Article ID: 1004-4213(2010)03-0389-4

Design of Yb-doped All-fiber Laser Device Based on Optical Fiber Gratings Resonator*

ZHOU De-chun[1], YU Feng-xia[1], LU Jing-juan[1], TAN Fang[2]
(1 *School of Electronic Information Engineering, Changchun University of Science and Technology, Changchun* 130022, *China*)
(2 *College of science, Changchun University, Changchun* 130022, *China*)

Abstract: By means of numerical analysis method, the influences of many factors on output threshold pumped and output powers were analyzed, such as fiber length and back cavity lens reflectivity. These results provide theoretical foundation for optimized design of all-fiber laser device. Yb-doped all-fiber laser device with stable narrowed spectral linewidth laser output was made successfully, using fiber gratings as feedback and frequency-selected cavity lens. Tapered fiber realizes low-loss conncection between pumped module and Yb-doped double cladding fiber, and high effective pumped laser output power transmission. The stable laser output can be gained in this test, of which the wavelength is 1 082.50 nm, spectrometric width is 0.113 nm, the largest stable laser output power is 8.5 W, pumped threshold power is 0.8 W, and slope effectivity is 70.8%.

Key words: Optical fiber gratings; Yb-doped double cladding fiber; Tapered fiber; All-fiber laser device
CLCN: TN253 **Document Code**: A **doi**: 10.3788/gzxb20103903.0389

0 Introduction

Fiber laser device has many virtues: good stability, low pumped threshold, narrow linewidth, tunable, high conversion efficiency, simple application and maintenance exempt these characteristics make it become the main topic in the laser technology field[1-2]. At present, with the development of double clad fiber and cladding pumped technologies, fiber laser device sigle mode output power has increased from belowe 1 watt to thousands of kilowatt and even more[3]. This kind of high power laser device resonator is composed of dichroscope and end reflective lens, which make the laser output spectrum line width enlarged, furthermore coupling system structure of pumped light is so complex that is need very tedious regulation. As a low loss device, fiber grating has very good wavelength selection property. This paper used fiber grating as laser device resonator, this simplified laser structure, meanwhile improved the single-noise ratio and reliability, wavelength tunable conviently, narrowed the linewidth, improved the beam quality[4-5]. Furthermore, this resonator and welded the end fiber of pumped source with optical gain fiber effectively, this will not bring additional loss and decreased the threshold and improved output laser slope efficiency. Fiber grating can not only simplify the structure of laser but improve the coupled effective, which is significant to the study and application of all fiber laser.

1 Theorectical modle and analyses

1.1 Theorectical modle

Because Yb^{3+} ion has many virtues: wide absorb and emit spectrum, simpler energy level structure、no excited state absorption and concentration quench, Yb^{3+}-doped fiber laser has become the key study topic[6-7]. In this article used linear cavity Yb^{3+}-doped fiber laser. Numerical analysis modle of Yb^{3+}-doped fiber laser is indecated in Fig. 1. The length of Yb^{3+}-doped double clad gain fiber is L, the reflective rate of the fore and behind cavity to lasing light is R_1 and R_2, reflection rate to pumped light is 0 and 1 respectively. According to C. Bamard theory and energy transition of 4 levels[8], considering the specific parameters of Yb^{3+}, at the stable

* Supported by the Jilin Province Education Department Key Project(129519)
Tel: 0431-85582269 Email: zhoudechun0912@cust.edu.cn
Received date: 2009-06-30 Revised date: 2009-07-08

condition, we simplified the C. Barnard formula, the slope effectivity of Yb^{3+}-doped fiber laser linear cavity is

$$\eta=\frac{\lambda_p}{\lambda_s}\left[1-e^{(\alpha_s\cdot P_p^{sat}/P_s^{sat}-\alpha_p)L}\cdot\left(\sqrt{R_1R_2}\right)^{-P_p^{sat}/P_s^{sat}}\right]\quad(1)$$

In this formula, λ_s and λ_p is wavelenth of lasing light and pumped light, α_s and α_p is loss coefficient of laser and pumped light, P_s^{sat} and P_p^{sat} is saturate power of lasing light and pumped light, respectively.

