# High-power random distributed feedback Raman fiber laser operating at 1.2-μm

**Hanwei Zhang (张汉伟)*, Hu Xiao (肖 虎), Pu Zhou (周 朴), Xiaolin Wang (王小林), and Xiaojun Xu (许晓军)***

*College of Optoelectronic Science and Engineering, National University of Defense Technology, Changsha 410073, China*

**Corresponding author: xuxj@21cn.com*

Received March 24, 2014; accepted May 3, 2014; posted online September 10, 2014

Random distributed feedback Raman fiber laser is a convenient method to generate laser without using cavity mirrors. We show for the first time to the best of our knowledge a 10-W-level random fiber laser operated at 1178 and 1212 nm (1.2-μm range). The power character and features in time domain and spectrum are presented.

*OCIS codes: 140.3510, 140.3490.*
*DOI: 10.3788/COL201412.S21410.*

Random distributed feedback (RDFB) Raman fiber laser is a new method to generate lasers[1]. The feedback is provided by the extremely weak Rayleigh scattering, and due to the random nature of such scattering in optical fiber, the output spectrum exhibits random emitting at the generation threshold. The most obvious advantage of such method is the simple design to produce laser without using cavity mirrors, such as fiber Bragg gratings. Both the feedback and the optical gain come from the passive fiber. In earlier studies, the researchers focused more on the spectrum characters and the generation threshold[2–6]. Moreover, the output power was relatively low and limited to watt level. Here we try to prove the concept of generation of high-power random fiber laser using short cavity. We have used here Raman gain fiber, which is a 1-km-long single-mode fiber (SMF) and is directly core-pumped by two kinds of ytterbium (Yb)-doped fiber lasers (YDFLs) of wavelengths 1120 and 1150 nm. By this cavity, we achieved for the first time to the best of our knowledge a 10-W-level random fiber laser operated at 1178 and 1212 nm (1.2-μm range). The output spectra emitted randomly at threshold and turned to smooth and stable when pump power was above the threshold. The spectral broadening was also recorded and discussed. The output power in two directions of the cavity was presented and the power difference was briefly analyzed. In time region, the self-oscillation of the Stokes wave was observed. The oscillation period was consistent to the transit time and the possible reason was proposed.

Figure 1 shows the typical random fiber laser pumped from one side. The pump source is a YDFL operating at 1120 nm. The length of the passive fiber that works as Raman gain medium is 1 km and the core diameter is 6-μm. The linear loss coefficients of the passive fiber are $\alpha_0 = 0.28\ km^{-1}$ for 1120 nm and $\alpha_1 = 0.23\ km^{-1}$ for 1178 nm. Raman peak gain coefficient, $g_R = 3\ W^{-1}km^{-1}$, is experimentally measured. Because of the core diameter of the YDFL being 10-μm, a tapered mode field adaptor is used to connect the YDFL and Raman gain medium. All the fiber-free ends of the system are angle cleaved for Fresnel-free reflection.

Random lasing is observed when the pump power is about 4 W. Figure 2 shows the measured spectra in the forward direction at different pump powers. The obtained Raman gain can balance the transit loss, as a result of which the backward Rayleigh scattering can feedback enough photons to their initial place when close to the threshold level. Thus, randomly emission peak at 1179 nm could be found in the spectrum. When the pump power is above the threshold, the spectrum becomes smooth and stable and attains a Gaussian shape. At the maximum pump power of 16.3 W, the central wavelength is 1178 nm and the 3-dB bandwidth

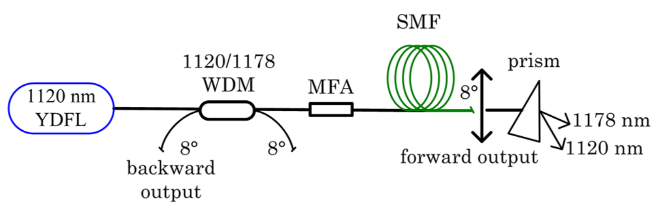



Fig. 1. The experimental setup of the random fiber lasers pumped by 1120-nm YDFL.

