability of the Erbium-doped fibers.

2. METHODS

The used Numerical aperture in that configuration was 0.3 . The schematic explanation of the setup in the simulations is shown in Figure 1 below.

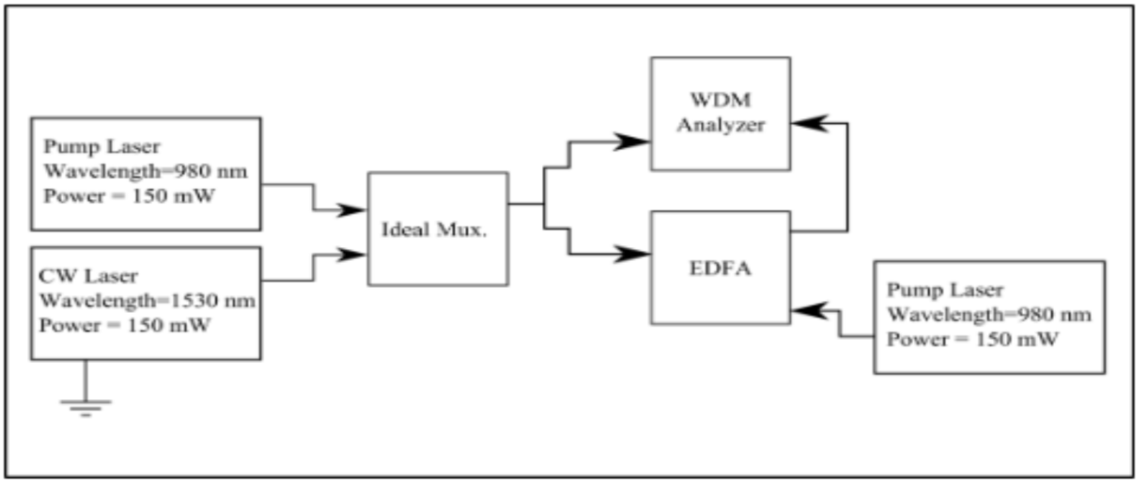

Figure 2.1: EDFA setup in simulation studies.

2.1 OPTIWAVE TOOL

(OptiSystem5.0, evaluated version) was used for the simulation layout of the optical communication system. Length was started from 1 meter and it was raised by 2 meter gradually, temperature value is started from -200 °C and ascended up to +80 °C, the wavelength was 980 nm with pump power of 150mW, 3 different concentration of ion density ($1 \cdot 10^{25}$, $7.5 \cdot 10^{24}$ and $5 \cdot 10^{24}$ m^{-3}) were used.

2.2 GAIN VALUES

2.2.1 Measurements

The highest gain value was 42.95 dB and it was at +80 °C degree and length of 3 meters in the fiber.In order to realize which length is the best with nominated temperature it is very crucial to get the optimized gain for amplification process. As it is expressed in Table 2.1.

Table 2.1: Gain values for different length.

Temperature (°C)	Length of the fiber (m)					
	1	*3*	*5*	*7*	*9*	11
-200	6.36	18.92	30.75	38.52	40.95	41.19
-180	6.98	20.78	33.34	39.94	41.42	41.33
-160	7.67	22.81	35.74	40.95	41.72	41.35
-140	8.43	25.03	37.88	41.63	41.78	41.23
-120	9.25	27.36	39.58	42.08	41.84	40.97
-100	10.16	29.86	40.81	42.24	41.60	40.59
-80	11.15	32.41	41.68	42.31	41.40	40.08
-60	12.25	34.87	42.24	42.21	41.98	39.19
-40	13.44	37.16	42.58	42.03	40.42	38.03
-20	14.77	39.00	42.72	41.67	39.52	36.23
0	16.12	40.44	42.71	41.16	38.33	33.47
20	17.73	41.49	42.59	40.46	36.44	29.67
40	19.43	42.22	42.30	39.41	33.67	24.45
60	21.25	42.73	41.87	37.85	29.80	17.78
80	23.36	42.95	41.24	35.61	42.39	9.88

While it was increasing for the 9 m and 11 m, therefore, the optimum length value to choose is 5 m when it is necessary to have more stability in gain and signal, because the gain and signal will be less affected by the environmental thermal changing [3].