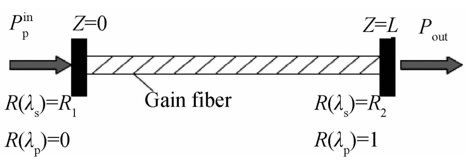

Fig. 1 Linear cavity numerical analysis modle

The output power of Yb^{3+}-doped fiber laser linear cavity[9] is

$$P_{out}=\frac{\lambda_p}{\lambda_s}\cdot\frac{(1-R_2)P_p^{sat}}{1-R_2-\sqrt{R_1R_2}+\sqrt{R_2/R_1}}\cdot\left[\frac{P_p^{in}}{P_p^{sat}}(1-\exp G)-G-\rho A_p\sigma_{ap}L\right]\quad(2)$$

In this formula, P_p^{in} is pump power when laser gained the threshold, ρ is Yb^{3+}-doped concentration, G is the fiber gain of double clad, which is exhibited[10]

$$G=-\frac{\rho A_p(\sigma_{ep}+\sigma_{ap})}{\sigma_{es}+\sigma_{as}}\left[\frac{\ln(R_1R_2)}{2\rho A_s}+\frac{\sigma_{es}\sigma_{ap}-\sigma_{ep}\sigma_{as}}{\sigma_{ep}+\sigma_{ap}}L\right]\quad(3)$$

In this formula, A_s and A_p is light field overlap integral of lasing light and pump light, σ_{es} and σ_{as} is the emission and absorption section of lasing light, σ_{ep} and σ_{ap} is the emssion and absorption section of pumped light, respectively.

When $P_{out}=0$, the threshold pump power is

$$P_{th}=P_p^{sat}\cdot\frac{G+\rho A_p\sigma_{ap}L}{1-\exp G}\quad(4)$$

1.2 Slope effectivity analyses

In this experiment, we used these following parameters to numerical simulate: $\lambda_p=976$ nm, $\lambda_s=1\,080$ nm、$\sigma_{ep}=\sigma_{ap}=2.5\times10^{-24}$ m^2、$\sigma_{es}=1.2\times10^{-25}$ m^2、$\sigma_{as}=1\times10^{-25}$ m^2、$A_s=1.13\times10^{-10}m^2$、$\alpha_s=2.4\times10^{-3}$ m^{-1}、$\alpha_p=3\times10^{-3}$ m^{-1}. According to formula(1), relation of slope effectivity with behind cavity efficiency and fiber length is indecated in Fig. 2. From this figure, laser slope efficiency become to limit value 85% with the increased of R_2 and L gradually. To the most efficiency, R_2 and L has their optimum value. When fiber length $L=20\sim25$ m, optimum value of R_2 is 0.20~0.25. So, in the design procession of laser, appropriate behind cavity reflectivity should be determined.

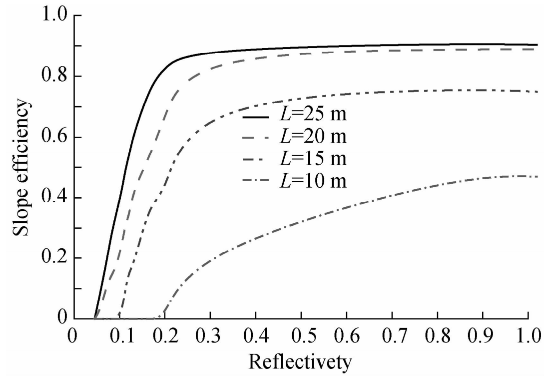

Fig. 2 Relation of slope effectivity with R_2 and L

1.3 Pumped threshold power analyses

Based on formula (4), threshold of Yb^{3+}-doped fiber laser linear cavity changes with the length of fiber is indicated in Fig. 3. From this figure, with the increase of R_2 and L, the pumped threshold decreases. When the fiber length is very short, the change of threshold power is obviously; When the fiber length is $L=5\sim25$ m, the threshold power reaches the minimum, then with increase of L, it increases slowly. So, in the design procession of laser, using appropriate length Yb^{3+}-doped fiber as gain media can decrease the pumped threshold of laser.

