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Study of Tm Doped Silica Fiber Lasers Pumped by LD

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Abstract: Fiber laser has many advantages. First of all, fiber lasers are relatively simple in structure, with fewer components than traditional solid state lasers, smaller volume, and easy to integrate into a small area. In addition, the energy conversion efficiency of fiber lasers is very high. The gain medium is rare earth doped glass, which is rich and cheap. Rare earth doped glass has very high beam quality and is widely used in industry, agriculture, laser communication, atmospheric detection, remote sensing, laser radar, medical surgery and other fields. Now fiber laser has become the mainstream of laser technology development and the main technology of laser industry application. Tm doped silica fiber lasers have been studied. The gain spectrum range of Tm ions is very wide, and its emission wavelength can cover 1800nm-2100nm. This range is just near the peak of the absorption spectrum of water molecules, which has great application value. This paper analyzes the structural characteristics of Tm doped fiber lasers, designs a new type of Tm doped silica fiber lasers, gives the equation of laser pulse, and then simulates the laser to obtain the mode locked pulse of the laser. The simulation results show that the designed Tm doped silica fiber lasers are feasible.

Keywords: Tm Doped Fiber, Pulse Laser, Fiber Laser, Mode Locking, Structure

1. Introduction

Fiber laser is a device that uses fiber as basic material and doped rare earth element as working material to emit light. From the energy point of view, the laser medium usually has multiple energy levels. From the energy point of view, laser media usually have multiple energy levels. When the number of particles at the high energy level is greater than the number of particles at the low energy level, a population inversion state is formed. At this time, if the laser medium is excited and guided by the outside, it will emit light [1-4]. If these lights resonate in the laser cavity, a stable laser can be output. At present, fiber laser technology is developing very rapidly [5-8]. Because the beam quality of fiber laser is very high, it can meet the application requirements in many fields. Fiber laser has good optical conversion efficiency, simple structure, few parts, easy maintenance, and is not easily affected by the external environment [9-12]. It is widely used in industry. For example, fiber lasers have important applications in industry, laser welding, laser cutting, laser marking, etc. Fiber lasers also have important applications in military. High power fiber laser, with high energy, can kill enemies. In addition, fiber laser has become one of the priority technologies of high-energy laser weapons because of its high brightness, small volume, small irradiation area and other advantages [13, 14]. Fiber lasers also have important applications in monitoring and sensing. Compared with other lasers, fiber lasers have the advantages of high efficiency, good stability, small size, etc., and can also realize wavelength tuning and other functions [15-17]. Compared with other light sources, fiber lasers have obvious advantages in the sensing field. The fiber laser can output a narrow linewidth, which indicates that the coherent length of the laser is relatively long, which is conducive to accurate measurement. Fiber lasers also have important applications in medicine. As the gain spectrum range of Tm ion is very wide, its emission wavelength can cover 1800nm-2100nm, and this range is just near the peak value in the absorption spectrum of water molecules, so it can be used in human surgery, especially in ultra precision surgery. Fiber laser can be used in gene therapy or human vision correction surgery. Fiber lasers can also be used in communications. Compared with conventional solid-state laser systems, fiber lasers have compact structure, high beam quality, easy heat dissipation, small size, and good compatibility with fiber systems, which make them very suitable for communication technology. Because of the wide use of Tm doped fiber lasers, people attach great importance to them. In this paper, the Tm doped fiber laser is studied, the mode locking characteristics of the laser are analyzed, the mode locking equation of the laser is given, a new Tm doped fiber laser is designed, and the simulation experiment is carried out, and the mode locking pulse is obtained.

2. Development of Fiber Laser Technology

Fiber laser can emit laser with excellent performance. In terms of structure, fiber laser is mainly composed of pump source, rare earth doped fiber, coupler, resonant cavity and other components. The pump source provides energy and is composed of one or more high-power laser diode arrays. The pump light emitted from the pump source is coupled into the gain medium through a special pump structure. The gain medium is usually composed of fiber doped with rare earth elements. When the energy of the pump light is absorbed by the gain medium, the particle number inversion will be formed. At this time, if guided by the outside world, stimulated emission will occur, as shown in figure 1. When the stimulated light oscillates several times through the laser resonator, it forms a laser and outputs outward, as shown in figure 2.

