Design and Optimization of S+C Band Fiber Amplifier

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Abstract. At present, with the continuous improvement of the information transmission rate required by society, the low-bandwidth amplification characteristics of ordinary fiber amplifiers can not meet the needs of people for quality of communication. Therefore, more and more people focus on the research of ultra-wideband fiber amplifier. There are many methods that can perform UWB(Ultra-wide Bandwidth) amplification, such as multi-ion doped fiber amplifiers and parallel fiber amplifiers. In this paper, the model based on parallel fiber amplifier will be established and discussed. According to the wavelength range, energy level structure and electron transport, the velocity and energy transfer equations are established. When the total pump power is 500mW, the gain spectrum is calculated by MATLAB programming, and the doping concentration of the two sections of fiber is optimized by genetic algorithm, so that the peak difference between the two sections of fiber amplifier is minimized, and the design optimization of the parallel fiber amplifier is completed.

Keywords: S-band fiber amplifier, C-band fiber amplifier, Parallel fiber amplifier.

1. Introduction

Since optical fiber communication was proposed by Dr. Charles Kao in 1966, people have found a very crucial link in the field of information. With the continuous improvement of optical fiber communication system, it has played a revolutionary role in the field of information transmission, and plays an important role in the next rapid development of the Internet era. At present, the optical fiber communication system mainly consists of transmitter, fiber, fiber amplifier and receiver. Among them, fiber amplifier is a device used to enhance the strength of optical signals in the fields of optical communication and lasers. The optical fiber amplifier uses the characteristics of light, so that the optical signal is directly amplified without photoelectric conversion, so as to avoid the noise and loss caused by the electro-optoelectric conversion process of the signal, and improve the performance and efficiency of the optical fiber communication system. Starting from the research of pumping Erbium-doped fiber amplifier using Ar ion laser as erbium-doped fiber amplifier,, the appearance of Raman Amplifier, and the research on the properties of EDFA, the optimization of all kinds of parameters, the C Band Erbium Doped Fibre Amplifier is mature [1-5].Similarly, from the appearance of thulium-doped fluorinated fiber amplifiers and 1.47nm lasers in the 1990s, it is easy to see that the parameters of erbium-doped fibers with different substrates were measured and the wavelength division multiplexing technology was maturely applied, and the application scenarios of S-band thulium-doped fiber amplifiers were also continuously developed [6-9]. However, with the increase of people's communication usage, the traditional optical fiber has gradually fallen into the development bottleneck, but the breakthrough in the research of parallel fiber amplifier has made people have a new idea to solve this problem [10-11]. The fiber amplifier based on parallel structure can bring wide and flat gain, effectively expand the channel capacity of the fiber, increase the efficiency of information transmission, and the needs of social development can be met. Therefore, this paper selected the parallel fiber amplifier based on the research object.

2. Working principle

2.1. Er^{3+} doped fiber amplifier

When the fiber amplifier doped with Er ions is excited by 980nm pump light, many electrons in the ground state (E1) will be transformed into an excited state (E3). Because the excited state (E3) is unstable, the electrons will transition to metastable state (E2) without radiation. The electron is in metastable state (E2) to ground state (E1) due to the stimulated radiation., and at the same time emit signal light of 1560nm frequency, so that the signal light is amplified (Fig. 1), so EDFA is generally a three-level system.

