Research on optimization of thulium-doped fiber laser based on optical communication system

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Abstract. With the rapid development of optical communication network and related technology, the frequency resource of light wave is becoming more and more insufficient, which requires new light sources to support the communication system. With the continuous development of fiber laser technology, Tm-doped fiber laser appears, which brings new vitality to the optical communication network with insufficient frequency resources. Because Tm-doped fiber laser can provide multiple frequencies of optical wavelength resources, it has attracted more and more attention. The development of rare earth doping technology and double cladding pumping technology has laid a solid foundation for the design of Tm-doped fiber laser with excellent performance. In this paper, the Tm-doped fiber laser is studied. The effect of each element in the Tm-doped fiber laser on the laser is analyzed. The influence of the reflectivity of the mirror on the performance of the whole laser is discussed. The simulation results show that the reflectivity of the mirror will seriously affect the output power of the laser, which is of great significance for the design of fiber lasers.

1. Introduction

With the continuous development of optical communication system, more laser wavelengths are required. Wavelength is an important resource in optical communication network, but not any wavelength can be used in optical communication network [1]. Only certain optical wavelengths can be used in optical communication systems. Therefore, the continuous development of new wavelength resources is of great significance for optical communication systems. Previously, fixed wavelength lasers were used in optical communication systems. However, with the continuous development of communication technology, the shortcomings of fixed wavelength laser are gradually revealed. On the one hand, with the development of DWDM technology and in an optical communication system, the number of optical wavelengths can reach hundreds. In the optical network that needs to provide protection path, the backup of each laser must be provided by the laser with the same wavelength, which leads to the increase of the number of backup lasers and the rise of cost. On the other hand, because fixed lasers need to distinguish wavelengths, the types of lasers increase with the number of wavelengths, which increases the complexity of optical communication systems and brings inconvenience to the daily maintenance of optical communication systems. The volume of fiber laser is relatively small. Optical fiber is the main medium in the working process of fiber laser [2]. Compared with other information transmission media, optical fiber has the characteristics of smaller
diameter but larger surface area under the same volume, and the shape of fiber is mainly cylindrical, which brings convenience for fiber coupling. In order to improve the transmission efficiency, a large number of optical fibers can be coupled together, and with the help of the characteristics of fiber softness and winding, the volume of fiber laser can be reduced to make it smart and convenient for handling. In addition, if a dynamic wavelength assignment is needed in an optical network, a large number of fixed lasers with different wavelengths are needed, but the utilization rate of each laser is very low, which will lead to a waste of resources [3-5]. With the development of semiconductors and related technologies, tunable lasers have been successfully developed. In other words, the same laser module controls the output of different wavelengths within a certain bandwidth. Tm-doped fiber laser is a kind of tunable fiber laser [6]. Therefore, Tm-doped fiber laser has attracted great attention, and a lot of manpower and material resources have been invested in the research.

2. Optical communication system

The early optical fiber system is mainly PDH system and SDH system, such system cannot meet the needs of network transmission. The transmission rate of these systems is limited by modulation technology and laser, so it is difficult to improve the transmission rate. The emergence of WDM (wavelength division multiplexing) technology has completely changed the shortcomings of traditional optical fiber transmission system and realized the development of high transmission rate of optical fiber communication system. Now, WDM system has become the core part of optical communication network, which mainly undertakes the task of long-distance transmission. A WDM communication system is mainly composed of optical transmitter and receiver, multiplexer and demultiplexer, fiber amplifier and optical fiber. The WDM communication system is shown in Figure 1.

![Figure 1. The structure of WDM communication system.](image)

In WDM system, the main function of optical transmitter is to provide a stable and reliable light source for communication system. In the optical communication system, the common light source devices are led and LD. LED is one of the most widely used light source devices in optical fiber communication. It has many advantages, such as good linearity, good temperature characteristics, low price, long life and simple use. However, due to the wide spectral line of LED, the application of LED in large capacity and long distance optical fiber communication is limited. Because of its narrow emission spectrum and high coupling efficiency with optical fiber, LD can be used in large capacity optical fiber communication system. In WDM system, the function of optical receiver is to detect the communication information from the weak optical signal, and then regenerate the original signal stream with neat waveform after amplification and equalization. Therefore, the quality of the optical detector in the optical receiver directly determines the sensitivity of the optical receiver. The function of multiplexer is to multiplex multiple optical wavelengths. It is mainly placed in the transmitter. It can combine optical signals of different wavelengths and send them into optical fiber for transmission. For optical fiber, the applicable wavelength range is divided into several bands, and then each band is taken as an independent channel to transmit optical signal. At the receiving end, the demultiplexer can
extract the different wavebands transmitted simultaneously in one optical fiber, and then send them to their respective optical fibers to continue to transmit to the destination. In the long-distance WDM system, because the signal is weakened after long-distance transmission, it is necessary to use relay equipment to supplement the energy of optical signal and improve the intensity of optical signal, so that the optical signal can continue to transmit. The common relay equipment is fiber amplifier, mainly erbium-doped fiber amplifier (EDFA). The emergence of EDFA completely solves the shortage of transmission distance in optical network, and directly promotes the rapid development of WDM optical network. EDFA has many advantages, such as high coupling efficiency, high energy conversion efficiency, high gain and low noise. It can simplify the system, reduce the cost of communication system and increase the relay distance. The optical fiber communication network is shown in Figure 2.