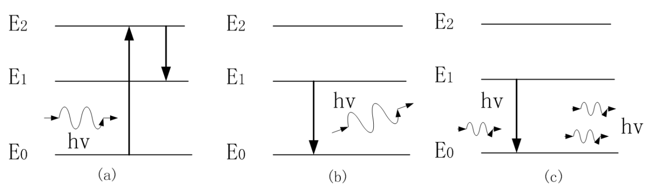

Figure 1. *Stimulated Radiation Process of Laser Medium.*

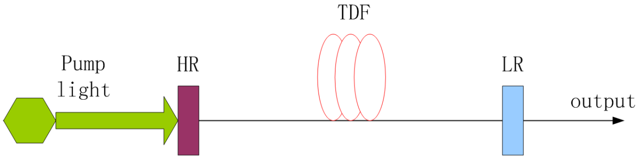

Figure 2. *Laser Resonator.*

According to the way of energy release, there are two kinds of lasers. One is continuous laser. At this time, the laser releases energy in a stable and continuous beam. Such lasers include carbon dioxide laser, CW fiber laser, etc. The other is pulsed laser. When the laser energy is released in a fixed time, a laser pulse is formed, which is called pulse laser.

From the geometric structure of the laser resonator, there are many forms of the resonator, one is linear, as shown in figure 3, and the other is annular, as shown in figure 4.

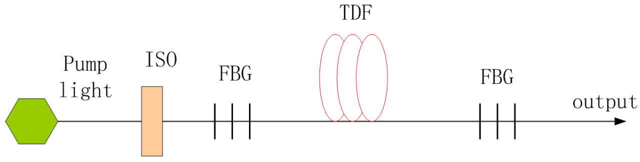

Figure 3. *Linear Resonator Fiber Laser.*

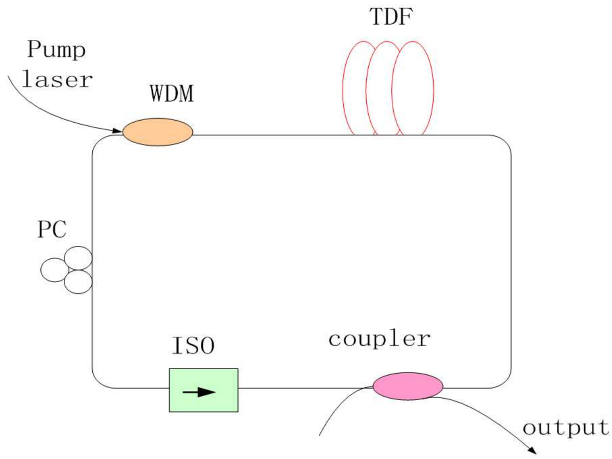

Figure 4. *Ring Fiber Laser.*

In addition, there is also a Fox-Smith resonator laser, whose structure is shown in figure 5.

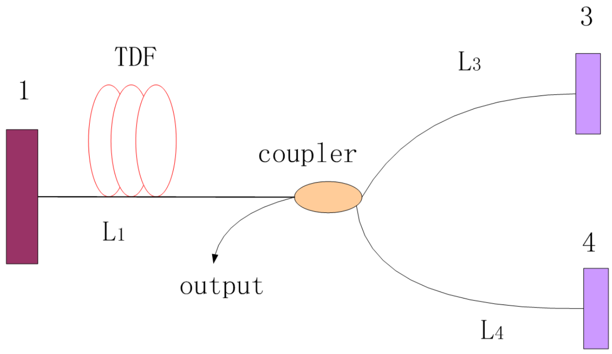

Figure 5. *Structure of Fox-Smith Laser.*

In Fox Smith laser, it is composed of two resonators. The first resonator is composed of arms corresponding to ports 1 and 3, and the second resonator is composed of arms corresponding to ports 1 and 4. These two laser cavities are coupled together, which constitutes a composite laser resonator.

3. Laser Ultrashort Pulse Technology

3.1. Q-Switching Technology of Laser

Q-switching technology is to suddenly release a high-energy pulse in a short time. Its working principle is as follows: at the beginning of pumping, the laser cavity is kept in a low Q value state, the laser is not allowed to oscillate, and the threshold value of laser oscillation is increased. In this way, the upper level of the laser medium can accumulate a large number of particles and form inversion. When the number of accumulated particles reaches a maximum, the loss of the laser cavity will suddenly decrease, and the Q value will suddenly increase, and the laser oscillation will quickly establish. In a very short time, the number of inversion particles of the energy level on the high end is rapidly consumed and converted into the optical energy in the laser cavity. Then, at the output end of the cavity, huge energy is released in the form of a single pulse, which forms a giant pulse laser output with high peak power. The structure of Q-switched laser is shown in figure 6.

