Cladding-pumped Tm^{3+}-doped Silica Fiber Laser with High Output Power and Good Beam Quality*

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Abstract: A cladding-pumped thulium(Tm^{3+}) doped silica fiber laser with high output power and good beam quality has been demonstrated. The Tm^{3+}-doped fiber laser produced a maximum output power of 6.1 W at wavelength around 2 μm when the incident pump power was 30 W. The slope efficiency was about 55.6% and the threshold was 2.2 W. The beam quality factor M_X^2 and M_Y^2 were 1.26 and 1.32 respectively when the output power was 3.3W.

Key words: Tm^{3+}-doped fiber; Cladding-pumped; Beam quality; Slope efficiency
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0 Introduction

High power ~2 μm laser sources have been attracted extensive interests due to their applications in various remote-sensing, medicine, military technology and lidar[1-2]. And the diode-pumped solid-state lasers based on crystals doped with thulium (Tm^{3+}) or with (Tm^{3+})-holmium have been usually used to obtain the ~2 μm laser sources in recent years[3]. But there are many drawbacks block the development of those diode-pumped solid-state lasers. The main drawbacks are thermal aberrations, thermal induced birefringence and damage of laser medium[4]. In order to solve these problems, the cladding-pumped Tm^{3+}-doped silica fiber lasers have been developed. Compared with diode-pumped solid-state lasers, the cladding-pumped Tm^{3+}-doped silica fiber laser has many virtues such as low threshold, broad wavelength tunability[3], good beam quality and simple configuration[5], large surface to volume ratio to make the double-cladding silica fiber have an excellent cooling property[6]. Furthermore, owing to cross-relaxation, the quantum efficiency for ~2 μm laser could reach 200% in the Tm^{3+}-doped fiber when the Tm^{3+}-doped concentration is about 5 wt. %.[7-8] Recently, in the Australian Photonics Co-operative Research Center, G. Frith, et al have obtained an 85 W Tm^{3+}-doped silica fiber laser at ~2 μm. Its slope efficiency is 56% and the measured M^2 factor is 4.1 at output power of 10 W[9]. Different from G. Frith, Y. Jeong et al have obtained a 75 W ytterbium-sensitised thulium-doped silica fiber laser at ~2μm and the beam quality factor M^2 is 1.3. Meanwhile, the slope efficiency is 32% with respect to the launched pump power[10]. And a 5.6 W cladding-pumped Tm^{3+}-doped silica fiber laser at ~2 μm with slope efficiency of 43.6% has been presented by WANG Yue-Zhu, et al. Furthermore, the output power and the slope efficiency increase to 8.4 W and 57% respectively by using a water-cooled fiber.[11]

In this letter, a 6.1 W cladding-pumped Tm^{3+}-doped silica fiber laser at ~2 μm has been studied. And the beam quality of the output laser has been measured. The obtained beam quality factor M_X^2, M_Y^2 are 1.26, 1.32 respectively when the output laser operating at 3.3 W. The Tm^{3+}-doped fiber laser operates at a maximum output power of 6.1 W and at a high slope efficiency of 55.6% compared to the launched pump power. And the threshold is about 2.2 W. In a word, compared with the reported articles before, the beam quality and slope efficiency that we obtained are very good. And we also can gain bigger output power by enhancing the pump power.

1 Experimental setup

The experimental setup is shown in Fig. 1. The Tm^{3+}-doped fiber is pumped by a fiber-coupled diode laser with wavelength of 790 nm. The diameter of the fiber core is 400μm and its numerical aperture (NA) is 0.22. About 43% of pumping power is coupled into the Tm^{3+}-doped fiber through a set of aspheric lens. The resonator