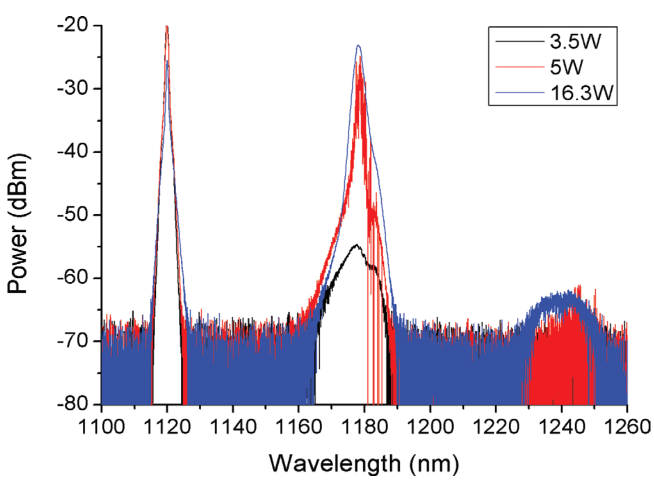



Fig. 2. Forward output spectra at different 1120-nm pump power.

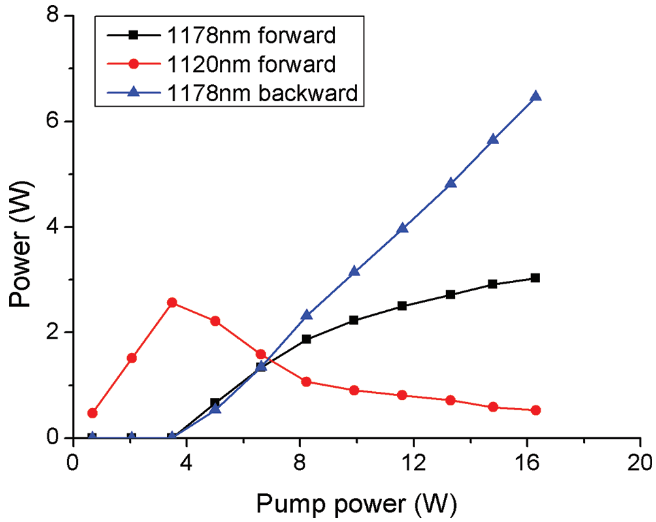
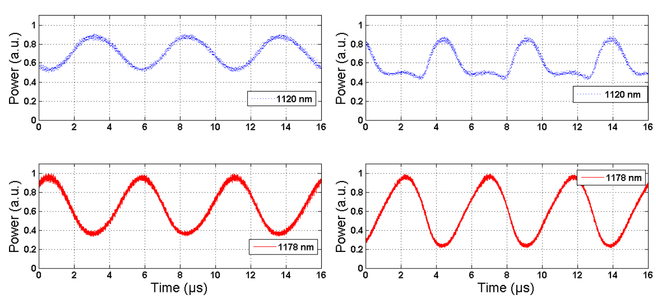



Fig. 3. Residual pump and generated Stokes wave power in forward and backward directions as a function of 1120-nm pump power.

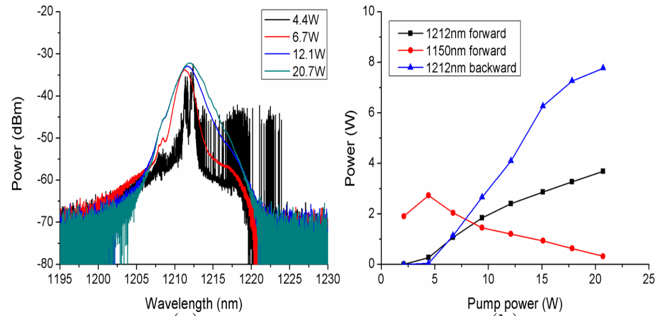
is about 2.3 nm. These spectral behaviors are similar to those of previously reported RDFB Raman fiber lasers[1–3].