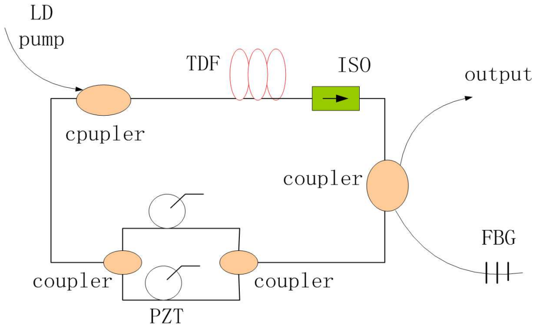

Figure 6. *Mach Zehnder (M-Z) Interferometer Fiber Q-switched Laser.*

The working principle of this type of Q-switched laser is as follows. In the laser structure, the element PZT is a piezoelectric ceramic. When a sinusoidal voltage is applied to the PZT, the PZT will produce a periodic deformation. Because of this deformation, the spatial distance will change slightly. In this way, the optical path of the optical fiber fixed with it will also change periodically, so that an interference phenomenon can be formed at the second coupler. This interference phenomenon is equivalent to a periodic loss change in the laser cavity, so as to realize the function of Q-switching.

3.2. Ultrashort Laser Pulse Technology

It is an effective method to realize ultrashort laser pulse by using mode locking technology. When multiple longitudinal modes oscillate freely in the laser cavity, the initial phase of each longitudinal mode is completely independent and random, and there is no constant relationship between the phases of each longitudinal mode. Therefore, the frequency intervals between adjacent longitudinal modes are not strictly equal at this time, which leads to an interference free relationship between longitudinal modes. At this time, the light intensity is a random and irregular fluctuation state. However, when a modulation is applied to these longitudinal modes, the initial phase of each oscillating longitudinal mode can be locked, and the frequency interval of each oscillating longitudinal mode is equal, then a stable mode locking state can be achieved, and ultrashort laser pulses with very narrow pulse width can be obtained.

3.3. Active Mode Locked Laser

The active mode locked fiber laser can control the mode locking state of the laser well, and the mode locking is relatively easy. The actively mode-locked fiber laser is shown in figure 7. The working principle of active mode locking is as follows: insert an active modulation device in the laser cavity to modulate the light wave in the laser cavity. After the light wave in the laser cavity is modulated regularly, the phase of all oscillating modes can be fixed, so as to realize the mode locking of the laser.

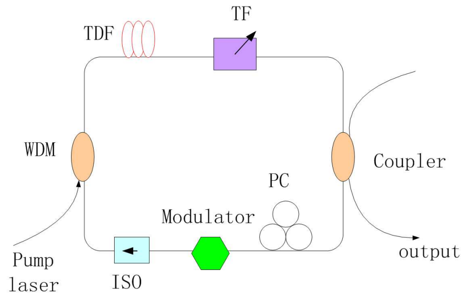

Figure 7. *Active Mold Locking Structure.*

3.4. Passive Mode Locked Laser

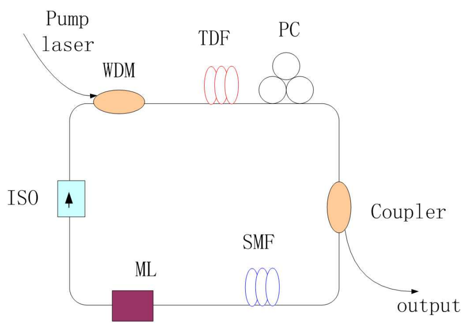

Figure 8. *Passive Mode Locked Fiber Laser.*

The passive mode locking technology of fiber lasers refers to placing a saturable absorption mirror (SESAM) in a laser cavity and using it to adjust the loss in the laser resonator. The basic structure of SESAM is to combine the reflector with the semiconductor saturable absorber. The bottom layer is generally a semiconductor mirror, on which a layer of semiconductor saturable absorber film is grown, and on the top layer a layer of mirror can be grown, or the interface between the semiconductor and the air can be directly used as the mirror, so that the upper and lower mirrors form a Fabry Perot cavity. By changing the thickness of the absorber and the reflectivity of the two mirrors, the modulation depth of the absorber and the bandwidth of the mirror can be adjusted. Before mode locking, the distribution of photons in the cavity is basically uniform, but there are some fluctuations. Weak signals have small transmissivity and large loss, while strong signals have large transmissivity and small loss, and their loss can be compensated by the amplification of working materials. Therefore, every time the light pulse passes through the absorber and the working material, the intensity of its strong and weak signals will change once. When the optical signal circulates in the cavity for many times, the difference between the maximum value and the minimum value will become larger and larger. The front edge of the optical pulse is continuously tapered, and the spike part can pass through effectively, which leads to the narrowing of the optical pulse. When the mode locking condition is satisfied, a series of mode locked laser pulses can be obtained. The passively mode-locked laser is shown in figure 8.