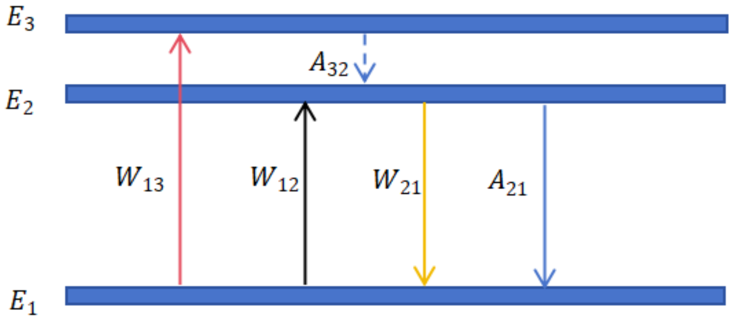

Figure 1. Schematic diagram of three-level system of erbium ion (original)

Rate equation of Er^{3+} three-level system:

$$\frac{\partial N_1}{\partial t} = -(W_{12} + W_{13}) \times N_1 + A_{21} \times N_2 + W_{21} \times N_2 \tag{1}$$

$$\frac{\partial N_2}{\partial t} = W_{12} \times N_1 - W_{21} \times N_2 - A_{21} \times N_2 + A_{32} \times N_3 \tag{2}$$

$$\frac{\partial N_3}{\partial t} = W_{13} \times N_1 - A_{32} \times N_3 \tag{3}$$

$$N = N_1 + N_2 + N_3 \tag{4}$$

$$W_{13} = \frac{\sigma_{13} P_P(z)}{h\upsilon_{13} A_{eff}} \quad W_{12} = \frac{\sigma_{12}(\upsilon) P_S(z)}{h\upsilon_{12} A_{eff}} \quad W_{21} = \frac{\sigma_{21}(\upsilon) P_S(z)}{h\upsilon_{21} A_{eff}} \tag{5}$$

W_{13} is the pump light absorption rate, W_{12} is the signal light absorption rate, W_{21} is the signal light stimulated emission rate, A_{32} is the radiation transition rate, A_{21} is the radiation transition probability, λ_p is the pump wavelength, A_{eff} is the core number value aperture, c is speed of light, h is Planck's constant, k is Boltzmann's constant, T is the ambient temperature.

$$\frac{dP_P(z)}{dz} = \Gamma_P(-\sigma_{12} N_1 - \alpha_a) P_P(z) \tag{6}$$

$$\frac{dP_S(z)}{dz} = \Gamma_S[\sigma_{21} N_2 - \sigma_{12} N_1 - \alpha_S] P_S(z) \tag{7}$$

$$\frac{dP_{ase}(z)}{dz} = \Gamma_{ase}[\sigma_{21} N_2 - \sigma_{12} N_1 - \alpha_S] P_S(z) + 2\sigma_{21} N_2 h\upsilon \Delta\upsilon \tag{8}$$

Γ Is the overlap integral factor, α and $\Delta\upsilon$ are the loss coefficient of the fiber material and the half-height full width of the frequency, respectively, and are the normalized frequency of the fiber.

$$\mathrm{G}(P_P(z), P_S(z), P_{ase}(z), N2, N1, z) = 10 * \ln(\frac{P_S(z)}{P_S(0)}) \tag{9}$$

Formula (9) is the gain calculation method.

Some parameters in the calculation formula are as follows:

Table 1. Partial parameters of Er^{3+} fiber

Parameter names	Unit	Value
Core radius	μm	2.5
λ_p	nm	980
λ_s	nm	1530
$\sigma_{12}(v)$	m^2	1.0×10^{-24}
$\sigma_{21}(v)$	m^2	0.8×10^{-24}
$\sigma_{13}(v)$	m^2	2.0×10^{-24}
A_{eff}	μm^2	10
A_{21}	/s	10^3
A_{32}	/s	10^6
α_p	/m	0.1
α_s	/m	0.1
c	m/s	3×10^8
h	J·s	6.626×10^{-34}
T	K	300
k	J/K	1.38×10^{-23}

After calculation, the gain values of erbium-doped fiber at different doping concentrations and fiber lengths are shown in Fig. 2.