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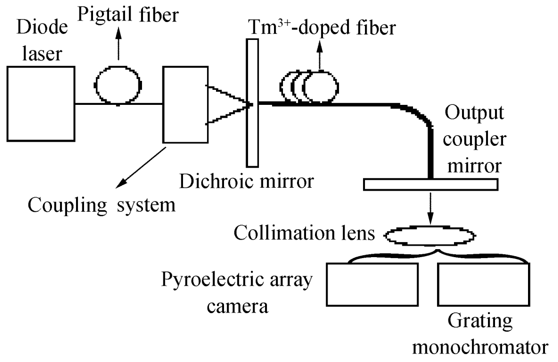


Fig. 1 The experimental setup

consisted of two dichroic mirrors. The input dichroic mirror has a >99% reflectivity in the range of 1.8~2.1 μm and a >95% transmission in the range of 780~800 nm. The output dichroic mirror has a >99% reflectivity for the pumping laser and a 65% transmission for the lasing wavelength (~2 μm). The Tm^{3+}-doped fiber which used in our experiment has a core diameter of 20 μm (NA=0.17). And the inner cladding geometry is a D-shaped transverse section with a core diameter of 300 μm (NA=0.4). The length of the Tm^{3+}-doped fiber is about 5 m. A grating monochromator is used to measure the spectrum of output laser and the Spiricon Laser Beam Profiler (Pyrocam III) is used to diagnose the beam quality.

2 Results and discussions

Fig. 2 shows the relationship of pump power and output power. The slope efficiency is 55.6%. And the threshold is about 2.2 W. In the experiment, we did not observe the thermal aberrations and damage of laser medium.

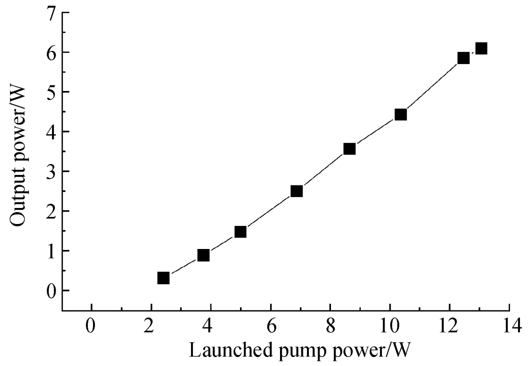


Fig. 2 The relationship of pump power and output power

Due to the output power limitation of the pumping source, our maximum output power is 6.1 W. It is reasonable to improve the output power using the higher power pump source. We can also use a water-cooled fiber to obtain higher outputpower and decrease the threshold[11]. On the other hand, the coupling efficiency of ~43% is far from optimized situation, thus the optimization of the coupling efficiency is another important approach to improve the output power and the optical-to-optical conversion efficiency.

Fig. 3 shows the spectrum of output laser which measured using a monochromator. The output wavelength with 15 W pumping power has a red shift compared to the output wavelength with 6 W pumping power. It is inevitable that the heat generated in the core of the fiber is larger and larger with increasing pump power. The Boltzmann population in the upper Stark levels of the ground state is increased and the population inversion for a given transition is reduced when the heat generated in the core of the fiber. Under these conditions, the emission extended to longer wavelength as the pump power was increased. More energetic phonons will be created in the glass under higher operating temperature and this will aid the rate of energy transfer upconversion (ETU). Higher rate of ETU will counteract the effect from cross relaxation and reduce the overall efficiency of the laser[9]. From Fig. 3 we can see that the laser spectrum shows a about 12 nm linewidth and two output peaks, owing to the broad $^3F_4 \rightarrow ^3H_6$ fluorescence spectrum[12].