3.5. Design of Tm Doped Fiber Laser

A mode-locked laser is designed by analyzing the mode-locked laser. This mode locked laser is of the active mode locking type, and its structure is shown in figure 9.

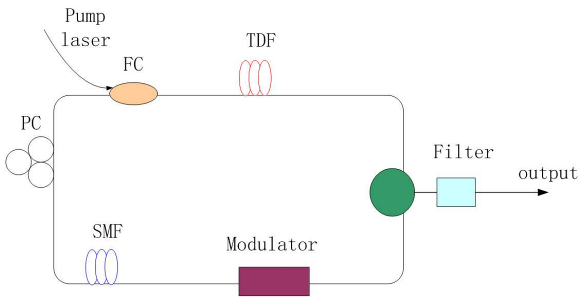

Figure 9. *Active Mold Locking Tm Doped Fiber Laser.*

The pump source is a LD with a wavelength of 793nm, and the whole laser is a ring structure.

When multiple longitudinal modes in the laser without mode locking operate freely, the frequency interval of longitudinal modes in the laser with laser cavity length L is

$$\Delta\nu_q = \nu_{q+1} - \nu_q = \frac{C}{2L} \tag{1}$$

Assuming that the oscillating light wave contains 2N+1 longitudinal modes, the light wave electric field output by the laser is

$$E(t) = \sum_{-N}^{N} E_q \cos(\omega_q t + \phi_q) \tag{2}$$

Where q=0, 1, 2,…, N.

If active modulation technology is adopted to synchronize these independent longitudinal modes in time, and the phase relationship of laser modes is fixed, the mode locking effect of laser pulses can be achieved.

Let the phase difference of each adjacent mode be α, and the qth oscillation mode be

$$E_q(t) = E_0 \cos(\omega_q t + \varphi_q) = E_0 \cos[(\omega_0 + q\Delta\omega)t + q\alpha] \tag{3}$$

The total optical field output by the laser is:

$$E(t) = E_0 \frac{\sin[\frac{(2N+1)(\Delta\omega t + \alpha)}{2}]}{\sin(\frac{\Delta\omega t + \alpha}{2})} \cos(\omega_0 t) \tag{4}$$

Using the simulation experiment, a series of mode locked pulses are obtained, as shown in figure 10.

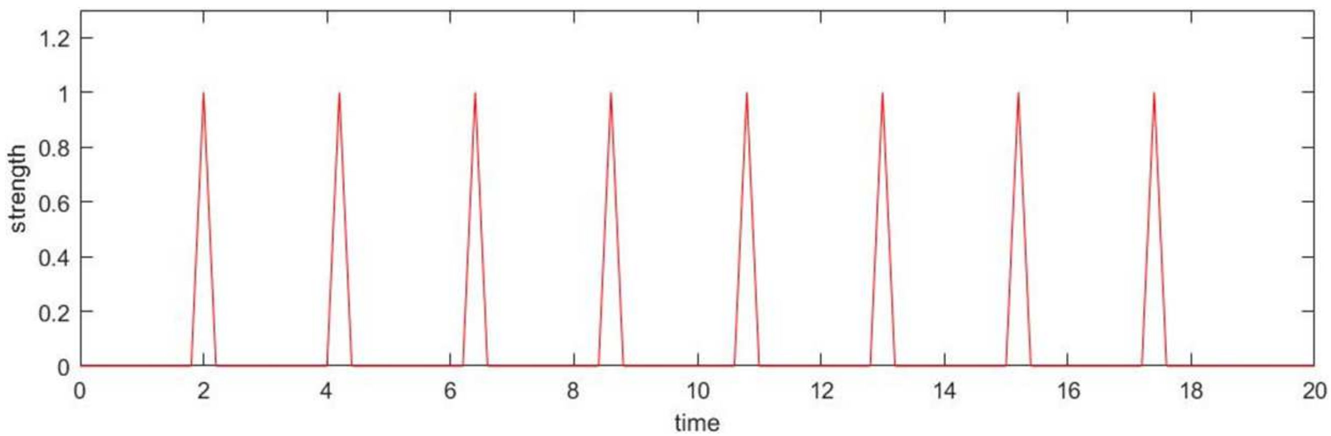

Figure 10. *Mode Locked Pulse.*

4. Conclusion

Fiber lasers have important applications in military and security, space communications, biochemical and atmospheric pollution detection, photoelectric countermeasures, and other fields. Fiber laser has attracted extensive attention because of its simple structure, small size and high energy conversion efficiency. At present, fiber lasers are developing towards miniaturization, intelligence and practicality. The characteristics of Tm doped fiber laser are analyzed, the equation of laser pulse is given, and a Tm doped fiber laser is designed. Finally, the simulation experiment is carried out, and the mode locked pulse of the laser is obtained. The simulation results show that the designed laser is feasible.

