Tandem-pumped 1120-nm actively Q-switched fiber laser

Wang Jian-Hua(王建华)[a)b)c)], Hu Jin-Meng(胡金萌)[b)], Zhang Shi-Qiang(张世强)[c)], Chen Lu-Lu(陈露璐)[c)], Fang Yong(房 勇)[c)], Feng Yan(冯 衍)[b)†], and Li Zhi(李 智)[a)]

[a)] *Department of Space and Command, Academy of Equipment, Beijing* 101416, *China*
[b)] *Shanghai Key Laboratory of Solid State Laser and Application, and Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai* 201800, *China*
[c)] *Northwest Institute of Nuclear Technology, Xi'an* 710024, *China*

(Received 26 May 2014; revised manuscript received 16 July 2014; published online 10 December 2014)

We report on a tandem-pumped actively Q-switched fiber laser system emitting at 1120 nm. Parasitic oscillation is challenging in Yb-doped Q-switched 1120-nm fiber laser, which is suppressed by pumping with a fiber laser at 1018 nm. At least four times improvement in output peak power is demonstrated in a single laser setup with 1018-nm fiber laser pumping instead of 976-nm laser diode pumping. This is, to the best of our knowledge, the first demonstration of a tandem-pumped Q-switched fiber laser.

Keywords: tandem pumping, Q-switching, fiber laser, ytterbium

PACS: 42.55.Wd, 42.60.Gd, 42.55.Xi **DOI:** 10.1088/1674-1056/24/2/024214

1. Introduction

There is a need for a pulsed fiber laser at 1120 nm due to its application in researching stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS).[1–4] However, reports on pulsed 1120-nm Yb-doped fiber laser are rare compared with those on a conventional pulsed fiber laser at 1 μm and a short wavelength pulsed fiber laser at 976 nm.[2,5–8] The major limiting factor is the parasitic oscillation at about 1060 nm for long wavelength operation of a Yb-doped fiber laser. At continuous wave (CW) operating mode, fiber lasers emitting beyond 1100 nm have been investigated.[9–12] The threshold of parasitic lasing can be improved by carefully choosing the gain fiber, employing high reflectivity output fiber Bragg grating (FBG), and heating the gain fiber for reducing the amplified stimulated emission (ASE) gain. With the active fiber heated up to 60 °C, a 15-W fiber laser at 1154 nm was obtained with a slope efficiency of 50%.[9] A 167-W fiber laser at 1178 nm was achieved with a slope efficiency of 61% by employing Yb-doped solid-core photonic bandgap fiber.[10] With a pump laser at 1090 nm, a 1179-nm fiber laser with up to 12 W was demonstrated by Kalita *et al.* using a standard Yb-doped gain fiber.[11]

Although methods are employed to improve the threshold of parasitic lasing and reduce the gain of ASE in a CW fiber laser, there are no papers reported on the suppression of parasitic lasing in pulsed fiber laser. The tandem pumping scheme,[13] in which one or several fiber lasers are used as a pump source, is mostly used to obtain high power CW laser output for low thermal load. In this paper, we focus on the parasitic oscillation suppression by using a tandem pumping scheme. We demonstrate an all-fiber, single-mode, tandem-pumped, actively Q-switched laser at 1120 nm pumped by a fiber laser at 1018 nm. The threshold of parasitic oscillation is improved and a peak power of 320 W with a pulse duration of 150 ns is realized.