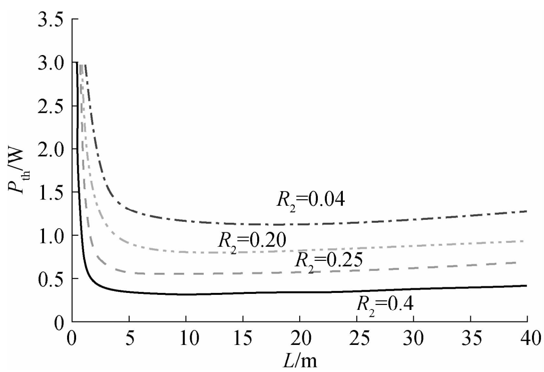

Fig. 3 Change of threshold power with fiber length

1.4 Laser output power analyses

According to formula (2) and the parametrers of 1.2, when input pumped power is 6, 8, 10, 12 W respectively, fiber length is $L=20$ m, mode field diameter of core fiber is 7 μm, the relationship of laser output power P_{out} and R_2 is indicated in Fig. 4.

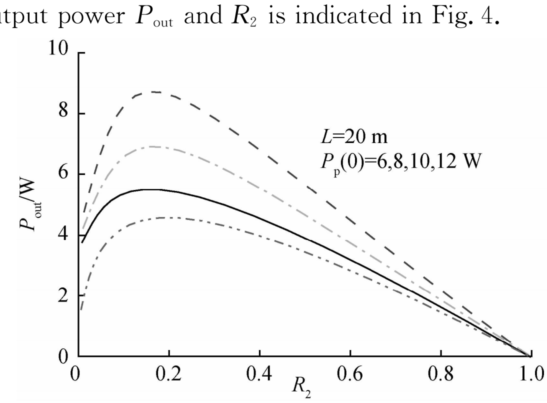

Fig. 4 Relation of laser output power with P_{out} and R_2

From this figure, with the increase of R_2, the output power also increases, when fiber length invariant. When R_2 increased 0.20, total output power $P_{out}=8.5$ W; When reflectivity exceed this value, output power decreases grudually. The numerical analyses of theoratical modle indicated, fiber length and reflectivity of output cavity must has better mathing ability if output power reach the maximum at given pumped power.

2 Design of structure

From formula (4), Yb^{3+}-doped fiber is pumped at different wavelength light, different absorption cross section would influence the threshold of laser device. When the pumped light waxelength is 975 nm, absorption cross section is maximum; when the wavelength is 980 nm, absorption and emmission of fiber is so strongly that it would decrease pump efficiency. In this experiment, we use wide cavity multimode LD as pump source[11], end-pumped method, the center wavelength is 976 nm.

In the design of structure, pump source LD tail fiber diameter is 300 μm, numerical aperture is 0.15; Yb^{3+}-doped double-clad gain fiber diameter is 200μm, fiber length is 20 m, fiber core shape is plum petal type, numerical aperture is 0.22, on which we ultilize phase-mask methodto write on fiber grating[12], use multimode fiber grating as before cavity len ($R_1=90\%$), use single mode as behind cavity len. According to numerical simulation, $R_2=20\%$. Because Yb^{3+}-doped double-clad gain fiber diameter is different from LD tail fiber, to gain high efficiency of weld couple, we ultilize tapered fiber, which realize low loss connection and high efficiency pump laser output transmission, increase high pomp couple efficiency. All-fiber laser design is indicated in Fig. 5, "×" is the fiber connection, which realize high power laser output of 8.5 W.