3. RESULTS AND DISCUSSION

In Fig. 3.1, Fig. 3.2 , and Fig.3.3 shows that up to 7 m of fiber length, gain has ascended with the temperature up to 80 °C. After 7 m the case is flipped and gain decreases with decreasing temperature down to -80 °C degree is the central point for 7 m fiber length, where the gain starts to decrease.

3.1 RESULTS

As for the results, the effects of temperature for 5 m length fibers is the smallest among the considered variants. Figure 3.1 explains the gain profile of EDFA with an ion density $5 \cdot 10^{24}$ m^{-3}. Shorter lengths (1 to 5 m) show a continuous linear ascend for the whole temperature period; however, the longer fibers gain becomes almost fixed around 43 dB, especially after -50 °C. For formulations with $7.5 \cdot 10^{24}$ m^{-3} ion density, as it is shown in figure 3.1 .

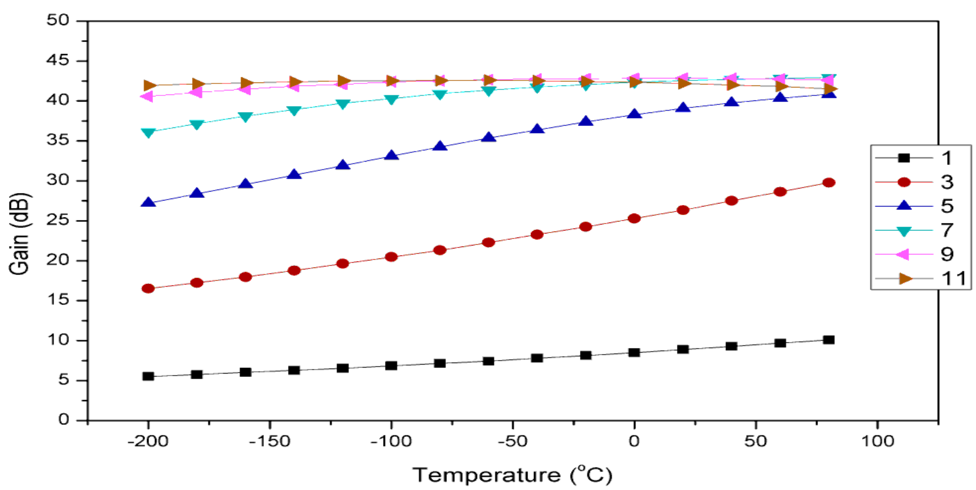

Figure 3.1: Effect of temperature on gain for different fiber length values, ion density: $5 \cdot 10^{24}$ m^{-3}

A similar ascend profiles were observed for the shorter lengths, however, after 0 °C the gain values have begun to descend for fibers longer than 7 m as it is expressed in Figure 3.2 . Most typical behavior for all formulations is that gain still constant for insignificant temperatures (<100 °C), around 43 dB. Additionally to gain profiles, That is noticeable by rising up the ion density, the length necessity for EDFA with the most stable gain decreases (11, 7 and 5 m) Respectively according to each dopant concentration in each of the three figures .

