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Study on High Power Thulium Doped Fiber Laser with Multistage Amplification

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Abstract: In recent years, with the continuous progress of science and technology, fiber lasers have been greatly developed. Fiber laser technology combines the waveguide characteristics of fiber and the pumping characteristics of semiconductor. It is simple in structure, high in energy conversion efficiency, good in beam quality, low in threshold, good in heat dissipation and easy to maintain. Fiber lasers can be developed on the basis of fiber amplifiers. Tm doped fiber lasers can emit relatively large wavelengths and have important application value in medical surgery. Therefore, people attach great importance to Tm doped fiber lasers. However, the output power of Tm doped fiber laser is relatively small, which can not meet the requirements for laser applications. In the fields of industry, agriculture and medical application, high power laser is required. High power fiber lasers have many important applications and can meet the needs of all walks of life. In order to obtain high power laser with excellent performance, laser amplification technology has been developed rapidly. Tm doped fiber laser is studied, several different laser amplification systems are analyzed, and a new laser amplification scheme is designed. In the design scheme, a small power Tm doped fiber laser with excellent performance is used as the seed source, and the seed laser is injected into a single-stage or multi-stage fiber amplifier system to finally realize the laser output of high power amplification. The simulation results show that the designed laser amplification scheme is effective.

Keywords: Thulium Doped Fiber Laser, Pulse Laser, Amplification, High Power

1. Introduction

Fiber lasers have important applications in many fields. In terms of detection technology, fiber laser can be used to measure distance, speed, different angles, and surface shape of objects [1-3]. In information technology, fiber lasers can be used in optical communication systems for optical storage, optical amplification, optical computing, etc [4-10]. In medicine, fiber laser can be used in various surgical operations, such as ophthalmic surgery, laser irradiation therapy, etc., by using the role of laser on biological tissues. In laser processing, fiber laser can be used for various welding, such as drilling holes on the surface of objects, cutting objects to a certain extent, heat treatment of objects, and rapid prototyping of objects [11-13]. In the military, fiber lasers can be used to manufacture laser weapons, laser radars, laser guidance and so on. In recent years, with the continuous improvement of laser technology and material preparation technology [14-18], a continuously tunable wavelength, high-power Tm doped fiber laser has been developed rapidly. Tm doped fiber laser has high repetition rate and narrow pulse width. The laser produced by Tm doped fiber laser can obtain higher peak laser power after multistage amplification. This makes high power Tm doped fiber laser attract people's attention.

2. Rare Earth Doped Optical Fiber

There are many types of lasers. Solid state lasers are generally small and solid, with high pulse radiation power and wide range of applications. Semiconductor lasers can change the wavelength of laser by adding electric field, magnetic field, temperature, pressure, etc., and can directly convert electrical energy into laser energy, so they are developing rapidly. Dye lasers are cheap and efficient,

and their output power is comparable to that of gas and solid lasers. However, these lasers have shortcomings, which greatly limit the application range of lasers. Fiber laser is based on rare-earth doped fiber as laser working material, which has low manufacturing cost, small size, flexible operation and easy integration. The wavelength range of fiber lasers is very wide, and the emission wavelengths of various rare earth doped fibers are different. The emission wavelength of rare earth doped fiber is shown in figure 1.

