Design of erbium-doped fiber laser in the 1550-1600 nm band

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Abstract. With the rapid development of the information industry, science and technology's demand for computer algorithms, demand for industrial production accuracy and demand for factors such as information transmission speed are increasing. Simple optical instruments can no longer meet the requirements. At this time, fiber lasers have emerged. born. Therefore, the research direction of this article follows the trend of the times and explores the design and physical simulation of erbium-doped fiber lasers. The research method of this article is as follows. Through physical simulation of the working process of the fiber laser combined with data calculation, the corresponding equations such as the fiber laser energy level transition rate equation, the power propagation equation, the pump power threshold equation, and the fiber laser output power equation are simultaneously evaluated, after completing the formula and its data, use drawing programming software to program and input the equation program, define the relevant variables, and run to find the relationship between pump power and laser power, and obtain the power change trend of pump power and signal light power as the fiber position length changes. with specific data. Finally, it can be obtained that the pump light power has a positive correlation with the laser power outside the pump threshold, and the pump light can be maximized when the fiber length is around 7m. As a result of this research, the theoretical data of erbium-doped fiber lasers have been improved and can be used in future fiber laser applications.

Keywords: Erbium ions, fiber laser, 1550-1600 band

1. Introduction

With the rapid development of electronic technology, the performance requirements of electronic displays are increasing, and the demand for visible wavelength lasers has surged. In the past few decades, scientific researchers have actively researched and developed laser displays, among which fiber lasers have become the first choice for laser displays [1]. Fiber laser is a type of solid laser based on optical fiber as its working medium. The fiber material is basically glass fiber doped with rare earth elements. Fiber lasers have relatively low costs based on other types of lasers. They have strong anti-electromagnetic interference capabilities, are lightweight and easy to quantify, and can play a huge role in transmitting information, cross-distance communication, and mechanical processing [2] [3]. At present, the research ideas on fiber lasers have been relatively complete and are used in various aspects of life, medical treatment, military industry, aerospace and aviation, etc. Cheng Tonglei and his research team used high-power fiber lasers for data demonstration, detected infrared radiation temperature and studied frequency shifts in optical fibers [4]. Maria and others used fiber laser cutting technology to improve low-precision defects in medical devices and achieve microscopic Scale medical operation [5], Kasman team used fiber laser to laser engrave the surface of titanium six aluminum four vanadium high entropy alloy, analyzed the parameter relationship between its roughness and signal-to-noise ratio, and studied the optimal process response [6], Dona Dro, Sirifanti and others applied fiber lasers to remote earthquake monitoring through remote observation of microscopic length changes of telecommunications cables, and analyzed the relationship between magnitude and fiber changes [7]. Andy used high-power lasers to study high-energy laser weapons against unmanned aerial vehicles. The impact of aircraft on war [8]. Etc. With the improvement and development of femtosecond laser writing technology, various types of transparent optical materials can be processed and utilized, and its erbium-doped ion fiber laser has also been developed [9]. The Erbium-doped fiber laser two-level system mainly corresponds to the output wavelength window of 1550 nanometers and has corresponding optimal output power and high-quality spectrum [10].

Erbium ions have the advantage of being tunable at multiple wavelengths, including but not limited to the range of 1550 nanometers and 980 nanometers, and can cover different wavelengths by changing the number of energy levels. At present, the research gaps in erbium ion fiber lasers are gradually being filled, and debugging the optimal wavelength is the most researched project.

The research goal of this article is to first learn the basic principles of fiber lasers, further understand the working mode of erbium-doped fiber lasers, and obtain the condition data required for the operation of erbium-doped fiber lasers in the 1550-1600 wavelength range by consulting the literature. This project is a physical simulation experiment, and the data obtained will be referenced in the subsequent programming code. The code part mainly reflects the relationship between pump power, signal light power, output power and the image obtained from the data. According to the principle of erbium-doped fiber laser Improve the code program, substitute the input parts of pump power and signal light power into the physical simulation program to obtain the output power of the erbium-doped fiber laser at a specific wavelength of 1575, then obtain the mathematical relationship between pump power and output power. Relationship to provide guarantee for subsequent detailed research.