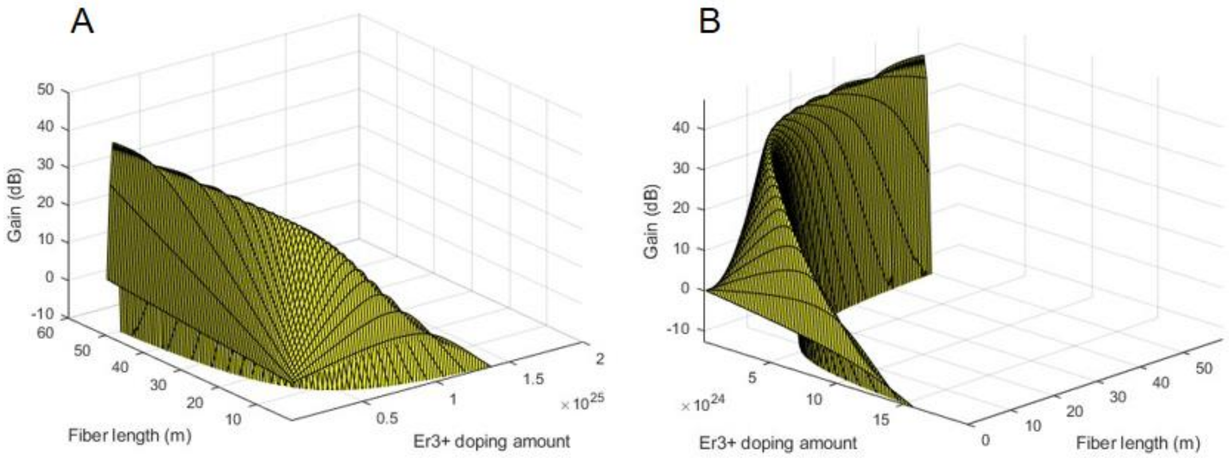

Figure 2. Different angle of the Erbium-doped gain 3D plot (original)

As can be seen from the figure, in the region with gain greater than 30dB, the length of erbium-doped fiber has little effect on the gain value, while the total amount of erbium ion doping increases gradually until it reaches a peak value at about 30dB, and then decreases gradually with the increase of erbium ion doping concentration.

2.2. Tm^{3+}doped fiber amplifier

While the Tm^{3+}doped fibre amplifier is excited by 793nm pump, the electrons are transferred from the ground to the high energy (E4), and then to the high energy (E3) of the laser, and the electrons are stimulated from the upper laser level (E3) to the lower laser level (E2), and they emit the S band. Lastly, there is no radiation transfer from the bottom of the laser (E2) to the ground (E1). The TDFA is thus a four-level system (Figure 3). It was found that the Ge tellurate glass with 20 ~ 30 mol% GeO2 had excellent heat and Vickers hardness, and the quantum efficiency was nearly 100%. For this reason, we will discuss the application of Ge Ti-Te Glass [12-13].

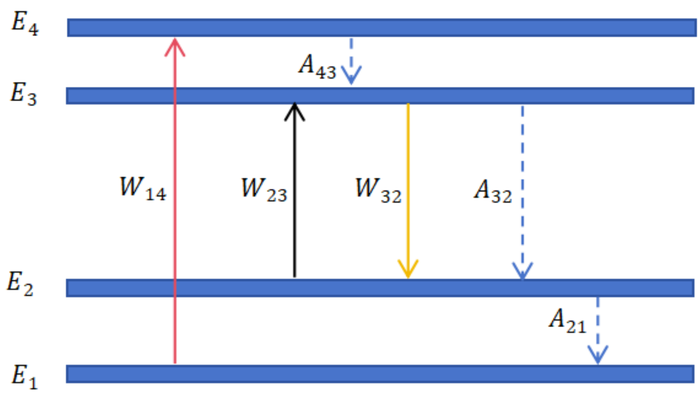

Figure 3. Schematic diagram of four-level system of thulium ion (original)

