LD clad-pumped high efficient Tm-doped fiber lasers with different laser cavities

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Abstract: LD clad-pumped high efficient Tm-doped fiber lasers with quantum efficiencies beyond the Stokes Limit were reported. Different laser cavities, including dichroic mirror with fiber end reflection, high reflective fiber Bragg grating (FBG) with fiber end reflection and dichroic mirror with low reflective FBG, were studied. A maximum slope efficiency of 56.9% was obtained with the dichroic mirror and the fiber end flection forming the laser cavity, corresponding to a quantum efficiency of 142%. Spectral linewidth of the laser output was closely related to the reflective mirrors used in different cavities. Selected by the broadband dichroic mirror, the laser resonated randomly with the high reflective band of t he dichroic mirror. With an FBG as the high reflective mirror of the laser cavity, narrow linewidth of 38 pm was attained at an output of 1 W. In another laser configuration, one low reflective FBG was exploited as the output coupler, and narrow linewidth of 69 pm was achieved at an output of 0.9 W. And the laser linewidth was limited by the reflection bandwidth of the FBG used.

Key words: LD clad-pump; Tm-doped fiber lasers; fiber Bragg grating
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LD 泵浦不同腔结构高效运转掺铥光纤激光器

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摘　要: 研究了掺铥光纤激光器的不同谐振腔结构方式。使用 LD 泵浦,分别采用双色镜和端面反射、高反光纤光栅和端面反射以及双色镜和低反光纤光栅构成激光器谐振腔,均获得了超过 Stokes 极限的斜效率。其中双色镜和端面反射腔结构下获得了最高斜效率 56.9%,对应的量子效率为 142%。三种腔结构下,激光光谱线宽由激光器系统所采用的反射腔的光谱特性所决定。在双色镜和端面反射腔结构下,激光器在双色镜的高反带宽内随机起振,光谱较宽;在使用光纤布拉格光栅作为激光器谐振腔的高反射腔镜和低反射腔镜的情况下,激光器都获得了 2 μm 处的窄线宽输出,线宽受限于所使用的光纤光栅的反射带宽。

关键词: LD 泵浦; 掺铥光纤激光器; 光纤布拉格光栅

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0 Introduction

2 μm laser has gained huge momentum[1] due to its promising wide applications in lidar[2], medicine[3] and, especially, in optical parametric oscillation (OPO) for mid-infrared lasers[4]. LD clad-pumped Tm-doped fiber laser is an important source providing 2 μm laser with advantages such as high efficiency[5], high output power capability[6] and good beam quality.

Current resonant cavities of LD clad-pumped Tm-doped fiber lasers are divided into two main categories, namely dichroic mirror cavity and FBG cavity. Exploiting a dichroic mirror cavity, National Key Laboratory of Tunable Laser Technology realized 8.4 W output around 2 μm[7], and the Shanghai Institute of Optics and Fine Mechanics reported an output of 150 W with a slope efficiency of 56.3%[8], setting a record for domestic high power Tm -doped fiber lasers. Taking a laser cavity formed by a dichroic mirror and the 4% fiber end reflection, Q-Peak and Nufern obtained 885 W laser output in 2009 with a slope efficiency of 49.2%[9]. Compared with dichroic mirror cavity, FBG cavity is more compact and easier to fabricate. More importantly, FBG cavity could offer excellent linewidth performance. With a cavity consisting of a high reflective dichroic mirror and a low reflective FBG output coupler, National Laboratory of Tunable Laser Technology reported a 50 pm linewidth Tm -doped silica fiber laser at 2.4 W[10]. Later, with a 10 mm double-clad FBG, they obtained 39.4 W laser output with the spectral width less than 2 nm near 1.94 μm[11]. In 2010, AdValue Photonics Inc. and NASA Langley Research Center built an FBG cavity single-frequency 2 μm fiber laser with a laser linewidth as narrow as 3 kHz[12].

In this letter, we report high efficient operation of LD clad-pumped Tm-doped fiber lasers with different cavity configurations. Performance of different laser cavities is studied and compared.

1 Experiments and discussion

The experimental setup is shown in Fig.1. The 1.7 m long Tm-doped double-clad fiber has a core diameter of 25 μm (Core NA=0.09). The octagonal shaped inner-clad diameter is 250 μm (flat to flat) and NA no smaller than 0.46. Absorption coefficient of the Tm-doped fiber is estimated to be 9.5 dB/m at the pump wavelength. Main part of the active fiber is conduction-cooled. And at the output end, a filter is used to block the unabsorbed pump power.