![Figure 2. Optical fiber communication network.](image)

3. Structure of fiber laser

The fiber laser is made of rare earth ions doped fiber as the gain medium, through stimulated radiation to form laser output. In the fiber laser, the ground state particles are continuously excited to some higher excited state levels by pumping, which makes the gain medium cause the inversion of the particle number distribution and realize the radiation forming laser. Tm-doped fiber laser is the fiber doped with Tm ions as the gain medium. Figure 3 shows the basic structure of Tm-doped fiber laser.

![Figure 3. The Tm-doped fiber laser.](image)
resonator is mainly divided into linear cavity and ring cavity. Practical fiber lasers often use fiber gratings to form resonators. Fiber Bragg gratings can replace high reflectors at both ends of Fabry Perot cavity, an all fiber laser is constructed, and the coupling loss between the cavity mirror and the fiber is eliminated. The fiber grating laser is shown in Figure 4.

![Figure 4. Configuration of FBG fiber laser.](image)

Another type of fiber laser is ring structure laser. The ring cavity is composed of wavelength division multiplexer (WDM), gain fiber, isolator (ISO), coupler and fiber Bragg grating (FBG). An ISO isolator is inserted into the ring to ensure the unidirectional operation of the laser. The ring structure laser is shown in Figure 5.

![Figure 5. Structure of ring fiber laser.](image)

4. Double clad fiber
For thulium-doped fiber laser, due to the low coupling efficiency of pump beam, the output power is also relatively small, which is not enough for many applications. Therefore, how to improve the output power of thulium doped fiber laser and get high-power laser output has become one of the research hotspots of fiber laser. Because the fiber length, doping concentration and pump power have an important impact on the output power of the laser, in order to improve the output power of the laser, people put forward a variety of methods to improve the laser power. Among them, the proposal of double clad fiber structure is of great significance for the development of high power laser. We know that for ordinary optical fiber, how to improve the absorption effective cross-sectional area and numerical aperture in order to improve the ability of optical fiber to absorb pump light is an important problem to be solved. It has been found that this problem can be solved successfully by using doped fiber with double cladding structure. The double clad optical fiber is shown in Figure 6. From the structure, the double clad fiber is composed of four parts. The optical fiber with this structure has two cladding layers, which are the core, the inner cladding, the outer coating and the protective layer from the inside to the outside. Although the structure of this kind of double clad fiber is relatively simple, it also has a disadvantage, that is, its energy absorption efficiency is not high. The specific reasons are as follows: in this circular symmetric optical fiber structure, the pump light is transmitted in the inner cladding in a spiral way, so it is unable to couple into the center of the fiber to excite thulium ions to absorb more energy, which makes the energy absorption efficiency decrease.
However, in recent years, with the progress of science and technology and the improvement of optical fiber manufacturing technology, some special shaped inner cladding structures have been invented to change this situation and improve the energy absorption efficiency. The change of optical fiber is shown in Figure 7, among which there are rectangular, D-shaped, eccentric circular, plum shaped, etc. These irregular cross-section bread layers have good absorption properties. This kind of fiber can suppress the spiral surround light in the circular symmetry inner cladding. The advantage of this method is that the pump light can be coupled into the fiber core for many times during the transmission of the inner cladding, thus greatly improving the absorption efficiency of the pump light and obtaining higher laser output power.

5. Influence of cavity mirror reflectivity on laser
In optical laser, the reflectance of the front and back mirrors in a linear cavity has an important influence on the output of the laser. Generally speaking, when designing an optical laser, the reflectivity of the front chamber mirror to the laser should be as high as possible, and the total reflectivity can be used. However, in practical application, due to coating or other reasons, the reflectivity of the anterior chamber mirror cannot reach 100%. The selection of the reflectance of the rear chamber mirror depends on the system parameters. In order to form feedback on the laser beam and obtain the laser output, the right-side mirror passes through the laser partly. Theoretical analysis shows that only a properly reflective rear mirror can achieve an optimal output power. The Tm-doped fiber laser is experimented and the results are shown in Figure 8.

In Figure 8, it shows the relationship between the output power of an iron-doped fiber laser and the reflectance of a cavity mirror. In the first part of the increase in the reflectance of the mirror, the output power of the laser increases with the increase of the reflectance of the mirror. However, when the laser power reaches the maximum value and the reflectance of the mirror is increased again, the laser power does not increase but begins to decrease. The reason for this phenomenon is that the number of laser oscillations in the cavity increases, which leads to the loss of laser transmission and the decrease of laser power. This indicates that the reflectance of the cavity mirror is not as high as possible, but has an optimal value.
6. Conclusion
For optical communication system, light source is a key factor to ensure the normal operation of optical communication system. Tm-doped fiber laser is an ideal light source for optical communication system because of its narrow line width, wide spectrum range and adjustable harmonic length. Tm-doped fiber laser is studied. The structure of Tm-doped fiber laser is analyzed, and the reflectance of the cavity is experimented. The results show that the reflectance of the cavity is not higher, but better. It has an optimal value. This is important for the design of Tm-doped fiber laser.

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