Rate equation and power propagation equation of Tm^{3+}:

$$\frac{\partial N_1}{\partial t} = -W_{14} \times N_1 + A_{21} \times N_2 \tag{10}$$

$$\frac{\partial N_2}{\partial t} = W_{32} \times N_3 + A_{32} \times N_3 - W_{23} \times N_2 - A_{21} \times N_2 \tag{11}$$

$$\frac{\partial N_3}{\partial t} = W_{23} \times N_2 + A_{43} \times N_4 - A_{32} \times N_3 - \mathrm{W}_{32} \times N_3 \tag{12}$$

$$\frac{\partial N_4}{\partial t} = W_{14} \times N_1 - A_{43} \times N_4 \tag{13}$$

$$N = N_1 + N_2 + N_3 + N_4 \tag{14}$$

$$\frac{dP_P(z)}{dz} = \Gamma_P(-\sigma_{14}N_1 - \alpha_a)P_P(z) \tag{15}$$

$$\frac{dP_S(z)}{dz} = \Gamma_S[\sigma_{32}N_3 - \sigma_{23}N_2 - \alpha_S]P_S(z) \tag{16}$$

$$\frac{dP_{ase}(z)}{dz} = \Gamma_{ase}[\sigma_{32}N_3 - \sigma_{23}N_2 - \alpha_S]P_S(z) + 2\sigma_{32}N_3 h\upsilon\Delta\upsilon \tag{17}$$

However, studies have shown that the high energy level (E4) of TDFA has a very short life span and can be ignored [14], so the rate equation and power propagation equation of the same three-level as that of erbium ion can be used for calculation. Fig.4 shows the gain value of thulium-doped fiber obtained after MATLAB calculation at different doping concentrations and fiber lengths.

Some parameters in the calculation formula are as follows:

Table 2. Partial parameters of Tm^{3+} fiber

Parameter names	Unit	Value
Core radius	μm	3.0
λ_p	nm	793
$\sigma_{12}(\upsilon)$	m^2	2.5×10^{-25}
$\sigma_{21}(\upsilon)$	m^2	0.4×10^{-25}
$\sigma_{13}(\upsilon)$	m^2	2×10^{-25}
A_{eff}	$μm^2$	8.55
A_{21}	/s	10^4
A_{32}	/s	2857
α_p	/m	6.5×10^{-3}
α_s	/m	4.2×10^{-3}

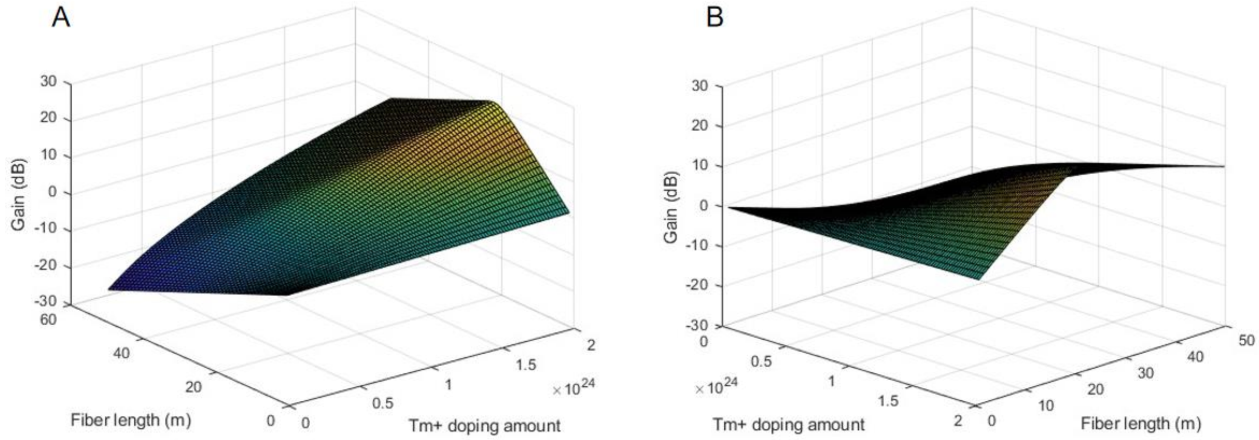

Figure 4. Different angle of the Thulium-doped gain 3D plot (original)

It can be observed from the figure that the gain is positively correlated with the number of thulium ion doping. At the same time, the gain value gradually increases with the increase of the length of thulium doped fiber, and the gain reaches its maximum at about 22m, which is 21.8dB. After that, the gain will continuously decrease as the fiber length increases.