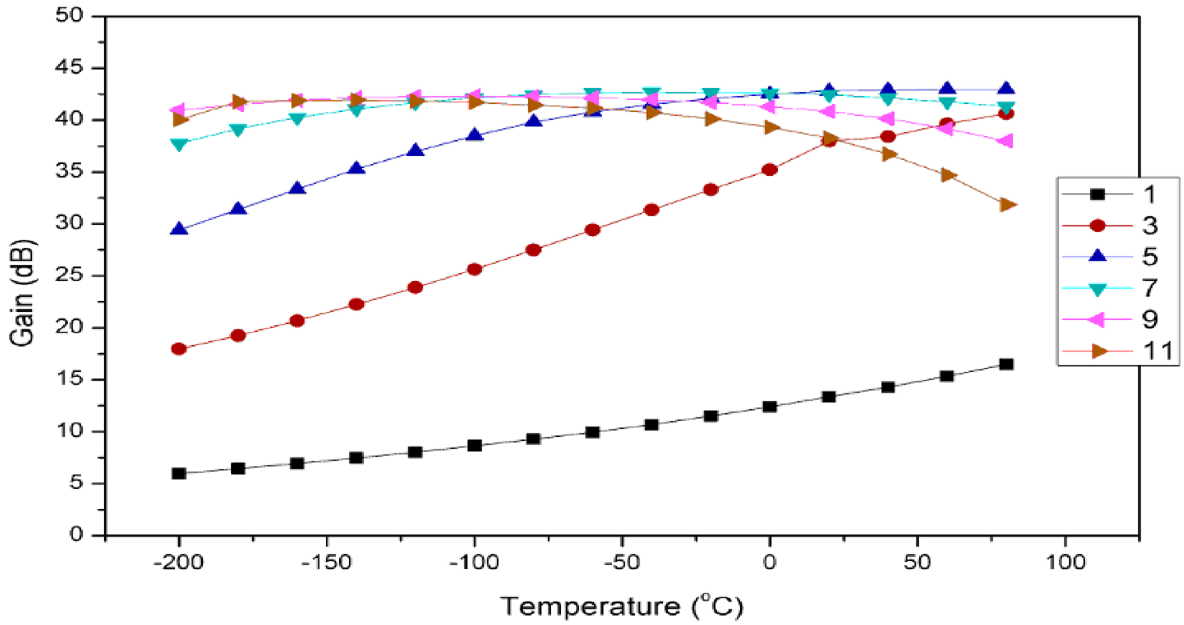

Figure 3.2: Effect of temperature on gain for different fiber length values, ion density: $7.5 \cdot 10^{24}$

The reversed trend of fluctations is obviously noticeable for the fibers with $1 \cdot 10^{25}$ m^{-3} (Figure 3.3), as the length becomes 11 m, the gain greatly decreased to ~10 dB with increasing temperature. This decrease can be clarified by the high signal power boost will be resulting in decreasing in the gain, additional arbitrary value of the erbium doped fiber cannot be kept in this case .

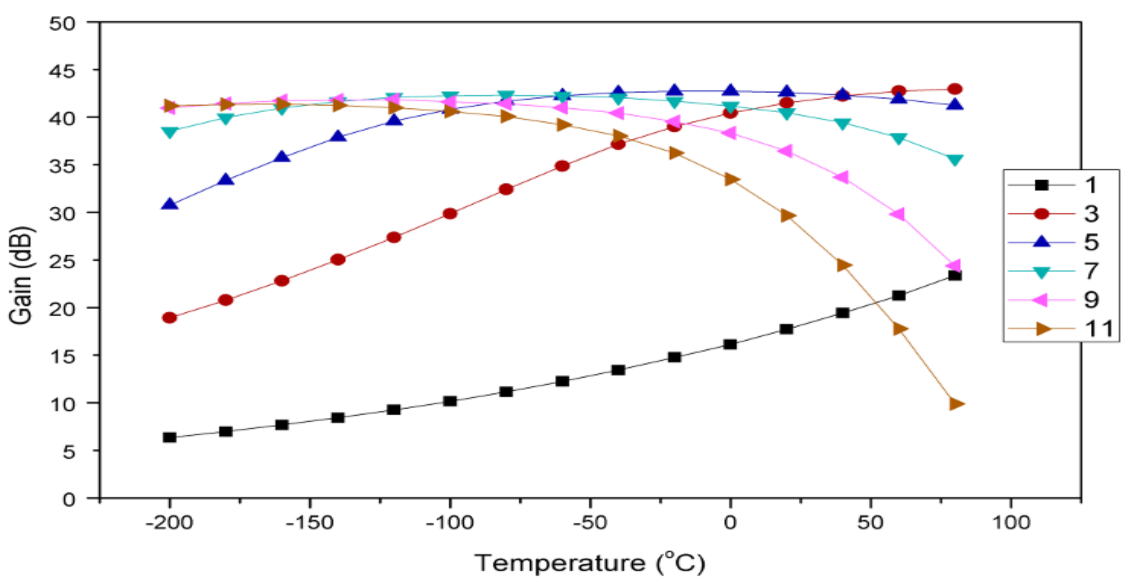

Figure 3.3: Effect of temperature on gain for different fiber length values, ion density: $1 \cdot 10^{25}$ m^{-3}

3.2 CONCLUSION

In this research , the temperature influence on short-length EDFA was simulated. Results show that for short-length EDFA of 11, 7 and 5 m had the most stable gain among the other changes for $5 \cdot 10^{24}$, $7.5 \cdot 10^{24}$ and $1 \cdot 10^{25}$ m^{-3} ion density values, respectively

3.3 FUTURE STUDIES AND RECOMMENDATIONS

In the following studies, the gain of short-length EDFA can be practically analyzed for the use of harsh-temperature conditions. This information could be very interesting for datacenters and another research centers, where are using long-haul networks for connections between servers or some special centers.

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