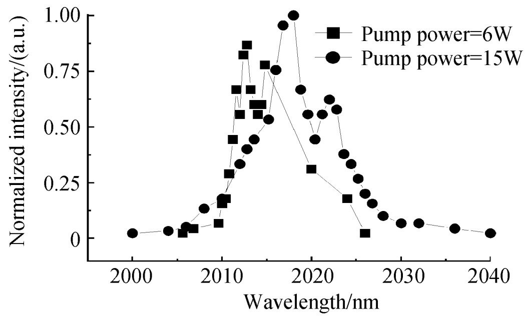
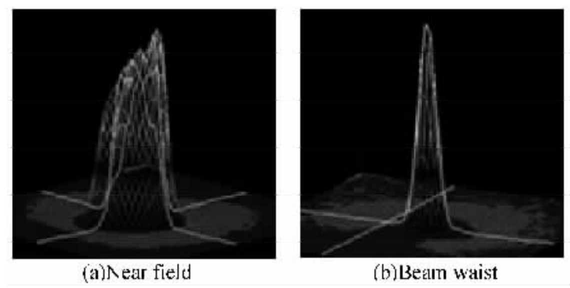


Fig. 3 The spectrum of output laser

Good beam quality with high output power is very important in many applications. In the experiment, we have measured the beam quality by the pyroelectric array camera (Pyrocam III). The obtained beam quality factor M_x^2, M_y^2 are 1.26, 1.32 respectively when the output power is 3.3 W. And the near-field, beam waist, and far-field intensity distributions have been shown in Fig. 4.



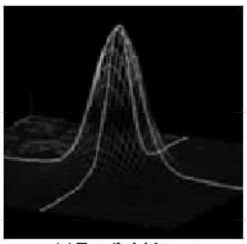


Fig. 4 The measured beam profile intensity distributions

From Fig. 4 we can see that the intensity distribution of far-field is smoother than that of near-field.

In the experiment, the beam quality M_x^2 and M_y^2 changed when the output power changed. Fig. 5 has shown the relationship of M^2 factor and the output power. From Fig. 5 we can see that the beam quality is fluctuant when the output power increased. But the whole tendency of the beam quality is become worse and worse when the output power increased. In the experiment, there are two major reasons result in the fluctuant of the beam quality. The first is that the generated output power of the Tm^{3+}-doped double-cladding silica fiber laser is unstable. And the second is that the operated stabilization of the whole beam analyzer system has big influence on the measured results.

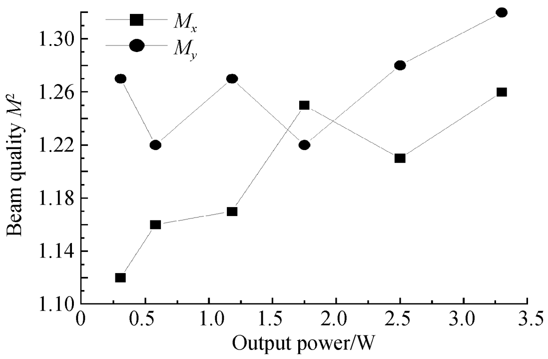


Fig. 5 The M^2 factor of output beam versus output power

3 Conclusion

In summary, a Tm^{3+}-doped double-cladding silica fiber laser at 2 μm with high output power and good beam quality has been demonstrated. When the pump power reached ~30 W, the obtained maximum output power is 6. 1W. The slope efficiency is about 55. 6% compared to the launched pump power. The threshold is 2. 2 W. When the output laser is 3. 3 W, the beam quality M_x^2 and M_y^2 are 1. 26 and 1. 32 respectively. Further optimization of the coupling efficiency, Tm^{3+}-doped concentration and fiber design should make a significant increase in output power and overall efficiency.

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包层泵浦的高功率掺铥光纤激光器

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摘　要：研究了一种输出功率高且光束质量好的包层泵浦的掺铥光纤激光器．当泵浦功率达到 30 W 时，该掺铥光纤激光器产生的最大输出功率是 6.1 W，且波长在 2 μm 左右，斜率效率达到 55.6%，产生激光的阈值是 2.2 W．当输出功率为 3.3 W 时，测得光束质量 M_X^2 和 M_Y^2 分别为 1.26 和 1.32.
关键词：掺铥光纤激光器；包层泵浦；光束质量；斜率效率

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