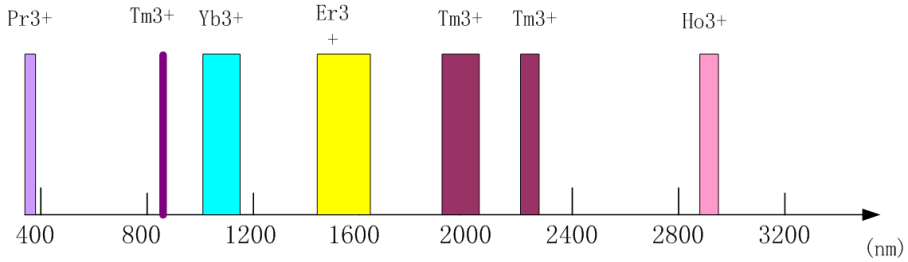

Figure 1. *Emission Wavelength of Rare Earth Doped Fiber.*

Fiber laser mainly uses rare earth doped fiber as gain medium. Different rare earth elements have different emission wavelengths, which enables the emission wavelength of fiber lasers to cover a large range. Therefore, fiber lasers can generally be made into tunable types, which is very suitable for the application of WDM optical communication systems. Tm ions have a wide emission spectrum, which covers 1700nm-2100nm. This makes the technology of Tm doped fiber lasers develop rapidly, and it plays an important role in the research field of mid infrared wavelength tunable lasers. Because the fiber core in the fiber laser is very thin, under the action of the pump light, it is very easy to form high power density energy in the fiber, causing the inversion of the laser energy level particle number of the laser working material and radiating light outward. Compared with semiconductor lasers, fiber lasers have many advantages. Fiber laser takes fiber as the gain medium, and the fiber has a large surface area, which makes it have a good heat dissipation function, and it is more convenient to manage the heat generated by it. Fiber lasers can be developed on the basis of fiber amplifiers. Any optical amplifier can form a laser through an appropriate feedback mechanism. The fiber amplifier made of rare earth doped fiber has brought great changes to the field of optical wave technology. With the development of laser research, high power laser beam is required in some application fields. High power fiber lasers have many important applications and can meet the needs of all walks of life. The structure of Tm doped fiber laser made of rare earth doped fiber is shown in figure 2.

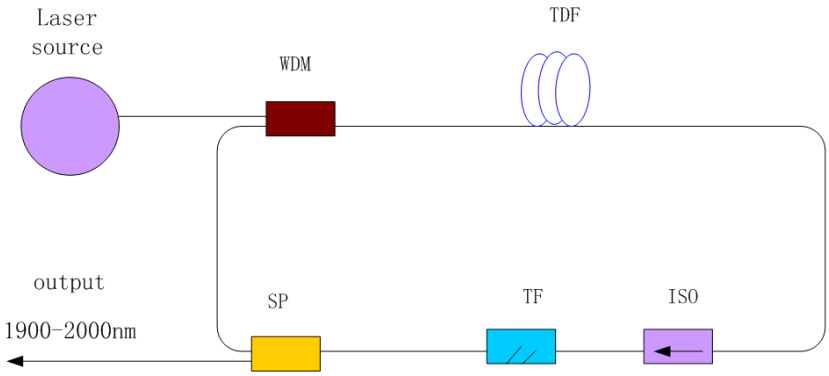

Figure 2. *Tm Doped Fiber Laser.*

3. Design of Laser Amplifier

High power fiber laser technology is one of the hottest research directions in the field of optoelectronic technology in recent years, especially in the field of laser technology. It has been widely used in industrial manufacturing, medical treatment, energy exploration, military defense and other fields. From the perspective of the development trend of the whole high-power laser industry, the fiber laser combines the waveguide characteristics of the fiber and the pumping characteristics of the semiconductor, and has the outstanding advantages of good beam quality, high efficiency, good heat dissipation, compact structure, flexible operation, etc., representing the development direction of high-power and high brightness lasers. High power fiber laser also has an important industrial application, which is the acquisition of natural gas drilling and deep-sea new energy. The American Institute of Gas Development Technology used the 5 kW fiber laser of IPG Company to conduct rock cutting and crushing experiments. Compared with the traditional method, the hole penetrated by the fiber laser is deeper, which can reduce damage and increase production. At present, high-power fiber lasers have been widely used in the industrial field. Due to its

productivity and cost advantages, they have gradually replaced other types of lasers. With the appearance of double clad fiber, the output power of fiber laser has been significantly improved. The typical double clad fiber structure consists of three parts: fiber core, inner cladding and outer cladding. The refractive index of the outer cladding is lower than that of the inner cladding, so pump light can be transmitted in the inner cladding. The diameter and numerical aperture of the inner cladding can be much larger than that of the fiber core, which is convenient for efficient coupling of pump light. After multiple total reflections in the inner cladding, the pump light enters the fiber core doped with rare earth ions and is absorbed to realize the generation or amplification of laser. With the appearance of cladding pumping technology, the output power of fiber laser has been improved from milliwatt level to watt level. With the continuous improvement of high-power LD laser technology and cladding pump coupling technology, the output index of Tm3+doped fiber laser has also stepped to a new level. How to effectively couple the pump light into the inner cladding of double clad fiber with a fiber diameter of only hundreds of microns to obtain high pump power is an important problem in the research of fiber lasers. High doped, large mode area fiber can break through these limitations. By increasing the core diameter and reducing its numerical aperture, the laser can operate in a single mode and reduce the power density in the fiber, thereby increasing the threshold of nonlinear effects. In 2009, T. S. McConib et al. of the University of Central Florida in the United States realized a high-power Tm doped fiber laser by using a primary power amplification system. The laser achieves a maximum average output power of 116W. Using the fiber with large mode field area, the fiber laser realizes the laser output with a single output close to kilowatt and high beam quality, and the fiber amplifier realizes the output with a peak power of megawatt.