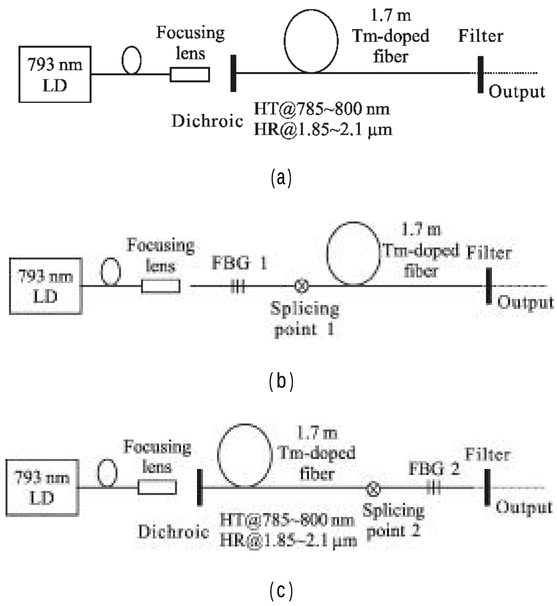


Fig.1 Experimental setup of different laser cavities

In Fig.1(a), a dichroic mirror with high reflectivity (HR)>99% at 1 850~2 100 nm and high transmissivity (HT)>99.5% at 785~800 nm is directly butted to the input end of the active fiber. At the other end, the 4% Fresnel reflection functions as the output coupler.

In Fig.1(b), a 98% reflection FBG(FBG 1) with a bandwidth of 1.8nm near 1996nm is spliced to the input end of the active fiber to replace the HR dichroic mirror used in Fig.1(a). The size of the FBG matches with the active fiber.

In Fig.1(c), an 8% reflection FBG(FBG 2) with a bandwidth of 0.7 nm near 1996nm is spliced to the output end of the active fiber to increase the output end reflectivity in Fig.1(a) to 8%.

Output power of the three different laser cavities is shown in Fig.2. A maximum output of 7.55 W is obtained when the launched pump reaches 17.9 W from laser cavity (a), which also contributes the maximum slope efficiency of 56.9% corresponding to a quantum efficiency of 142%. Compared with cavity (a), laser cavity (b) bears relatively lower slope efficiency. It can be explained by the much narrower reflective band and the lower reflectivity of FBG 1 compared with the dichroic mirror. The thresholds of cavity (a) and (b) are almost the same, showing a good splicing quality of splicing point 1 in Fig.1 (b). Theoretically, 8% reflection in cavity (c) should bring in a smaller threshold compared with cavity (a) as bigger output reflection makes lasing easier. However, the experimental results show that the threshold of cavity (c), 4.64 W, is almost the same with that of cavity (a). This is mainly due to the splicing loss induced by splicing point 2 in Fig.1(c).

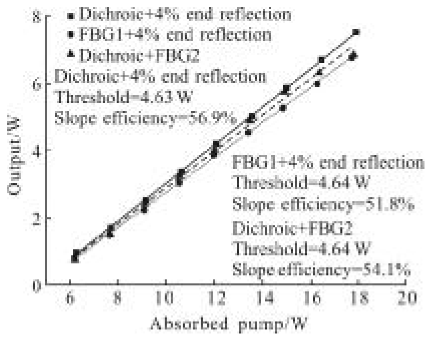
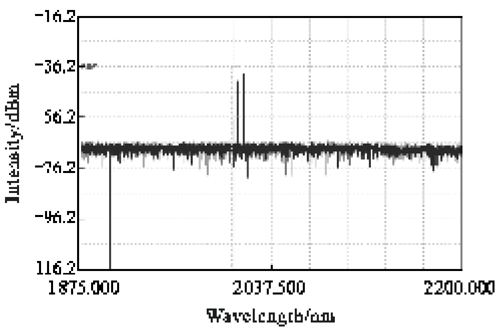
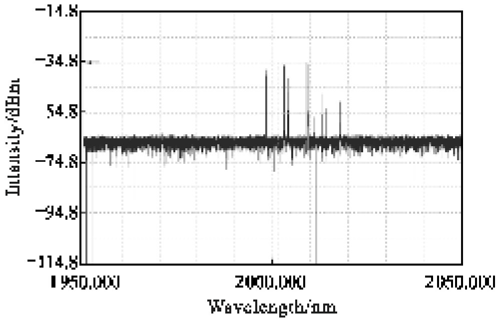