3. Funding

In this paper, the dual-channel parallel hybrid fiber technology is adopted as the basis. Under the condition of the total power of 500mW, the number of dopants, the length of the fiber, the number of dopants and the length of the fiber were set as variables. After calculating these five variables in the genetic algorithm in MATLAB, it is found that: Under the parameters set in this paper, when the length of doped fiber is 6.1357m, the doping concentration of erbium ion is 2.3811×10^{24}, the length of doped fiber is 7.1748m, the doping concentration of thulium ion is 1.89498×10^{24}, and the EDF pump power is 0.1448W, the gain is 17.5654dB and the TDF gain is 18.0733dB. In this way, the gain of the two parts amplifiers in parallel is large, and the peak gain difference between the two parts is kept in a small value

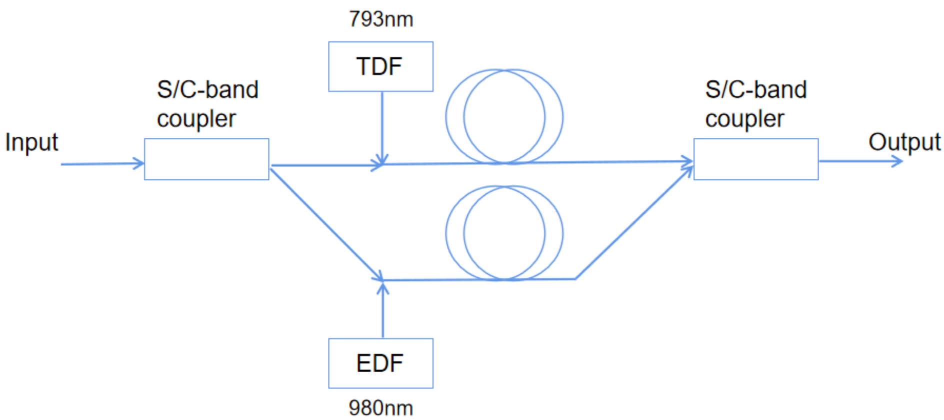

Figure 5. Schematic diagram of the parallel structure (original)

4. Conclusion

In this paper, based on the three-level rate equation and power propagation equation, an optimal calculation method of gain control in S-band and C-band dual-channel parallel hybrid fiber is proposed. Ignoring the non-radiative transition of ion high energy level, the parallel form of EDF and TDF is discussed in detail. According to MATLAB, the rate equation of ion and ion is solved with symbols, and the corresponding data of EDF and TDF are input into it. Then the required length of fiber, ion doping concentration and pump power range are written. Thus, the parameter information that minimizes the gain difference of the two wave peaks is quickly obtained with the help of genetic algorithm. It is proved that this method can be used to obtain the parameters such as the fibre length, the amount of dopant and the pump power which can meet the need of higher gain.

Taking it as a theoretical basis, it will help us to better solve the problems faced by the current fiber amplifier, such as narrow bandwidth, low gain, and serious fiber loss. At present, there are also international research on rubidium doped, niobium doped and other ion doped fiber amplifiers, but there is still some distance from the practical. In addition to parallel fiber amplifiers in different bands, EDFA is also gradually developing to C-band and B-band. However, the locally flat EDFA in series with the Raman amplifier can also obtain a flat gain amplifier for UWB. It can be said that the prospect of fiber amplifier is still very broad, and people need to continue to develop.

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