2. Method

The working wavelength of the erbium-doped ion fiber laser can take multiple wavelength ranges depending on the number of working energy levels. Here, the intermediate wavelength value 1575 between 1550 and 1600 is selected as the standard. As shown in the energy level diagram in Fig 1, the pump at this fiber wavelength the wavelength of the pumped light should be 980. Under the light input condition of this wavelength, the energy enters the left grating and excites the electrons in the first energy level to the third energy level. However, since the electrons in the third energy level are not stable, they will be adjusted to the second energy level very quickly. The electrons in the second energy level will absorb and stimulate the emission of signal light between the first energy level. During this process, the electrons spontaneously emit transitions, stimulate the emission transitions, and release photon energy to the right grating. At this time, the incident signal The light and excitation photons are combined into coherent light and propagated together to the right grating.

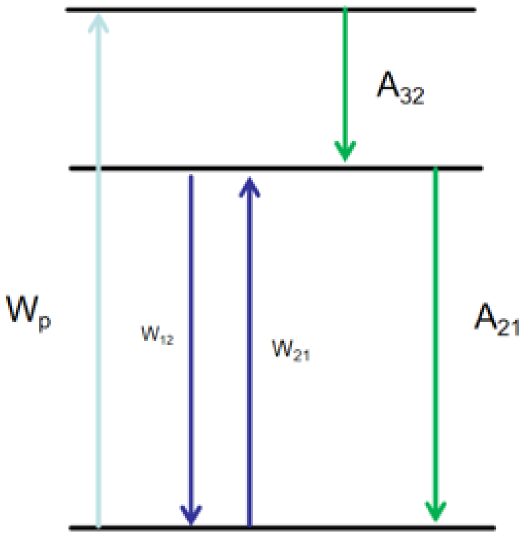

Fig 1. Three level system (Picture credit: Original).

The transmittance of the grating on the right side is higher than that of the grating on the left side. According to its transmittance, a small number of photons are released from the right side. However, most photons will still be reflected back to the grating on the right. The pump light is Pp (z) in the Fig. It is incident from the pump. The pump light and the excited laser light are reflected multiple times between the two gratings, accumulating. The photon energy eventually reaches a certain threshold and the laser is output from the left grating with relatively low transmittance.

Table 1. Obtain the required data [11].

symbol	Physical parameters	numerical value	unit
λ_{sp}	Pump light center wavelength	980	nm
λ_s	Fiber laser center wavelength	1575	nm
τ	Erbium ion average energy level lifetime	0.8	ms
σ_{ap}	Pump light absorption cross section	$1.358*10^{-26}$	m^2
σ_{ep}	Pump light emission cross section	$0*1.358*10^{-26}$	m^2
σ_{as}	Signal light absorption cross section	$1.595*10^{-24}$	m^2
σ_{es}	Signal light emission cross section	$2.673*10^{-24}$	m^2
A_c	Core cross-sectional area	$3.1416*10^{-11}$	m^2
N	The number of erbium ions doped in the fiber core	$5.535*10^{25}$	m^3
α_p	Loss of pump light from double-clad fiber	$2*10^{-3}$	m^{-1}
α_s	Laser loss from double-clad fiber	$4*10^{-4}$	m^{-1}
L	Double clad fiber length	7	m
Γ_p	Pump light overlap factor	0.73	
Γ_s	laser overlap factor	0.82	
R_1	left specular reflectance	0.99	
R_2	Right side specular reflectance	0.635	

3. Results and discussion

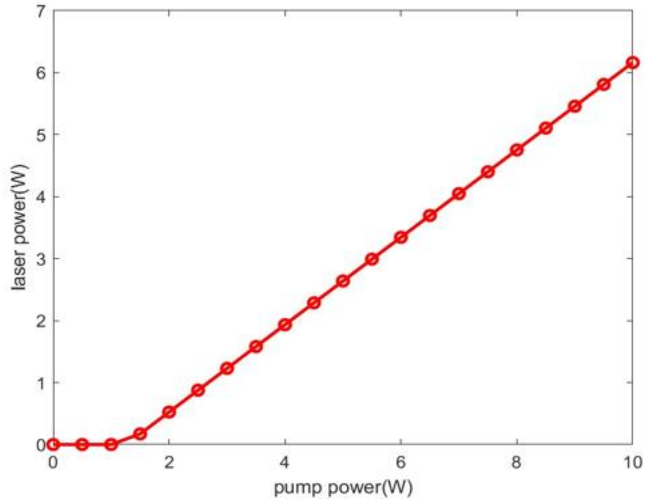

Fig 2. Relationship between pump power and laser power (Picture credit: Original).