2. Experimental setup

The experimental configuration is shown in Fig. 1. The laser cavity consists of a pair of FBGs, 5-m Yb-doped fiber, and a fiber-pigtailed acousto–optical modulator (AOM). The detailed parameters of gain fiber, FBGs, and AOM are the same as those in our previous report.[2] There are two different pump lasers injected to the laser cavity by a (2+1)×1 combiner. The pump input fibers of the combiner are multi-mode fiber with a 105-μm core diameter and a numerical aperture (NA) of 0.15. The input and output signal fibers have the same parameters as the FBG fiber. Pump 1 is a laser diode (LD) of 10 W at 976 nm, whose output fiber has a core diameter of 105 μm and an NA of 0.15. Pump 2 is a Yb-doped phosphosilicate fiber laser at 1018 nm,[14] whose output fiber has a core and inner cladding diameter of 15 μm and 130 μm, respectively. An isolator (ISO) at 1015 nm is used to block any backward light, as shown in Fig. 1. The pigtail of the ISO is a single cladding fiber, which is used to provide core-pumping for tandem-pumped 1120 nm actively Q-switched laser. The parasitic oscillation, which is harmful for a laser, can be produced with a low pump power in a Q-switched laser with large cavity loss. In order to illustrate the suppression effect of parasitic oscillation with tandem-pumping by a 1018-nm fiber laser, the loss at spliced point *A* is increased compared with the result in our previous paper.[2]

†Corresponding author. E-mail: feng@siom.ac.cn

© 2015 Chinese Physical Society and IOP Publishing Ltd

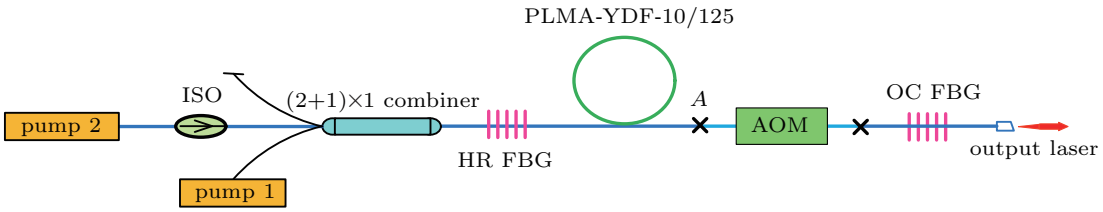


Fig. 1. (color online) Experimental configuration with pump 1 (976-nm laser diode) and pump 2 (1018-nm fiber laser).

Pump 1 and pump 2 are injected into the laser cavity through the pump fiber and signal fiber of the combiner, as shown in Fig. 1, respectively. The residual cladding power of pump 1 is removed by the single cladding fiber of the AOM. All of the fiber ends are cleaved with an angle of 8° to suppress parasitic oscillation.

3. Results and discussion

With our experimental configuration, there is a range of AOM switching rates that can produce a stable pulse train from 2 kHz to 20 kHz. The output powers of 1120-nm Q-switched fiber laser versus launched 1018-nm and 976-nm pump powers are shown in Figs. 2 and 3, respectively. One can see that the output power increases with the increase of repetition rate. At repetition rates of 2 kHz and 20 kHz, the output powers of 1018-nm pumped Q-switched fiber laser are 95 mW and 120 mW, respectively, which are limited by the available pump power. When the same laser setup is pumped with the 976-nm laser diode, parasitic lasing is encountered at a pump power as low as 1.5 W. The maximum achieved outputs are only 34 mW and 45 mW at repetition rates of 2 kHz and 20 kHz, respectively. Higher parasitic lasing threshold and lower ASE with 1018-nm pumping is understood for the lower ratio of excited ions than with 976-nm pumping, and red-shifted gain spectrum.

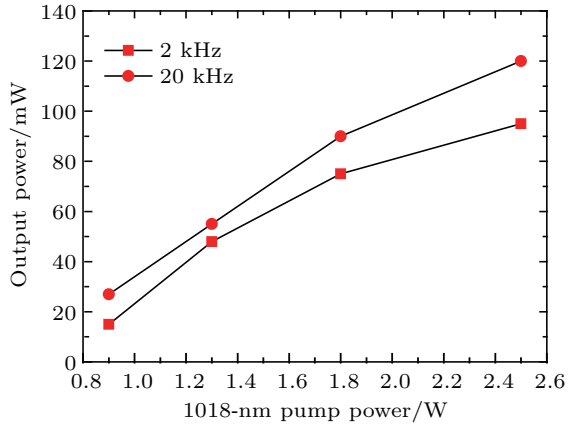


Fig. 2. (color online) Plots of output power of 1120-nm Q-switched fiber laser versus launched 1018-nm pump power at two different frequencies.