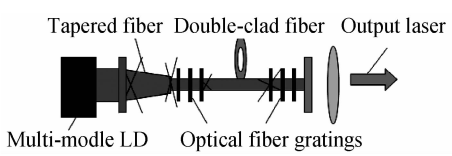

Fig. 5 Structure of all-fiber laser device

3 Results and discussion

When LD pumped power is 18 W, pumped source temperature is 23 ℃、threshold current is 3A, the laser is input into spectrometer after it is collinated through attenuator, output spectrum is indicated in Fig. 6. From this figure, its center wavelength is 1 082.50 nm, line width is 0.113 nm. In this spectrum, there are many weaker subpeaks, which may be raman or brillouin scatterings incented by pumped light[13].

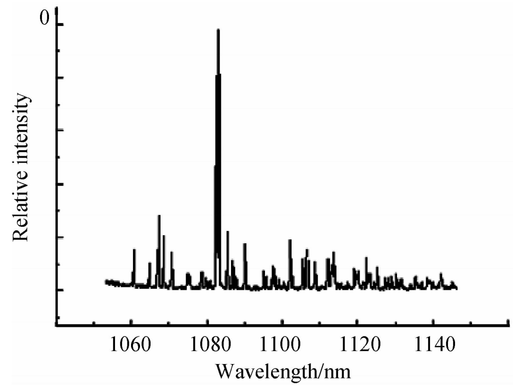

Fig. 6 Output spectrum of fiber device

The change curve of output and input power of all-fiber laser is indicated in Fig. 7. From this figure, pump threshold power is 0.8 W, the largest output power is 8.5 W, the largest enter fiber pump power is 12 W, slope efficiency is 70.8%.

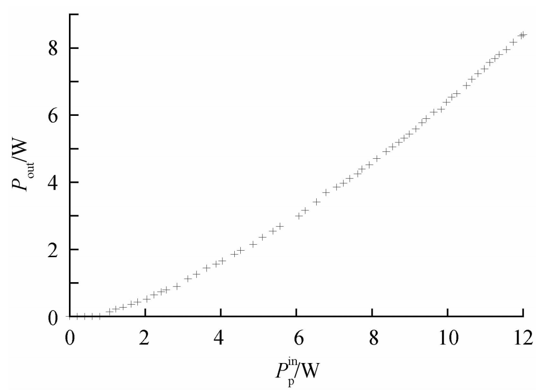

Fig. 7 Output power of fiber device

4 Conclusion

According to the C. Bamard theory, linear cavity numerical analysis modle of Yb^{3+}-doped fiber laser is build, the relation of slope efficiency、output power、threshold pump power and fiber length and behind cavity len reflctivity is analysesed. End-pump fiber laser device is designed, realized low loss connection and high efficiency pump laser power transmission between pump module、fiber grating and double-clad fiber. We gained stable laser output of peak wavelength is 1 082.50 nm, line width is 0.113 nm, slope efficiency is 70.8% and largest outpot power is 8.5 W when enter fiber power is 12 W.

References

[1] DUAN Yun-feng, ZHANG Peng, HUANG Bang-cai, *et al*. Fiber Amplifier[J]. *Chinese Journal of Lasers*, 2009, **36**(3): 640-642.

[2] ZHOU Jun, LOU Qi-hong, ZHU Jian-qiang, *et al*. A continuous-wave 714 W fiber laser with China-made large-

mode-area double-clad fiber [J]. *Acta Optica Sinica*, 2006, **26**(7): 1119-1120.

[3] SHANG Liang, SONG Zhi-qiang, MAO Qing-he. Experimental-research on output characteristics of high power Yb^{3+}-Doped double clad fiber laser[J]. *Chinese Journal of Lasers*, 2007, **34**(6): 755-758.