Because the output laser power of fiber laser is relatively small, it cannot meet the demand. In order to improve the output power of the laser, it is necessary to amplify the laser to obtain high-power laser. There are many kinds of laser amplification systems, and their structures are not exactly the same. A general laser amplification system is shown in figure 3.

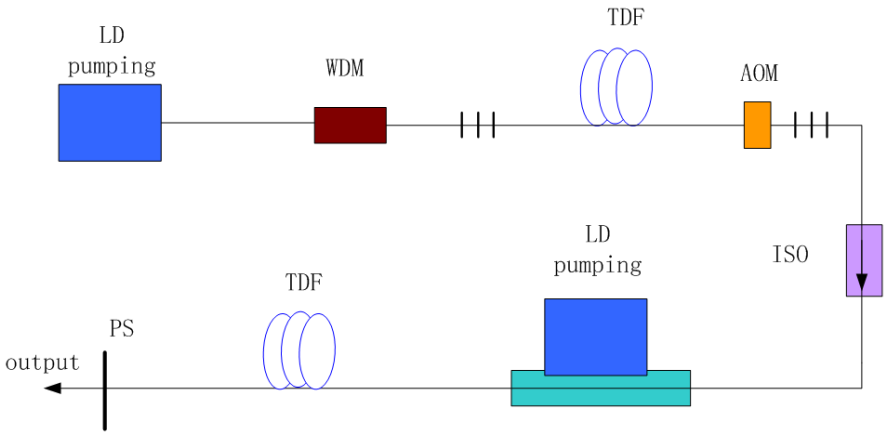

Figure 3. *Laser Amplification System.*

Tm doped fiber laser plays an important role in the near infrared band that other lasers cannot replace, so it has an important application prospect. Because the traditional laser amplification system has certain restrictions on the laser peak power, in order to improve the laser amplification effect and the laser amplification peak power, a Master Oscillator and Power Amplifier (MOPA) laser amplification system has emerged. The working principle of MOPA laser amplification system is shown in figure 4.

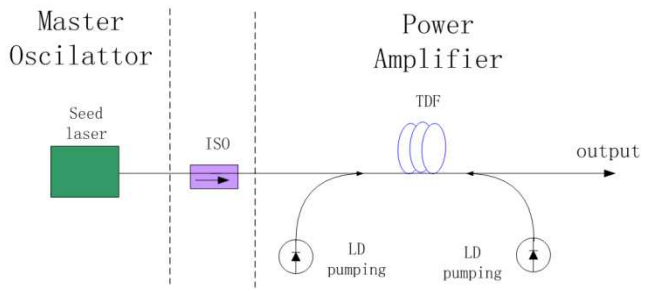

Figure 4. *Working Principle Diagram of MOPA Laser Amplification System.*

The seed source only provides low power laser output, but the seed light must have good beam quality, narrow linewidth and high stability. The seed source adopts rational harmonic mode locked (RHML) fiber laser, and the laser structure is shown in figure 5.