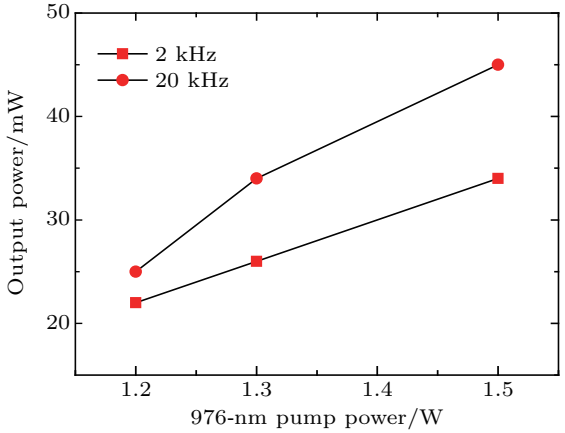


Fig. 3. (color online) Plots of output power of 1120-nm Q-switched fiber laser versus launched 976-nm pump power.

Measured with a spectral analyzer (AQ 6370, Yakogawa Corp.), the spectral characteristics of tandem-pumped actively Q-switched fiber laser at the 1120 nm is shown in Fig. 4. Although core pumping is employed for adequate absorption, little residual 1018-nm pump laser is observed in Fig. 4. The signal laser at 1120 nm is 30 dB higher than ASE at a repetition rate of 2 kHz with a pump power of 2.5 W. The full width at half maximum (FWHM) linewidth is 0.3 nm, measured with a resolution of 0.02 nm. Estimated by spectral integration,[6] the ratio of ASE to laser power is lower than 4.5%. The spectral characteristics of the 1120-nm actively Q-switched fiber laser at 2 kHz pumped by 976-nm laser diode are shown in Fig. 5, in which there appears a sign of parasitic lasing at ∼1060 nm. The ratio of ASE to the total power is about 41.7%, which is calculated by the spectral integration. The large ratio of ASE also illustrates that the tandem-pumping scheme with 1018-nm fiber laser serving as a pump source is beneficial to the ASE suppression.

The single pulse profile at a repetition rate of 2 kHz is illustrated in Fig. 6, where the inset shows the pulse train. The pulse is recorded by a digitally sampled oscilloscope (600-MHz bandwidth, LeCroy Corp.) together with a 2.3-ns rising time photodiode (PDA 10CF, Thorlabs Inc.). No interpulse ASE is observed.

The variations of pulse duration with pulse repetition are shown in Fig. 7. The pulse duration increases with the increase of the repetition rate. When the actively Q-switched fiber laser is pumped by the 976-nm laser diode, the least pulse

durations are 190-ns at a repetition rate of 2 kHz, and 260 ns at 20 kHz, respectively. In the tandem-pumping scheme with a 1018-nm fiber laser as a pump source, the least pulse durations of 150 ns and 220 ns are obtained at repetition rates of 2 kHz and 20 kHz, respectively. The threshold of parasitic lasing is improved by tandem-pumping, so more pump power can be injected and the pulse duration is much smaller than that pumped by a 976-nm laser diode.