Fig.2 Laser output of three different laser cavities

Laser spectra of cavity (a) are shown in Fig.3. As the reflection of the dichroic mirror and the Fresnel reflection of the fiber end are broadband, the laser resonates randomly within the reflective range of the dichroic mirror. At 0.2 W output, the spectrum ranges around 2 μm with many separated lines, totally, showing a -3 dB linewidth of 7.94 nm. When the output power increases to 1 W, the spectrum broadens to 8.33 nm.



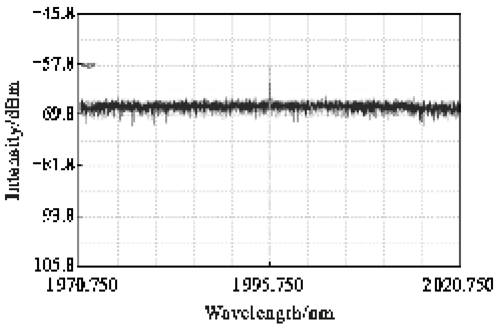
(a) 0.2 W output with a -3 dB linewidth of 7.94 nm



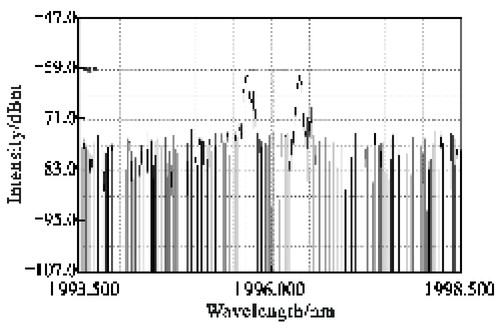
(b) 1 W output with a -3 dB linewidth of 8.33 nm

Fig.3 Laser spectra of cavity (a)

Different from the dichroic mirror, FBG 1 is a narrow reflector near 1996nm. So, the spectrum of cavity (b) shown in Fig. 4 is much narrower with the spectral width stay within the 1.8 nm reflective band of FBG 1 though multi-peaks may appear. At a low output power of 1 W, the -3 dB spectral linewidth is 38 pm, while at 4 W output, the linewidth increases to 0.73 nm.



(a) 1 W output with a -3 dB linewidth of 38 pm



(b) 4 W output with a -3 dB linewidth of 0.73 nm

Fig.4 Laser spectra of cavity (b)

Different from FBG 1, FBG 2 is partially reflective near 1 996 nm with a -3 dB bandwidth of only 0.7 nm. So, cavity(c) gives the narrowest spectral linewidth as shown in Fig.5. The -3 dB linewidth is 69 pm when the laser output is 0.9 W. And it increases with the output power to 0.49 nm at 3 W output with a splitted spectrum. But the further increase of the spectral width is limited by the 0.7 nm bandwidth of FBG 2.

Performance of the three different laser cavities is shown in Tab.1. It demonstrates that high quantum efficiency exceeding 100% is easily accessible in 793 nm LD-clad pumped Tm-doped fiber lasers with heavily doped active fibers under proper heat management. The traditional dichroic mirror cavity offers the highest slope efficiency while FBG cavity generates narrow spectral linewidth.

Tab.1 Performance of the three different laser cavities

Cavity	Quantum efficiency	Linewidth @ 1 W output
a	1.42	8.33 nm
b	1.30	38 pm
c	1.35	69 pm

2 Conclusion

High efficient operation of LD clad-pumped Tm-doped fiber lasers at 2 m is realized in different cavity configurations. A maximum slope efficiency of 56.9% is obtained with a dichroic mirror cavity. Spectral linewidth of the laser output is determined by the reflective bandwidth of the cavity mirror. With a dichroic mirror, the linewidth can be tens of nanometers wide while with an FBG, the linewidth is limited by the bandwidth of the FBG. Exploiting a 98% reflection FBG with a bandwidth of 1.8 nm as the HR mirror of the laser cavity, a laser output of 1 W with a -3 dB linewidth of 38pm is generated.

In conclusion, FBG cavity not only maintains the high efficiency of the dichroic mirror cavity, but also offers much better spectral performance depending on the reflective band of the FBG.

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