The pump and Stokes waves are separated by a prism in free space. The output power of pump and Stokes waves in forward and backward directions are carefully recorded at different 1120 nm pump powers (see Fig. 3). The threshold is around 4 W. On increasing the pump power above the threshold, the Stokes wave starts increasing in both directions. Finally, we achieve the values of 3.4 and 8.4 W in forward and backward directions, respectively. The total output power is 11.8 W and the optical–optical efficiency is 76%. In our experiment on further increasing the pump power the lower order Stokes wave might be completely converted to the second-order Stokes wave, but higher power could be expected with shorted fiber. It is to be noted that the Stokes wave increases differently in forward and backward directions on increasing the pump power: in backward direction, the Stokes wave increases linearly with the pump power, but it becomes saturated and tends to be constant with increasing pump power in the forward direction. It can be qualitatively explained as follows: the position where pump and




(a) (b)

Fig. 4. The experimental waveforms of the residual pump power and output Stokes wave at pump power of (a) 8.2 and (b) 16.3 W.




(a) (b)

Fig. 5. The output (a) spectra and (b) power of the random fiber laser pumped by 1150-nm YDFL.

Stokes wave interacted with each other moves to the left (which is the pump injected side) with the pump power increasing. Rapid pump wave depletion occurs at this position, thus inducing the forward Stokes wave that experiences attenuation in its residual propagation. But amplification of the backward Stokes wave would not be affected because it happens only at the front part of the passive fiber[7].

We monitored the temporal characters of the output waves at the forward end of the laser. Interestingly, the output waves turn from CW mode to disciplinary pulse operation when the Stokes wave arises. Figure 4 shows two typical waveforms of the output Stokes waves. The self-oscillations have a period of about 4.9-μs, which is close to the transit time $nL/c$ (where $n$ is the refraction index of fiber, $L$ the length of the cavity, and $c$ the speed of light in vacuum) in the SMF, which is about 4.8-μs. The period remains almost unchanged when altering the pump power. Moreover, in a long time range the pulses are still in a stable state. It should be noted that the power oscillations of the pump and Stokes waves occur in antiphase motion. Such oscillations can also be found in traditional Raman fiber lasers, which result from the instability of the states of polarization of the pump and Stokes waves[8,9]. It is believed that the birefringence- and Kerr-induced changes in polarization states dramatically affect the dynamics of Raman fiber lasers.

We also pumped the random fiber laser by a YDFL operating at 1150 nm; the spectrum and power are shown in Fig. 5. It can be found that the output characters are nearly the same as in the case when pumped by YDFL operating at 1120 nm. Finally, we achieved 7.8- and 3.7-W laser power in forward and backward directions, respectively, operating at of 1212 nm. Without using wavelength selected component, the central wavelength of the presented random fiber laser usually located at the peak of the Raman gain spectrum. In the 1120 nm pumped case, the frequency downshift is 13.188 THz, but the value increased to 13.345 THz when pumped with YDFL operating at 1150 nm.

In conclusion, a Raman fiber laser based on Rayleigh backward scattering operated at 1.2-μm is shown here. Core-pumped by YDFLs, we achieve totally 11.8- and 11.3-W laser output, respectively, operating at 1178 and 1212 nm. The randomly emitting character at generation threshold is recorded and the power increasing tendency in forward and backward directions is discussed. The self-oscillation character in time region is also observed, which is similar to that of the traditional Raman fiber lasers resulting due to the instability of the states of polarization of the pump and Stokes waves.

This work was supported by the National Natural Science Foundation of China (No. 61322505), the Foundation for the Author of National Excellent Doctoral Dissertation of China, and the Hunan Provincial Innovation Foundation for Postgraduate Student.

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