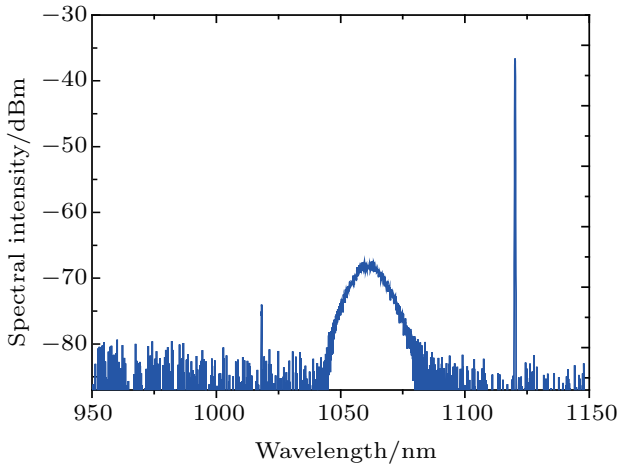


Fig. 4. (color online) Spectral characteristics of tandem-pumped 1120-nm actively Q-switched fiber laser at 2 kHz.

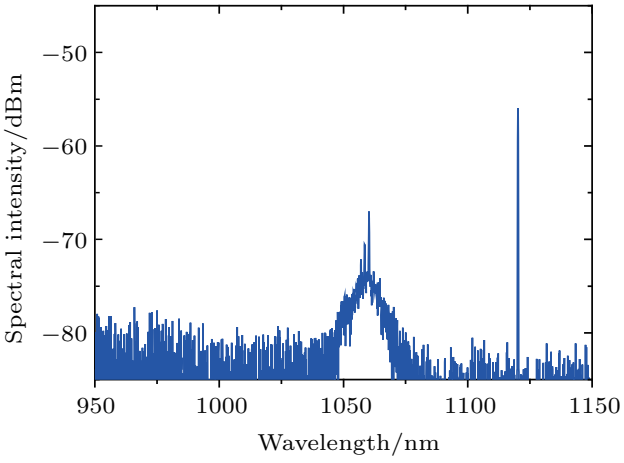


Fig. 5. (color online) Spectral characteristics of 1120-nm actively Q-switched fiber laser at 2 kHz pumped by 976-nm laser diode.

The variations of peak power of actively Q-switched fiber laser at 1120 nm with pulse repetition are shown in Fig. 8. With the increase of pulse repetition, the peak power decreases due to the increase of pulse duration. A peak power of 80 W is achieved at a repetition rate of 2 kHz pumped by 976-nm laser diode. Correspondingly, the peak power tandem-pumped by 1018-nm fiber laser is 320 W at a repetition rate of 2 kHz, which is four times higher than that achieved by 976-nm laser diode pumping. The experimental results show that the tandem-pumping is more suitable to obtain high average power and high peak power Yb-doped actively Q-switched fiber laser at 1120 nm.

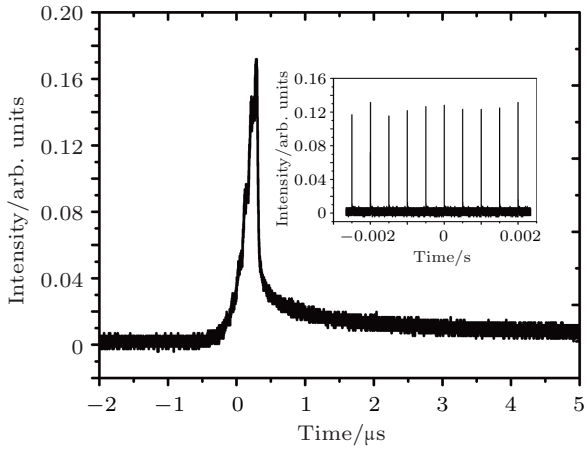


Fig. 6. Single pulse profile at 2 kHz from tandem-pumped 1120-nm actively Q-switched fiber laser, with the inset showing the measured pulse train.