[4] WU Bo, LIU Yong-zhi, ZHANG Qian-shu, *et al*. High efficient narrow linewidth fiber laser based on fiber grating fabry-perot cavity[J]. *Chinese Journal of Lasers*, 2007, **34**(3): 350-353.

[5] SI Li-bin, FU Sheng-gui, JIA Xiu-jie, *et al*. High power switchable multi-wavelength double-clad fiber laser[J]. *Acta Photonica Sinica*, 2008, **37**(2): 209-211.

[6] XIE Chun-xia, LÜ Fu-yun, WANG Jian, *et al*. Experimental study on large-mode-area Yb^{3+}-doped double-clad fiber laser [J]. *Acta Photonica Sinica*, 2005, **34**(5): 645-647.

[7] CHEN Shuang, FENG Ying, ZHANG Jun. Effect of bsck-cavity mirror on output characteristecs of Yb^{3+}-doped double-clad fiber laser[J]. *Acta Photonica Sinica*, 2008, **37**(5): 901-905.

[8] BAMARD C, MYSLINSKI P. Analytical model for rare-earth-doped fiberamplifiers and lasers. IEEE [J]. *Quantum Electronics*. 1994, **30**(8): 1817-1829.

[9] WANG Ji, ZHAO Cong-guang, LIU Yang, *et al*. Yb-doped double-clad fiber laser device based on double-clad optical fiber gratings[J]. *Semiconductor Optoelectronics*, 2006, **27**(5): 522-555.

[10] HU Gui-jun, DENG Xiao-ying, ZHANG Liang, *et al*. Study of Yb-doped double-clad high power fiber device output [J]. *Semiconductor Optoelectronics*, 2003, **24**(6): 402-405.

[11] ZHOU Shou-heng. Development on all solid state laser technology [J]. *Development on Modern Optics and Photonics*, 2006, **1**(2): 45-72.

[12] WANG Li, CHEN Bai, CHENG Jia-lin, *et al*. Fabrication of Yb-doped phase-shifted fiber grating laser [J]. *Chinese Journal of Lasers*, 2007, **34**(12): 1617-1620.

[13] HU Shu-ling, ZHANG Chun-xi, GAO Chun-qing, *et al*. Stimulated raman scattering and stimulated brillouin scattering effects in Ytterbium doped double clad fiber laser [J]. *Chinese Journal of Lasers*, 2008, **35**(1): 6-10.

基于光纤光栅谐振腔的掺镱全光纤激光器设计

周德春[1]，于凤霞[1]，卢敬娟[1]，谭芳[2]

(1 长春理工大学 电子信息工程学院，长春 130022)

(2 长春大学 理学院，长春 130022)

摘 要：采用数值分析方法分析了光纤长度、后腔镜反射率等因素对激光器输出阈值泵浦功率、输出功率的影响，为全光纤激光器的优化设计提供了理论基础. 在设计过程中采用光纤光栅作为光纤激光器的反馈与选频腔镜，通过锥度光纤实现了泵浦模块与掺镱双包层光纤之间的低损耗连接以及高效率的泵浦激光功率传输，成功研制了具备稳定窄化线宽激光输出的掺镱全光纤激光器. 实验得到了波长峰值在 1 082.50 nm，谱线宽度 0.113 nm，最大输出功率 8.5 W，泵浦阈值功率 0.8 W，斜率效率为 70.8%的稳定激光输出.

关键词：光纤光栅；掺镱双包层光纤；锥度光纤；全光纤激光器

ZHOU De-chun was born in 1964. He received his M. S. degree from Northeast Normal University, and currently pursuing the Ph. D. degree, and his research interests focus on optics material and device application.

YU Feng-xia was born in 1950. She is a professor and Doctoral Supervisor at Changchun University of Science and Technology, and her research interests focus on fiber material and optical fiber device.