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References

[1] Heuermann, T. and Wang, ZY. (2022). Ultrafast Tm-doped fiber laser system delivering 1.65-mJ, sub-100-fs pulses at a 100-kHz repetition rate. Optics Letters, 47 (12), pp. 3095-3098.

[2] Huang, ST. and Zheng, SK. (2022). Tunable mode-locked Tm-doped fiber laser based upon cross-phase modulation. Optics Express, 30 (18), pp. 32256-32266.

[3] Hao, Q. and Wang, QG. (2022). Diode-pumped SESAM mode-locked Tm: Sc_2SiO_5 laser. Optics letters, 47 (17), pp. 4495-4498.

[4] Dupont, H. and Guillemot, L. (2022). Dual-wavelength-pumping of mid-infrared Tm: YLF laser at 2.3 mu m: demonstration of pump seeding and recycling processes. Optics Express, 30 (18), pp. 32141-32150.

[5] Lin, ZW. and Chen, JX. (2022). 1.7 um figure-9 Tm-doped ultrafast fiber laser. Optics Express, 30 (18), pp. 32347-32354.

[6] Wang, JL. and Dong, JF. (2022). 63 W wing-pumped Tm: YAG single-crystal fiber laser. Optics Express, 30 (16), pp. 29015-29021.

[7] Zhang, N. and Liu, SD. (2022). SESAM mode-locked Tm: Y_2O_3 ceramic laser. Optics Express, 30 (16), pp. 29531-29538.

[8] Zhang, L. and Sheng, Q. (2022). Single-frequency Tm-doped fiber laser with 215 mW at 2.05 um based on a Tm/Ho-codoped fiber saturable absorber. Optics Letters, 47 (15), pp. 3964-3967.

[9] Ren, B. and Li, C. (2022). Stable noise-like pulse generation from a NALM-based all-PM Tm-doped fiber laser. Optics Express, 30 (15), pp. 26464-26471.

[10] Cai, EL. and Kong, XZ. (2022). Nickel-vanadium layered double hydroxide for a mid-infrared 2 mu m Tm: YAG ceramic ultrafast laser. Applied Optics, 61 (20), pp. 6057-6061.

[11] Mi, SY. and Wei, DS. (2022). 113 W Ho: YLF oscillator with good beam quality efficiently pumped by a Tm: YAP laser. Applied Optics, 61 (19), pp. 5755-5759.

[12] Ponarina, MV. and Okhrimchuk, AG. (2022). Waveguide Tm: YAP Laser with a Pulse Repetition Rate of 8 GHz. Bulletin of The Lebedev Physics Institute, 49 (7), pp. 229-234.

[13] Zhang, L. and Zhang, JX. (2022). Intracavity Tandemly-Pumped and Gain-Switched Tm-doped Fiber Laser at 1.7 um. JOURNAL OF LIGHTWAVE TECHNOLOGY, 40 (13), pp. 4373-4378.

[14] Zhang, N. and Wang, ZX. (2022). Watt-level femtosecond Tm-doped "mixed" sesquioxide ceramic laser in-band pumped by a Raman fiber laser at 1627 nm. Optics Express, 30 (13), pp. 23978-23985.

[15] Rim Wi-Song, Kim Kwang-Hyon, An Jong-Kwan. (2022). Dielectric slotted nanodisk laser with ultralow pump threshold by anapole excitation. Applied Physics B: Lasers & Optics, Vol. 126 Issue 7, pp. 1-5.

[16] Yarunova E. A.; Krents A. A.; Molevich N. E. (2021). Spatiotemporal Dynamics of Broad-Area Lasers with the Pump Modulation and Injection of External Optical Radiation. Radiophysics & Quantum Electronics, Vol. 64 Issue 4, pp. 290-299.

[17] Satoh D, Shibuya T, Terasawa E, Moriai Y, Ogawa H, Tanaka M, Kobayashi Y, Kuroda R. (2020). Ultrafast pump-probe microscopic imaging of femtosecond laser-induced melting and ablation in single-crystalline silicon carbide. Applied Physics A: Materials Science & Processing, Vol. 126 Issue 10, pp. 1-8.