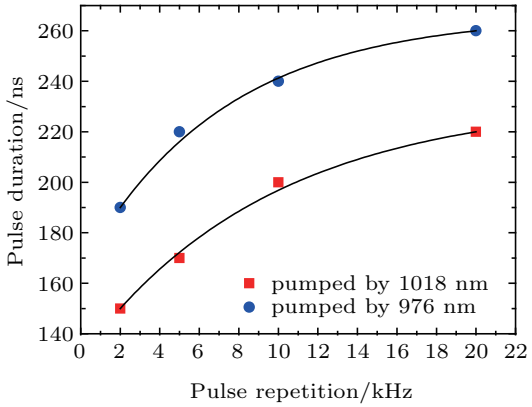


Fig. 7. (color online) Plots of pulse duration versus pulse repetition.

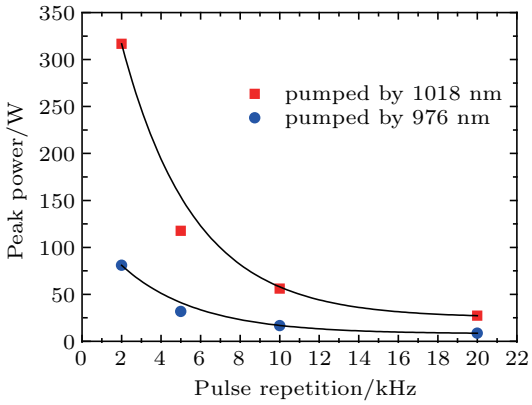


Fig. 8. (color online) Variations of peak power with pulse repetition.

4. Conclusion

In this paper, we demonstrate an all-fiber single-mode actively Q-switched fiber laser at 1120 nm with ASE and parasitic oscillation suppression by a tandem-pumping scheme. At least four times suppression of parasitic lasing is achieved with 1018-nm fiber laser pumping instead of 976-nm laser diode pumping. As far as we know, this is the first report on a

tandem-pumped Q-switched Yb-doped fiber laser. Better performance can be obtained by optimizing the laser setup and a much higher peak power with large mode area gain fiber and tandem pumping scheme can be expected.

References

[1] Wang J, Hu J, Zhang L, Gu X, Chen J and Feng Y 2012 *Opt. Express* **20** 28373
[2] Wang J, Cui S, Si L, Chen J and Feng Y 2013 *Opt. Express* **21** 289
[3] Zhang L, Hu J, Wang J and Feng Y 2012 *Opt. Lett.* **37** 4796
[4] Feng Y, Taylor L R and Calia D B 2008 *Opt. Express* **16** 10927
[5] Brooks C D and Teodoro F D 2005 *Opt. Express* **13** 8999
[6] Stutzki F, Jansen F, Liem A, Jauregui C, Limpert J and Tünnermann A 2012 *Opt. Lett.* **37** 1073
[7] Boullet J, Dubrasquet R, Medina C, Doua R B, Traynor N and Cormier E 2010 *Opt. Lett.* **35** 1650
[8] Schmidt O, Rothhardt J, Roser F, Linke S, Schreiber T, Rademaker K, Limpert J, Ermeneux S, Yvernault P, Salin F and Tünnermann A 2007 *Opt. Lett.* **32** 1551
[9] Jacquemet M, Mugnier A, Corre G L, Goyat E and Pureur D 2009 *IEEE J. Sel. Top. Quantum Electron.* **15** 120
[10] Olausson C B, Shirakawa A, Chen M, Lyngeo J K, Broeng J, Hansen K P, Bjarklev A and Ueda K 2010 *Opt. Express* **18** 16345
[11] Kalita M P, Alam S, Codemard C, Yoo S, Boyland A J, Ibsen M and Sahu J K 2010 *Opt. Express* **18** 5920
[12] Wang J, Cui S, Hu J, Cao F, Fang Y and Lu H 2014 *Chin. Phys. Lett.* **31** 064210
[13] Hao J, Yan P, Xiao Q, Li D and Gong M 2014 *Chin. Phys. B* **23** 014203
[14] Wang J, Chen G, Zhang L, Hu J, Li J, He B, Chen J, Gu X, Zhou J and Feng Y 2012 *Appl. Opt.* **51** 7130