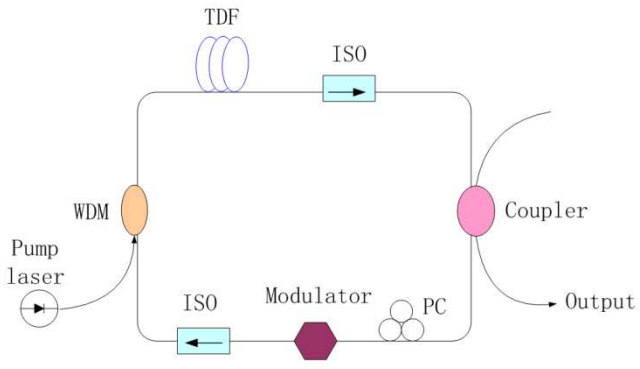

Figure 5. *Fiber Laser Based on RHML.*

For a laser amplification system, if only one LD pump is used to provide energy, the amplification effect is extremely limited. In order to increase the output power of the laser amplification system, multiple LD pumps are often used to improve the output power of the laser amplification system and obtain high intensity laser output. The laser amplification system using multiple LD pumps is shown in figure 6.

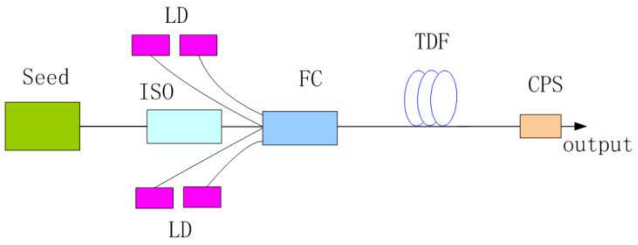

Figure 6. *Pulse Laser System Based on MOPA Structure.*

In order to further improve the output power of the laser amplification system, multi-level amplification can also be used to obtain stronger laser output. The multi-stage laser amplification system is shown in figure 7.

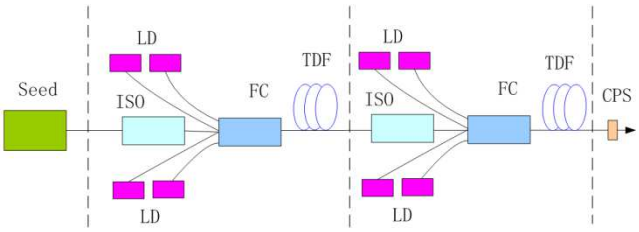

Figure 7. *Laser Multi-stage Amplification System.*

The laser amplification system is simulated and the results are shown in figure 8.

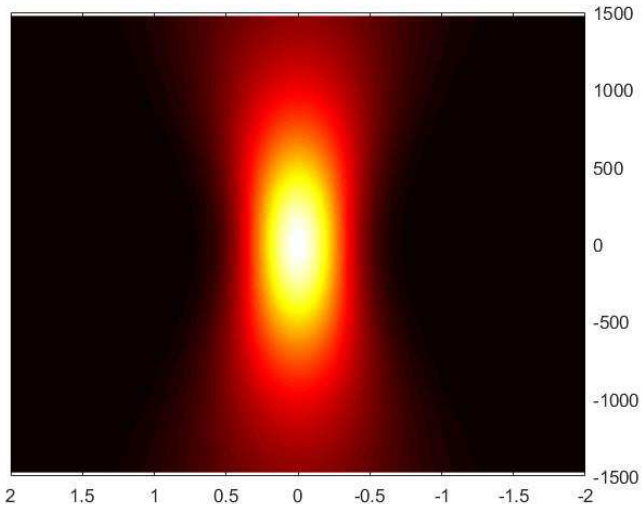

Figure 8. *Experimental Simulation Result.*

However, the power of general fiber lasers is too small, and the energy they can provide is insufficient to meet customer needs. In order to obtain high energy laser with excellent performance, laser amplification technology has been developed rapidly. In the process of laser amplification, a low-power laser with excellent performance is used as the seed source, and the seed laser is injected into a single-stage or multi-stage fiber amplifier system to finally achieve the laser output of high-power amplification. The simulation results show that the designed laser amplification scheme is effective.

4. Conclusion

Fiber lasers are widely used Compared with traditional lasers, fiber lasers have many advantages. The optical path of the fiber laser is composed of fiber and fiber components. The fiber and fiber components are connected by fiber fusion technology. The entire optical path is completely enclosed in the fiber waveguide. Therefore, once the optical path is completed, it forms a whole, avoiding the instability of the laser caused by the separation of components. As a result, the reliability of the laser is greatly enhanced. The Tm doped fiber laser can emit a wavelength of 2000nm, which is just near the absorption peak of water. After being amplified, the laser has a very high peak power, which can be used in surgery and has important applications in industry, agriculture and other fields.

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