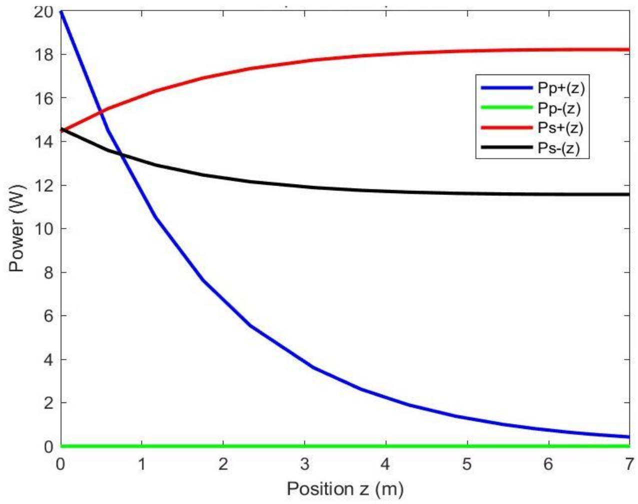

Fig 3. Variation trend of pump power and signal light power with position length (Picture credit: Original).

According to the results obtained by running the program, two power diagrams, Fig 2 and Fig 3, can be obtained. Fig 2 shows the relationship between pump power and laser power. It can be seen that there is no laser power output in the pump power range of about 0 to 1. It can be seen that the threshold power of the fiber is about 1w, and the laser power can be seen in the part behind the curve. As the pump power increases, it shows a steady growth trend. It can be seen that increasing the pump power after exceeding the pump threshold can increase the laser power output. There is a positive correlation between the pump power and the output power. In practical applications, by increasing the pump power increases the output laser power, but as the pump power increases, the output cost also increases. Therefore, the relationship between output power and cost should be taken into consideration. Improving the pump power can also change the grating transmittance and change the laser channel. Adjust the output power through the length and other methods. Fig 3 shows the changing trend of pump power and signal light power with position length, where Pp+ is the forward propagation of pump power, and Ps+ and Ps- are the forward and reverse output of signal light power respectively. It can be seen that in this physical simulation, the initial value of the signal optical power under the data conditions is about 14.5. Due to the output laser power consumption, it can be seen that the reverse signal optical power continues to decrease to a stable value. According to the green line in Fig 3, it can be seen that the reverse pump Pp-power under this design condition is always 0, indicating that the laser is being output from the right grating under this condition, and the pump power exceeds the threshold power, ensuring stable laser output. The most important part is the Pp+ part. It can be seen that the forward pump optical power has been continuously decreasing from the initial value of the data and has gradually approached zero. This is the relationship between the pump power and the fiber length. The higher the pump power. It is close to zero, indicating that the pump power is fully utilized and the cost can be maximized. When the position is around 7, the forward pump power tends to be flat, which means that the pump light utilization rate is close to the maximum value, and cost issues need to be considered when lengthening the fiber length. It can be seen that the length position when it is around 7 is most suitable for the 1575 wavelength erbium-doped fiber laser to output laser power.

4. Conclusion

This project demonstrates the feasibility of using an erbium-doped fiber laser to excite a pump light of 980 in the 1550-1600 wavelength range and output relatively optimal laser power under specific data. According to the program simulation, it can be seen that the laser is within the pump threshold. If the output cannot be started, only when the pump threshold power is exceeded can the laser output be stably increased, in which the pump power and laser power are positively correlated. Through this project, the data of the erbium-doped fiber laser has been further optimized. As a type of rare earth ion fiber laser, the erbium-doped fiber laser has the advantage of a wide usable waveband and can work in multiple wavebands. It is also widely used in real life, such as fiber laser welding technology. In real life, many instruments require precision welding. The most common ones, such as mobile phone welding, require extremely precise welding points, even less than 0.5mm in diameter. MOPA Welding technology can be fully utilized. Materials of different materials are spirally welded through high-precision welding by fiber lasers, ensuring the stability and firmness of the welding and reducing the degree of deformation. In addition to high precision, erbium-doped fiber lasers also have the advantage of high energy. For example, fiber laser beam lithotripsy technology is a major breakthrough in the medical field. Fiber lasers are used to perform kidney stone lithotripsy under temperature conditions that the human body is adapted to. The corresponding absorption peak is found according to the water temperature condition, the laser power exceeds 6w, and the accuracy can reach pm level, far exceeding the required nm level conditions. Fiber lasers are widely used and can also be used in industrial welding, high-energy weapons, etc. This study specializes in the data for the study of the 1550-1600 band, that is, selects specific wavelengths for physical simulation calculations, which cannot represent the optimal output power results of the band, and has certain shortcomings that need to be supplemented.

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