1053 nm Raman random fiber laser with 182% slope efficiency

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***Abstract*—In high power laser facilities, using low-coherence lightwave could effectively suppress laser-plasma instability. Raman random fiber laser (RRFL) is a typical low-coherence light source whose working wavelength is determined by pump wavelength and gain medium. Utilizing the home-made 1010 nm laser to pump HI 1060 Flex fiber, 1053 nm RRFL is achieved for the first time with 182% slope efficiency. The work could further broaden the application of RRFL in the field of high energy density physics.**

Keywords—Random distributed feedback fiber laser, Raman gain, Ytterbium-doped fiber laser.

I. Introduction

Laser-plasma instability (LPI) is one of the main reasons for hindering the research of high energy density physics and laser-driven inertial confinement fusion (ICF) [1]. In recent years, low-coherence laser is considered as one of the effective schemes to overcome LPI effect [2]. A new type of low-coherence light source with adjustable spectrum, namely, the random fiber laser (RFL), was proposed in 2010 [3]. RFL has the characteristics of high efficiency [4-7], low threshold [8-9], wide wavelength range [10-12], low coherence [13] etc. Particularly, the 1053 nm RFL is considered as one of the seed source candidates for the next generation of ICF.

Generally, RFL working at 1 μm band employs active fiber to provide gain [10]. The 1053 nm ytterbium-doped RFL (YRFL) with forward pumping structure has been demonstrated to have advantages in efficiency and threshold [14]. In addition, the wideband 1053 nm YRFL with forward pumping structure had been utilized as a seed source to realize the first random laser system with megawatt-class peak power [15]. However, the self-pulsing effects and other nonlinear effects in YRFL may cause the unstability of the output spectrum, which needs to be further improved.

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The traditional RFL system is based on Raman gain, i.e., Raman random fiber laser (RRFL). RRFL shows stability in time-domain and spectral domain [16]. However, due to the lack of suitable high-power pump source, RFL that utilizes both Raman gain and random distributed feedback from passive fiber in the wavelength of ~1.05 μm has not been reported yet.

In this paper, a stable and efficient 1053 nm RRFL is proposed for the first time, using a home-made 1010 nm ytterbium-doped fiber laser (YDFL) as the pump. The 1053 nm RRFL utilizes passive HI 1060 Flex fiber to provide Raman gain and random distributed feedback, and a fiber loop mirror (FLM) to provide wideband point feedback. Based on this scheme, a stable spectral output and 182% slope efficiency is achieved.

II. Experimental Setup and Results

The structure of the RRFL system is shown in Fig 1. A home-made YDFL operating at 1010 nm with high-spectral-purity acts as the pump source of RRFL system. An optical isolator (ISO) operating at 1010 nm is added between 1010 nm pump and the Raman random fiber laser cavity, to avoid the backward propagating waves affecting the pump laser. Through a 1053/1010 nm wavelength division multiplexer (WDM), the pump laser is injected into a 3 km passive fiber (HI 1060 Flex fiber). The HI 1060 Flex fiber provides Raman gain and random distributed feedback. The FLM is connected to the 1053 nm port of WDM to realize the half-open cavity 1053 nm RRFL.

HI 1060 Flex fiber has higher Raman gain coefficient and Rayleigh scattering coefficient than standard single mode fiber, so it can provide lower lasing threshold. Moreover, the cut-off wavelength of the HI 1060 Flex fiber is 930 nm, so the 1.05 μm band is single-mode operation, which can produce lasing output with good beam quality.

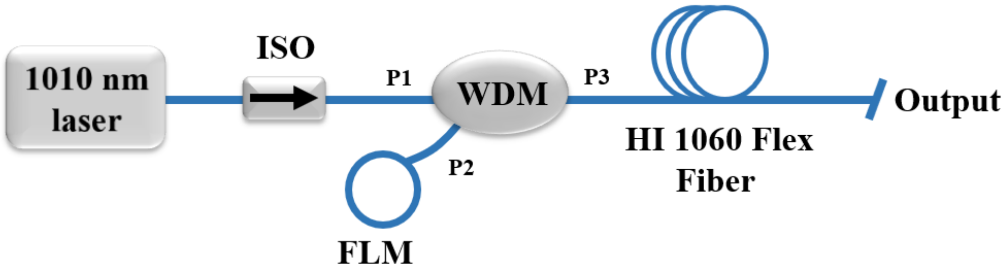

Fig. 1. Experimental setup of the RRFL system. ISO: optical isolator; WDM: wavelength division multiplexer; FLM: fiber loop mirror.

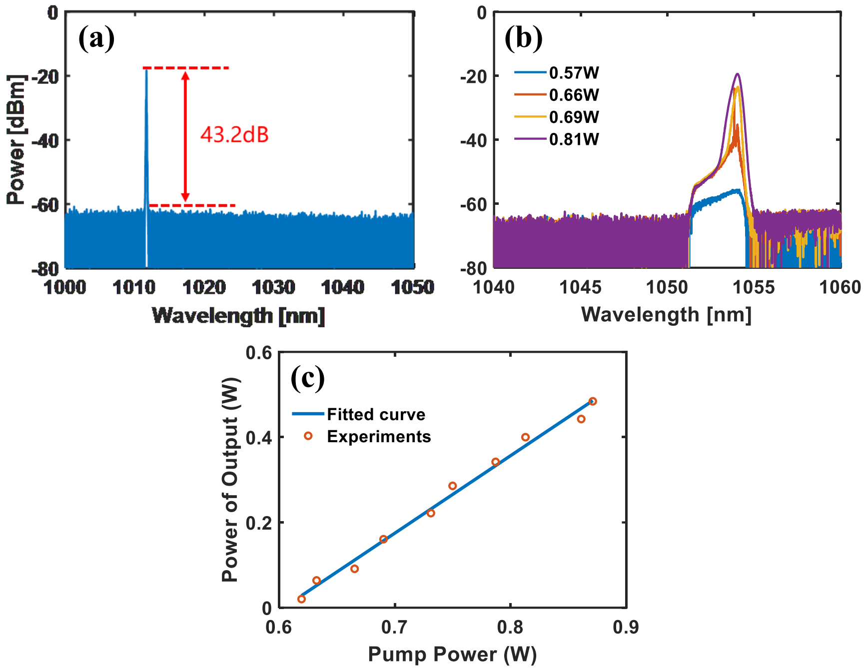

Fig. 2. Spectrum of (a) 1010 nm pump source and (b) 1053 nm RRFL. (c) Output power of the RRFL vs pump power.

An optical spectral analyzer (OSA) with a resolution of 0.01 nm is utilized to measure the spectrum of the pump source (1010 nm YDFL) of the RRFL system, shown in Fig 2 (a). The optical signal-to-noise ratio (OSNR) of the 1010 nm pump source is as high as ~43.2 dB. In addition, the RRFL spectrum measured under different pump power is illustrated in Fig 2 (b). When the pump power is 0.66 W, which is close to the RRFL lasing threshold, the spectrum fluctuates violently around 1053 nm. Fig 2 (c) illustrates the output 1053 nm RRFL power at the fiber end as a function of 1010 nm pump power, showing a slope efficiency of about 182%. The experimental results indicate that the system generates a stable and efficient 1053 nm first-order RRFL.

III. Conclusion

In this paper, a stable and efficient 1053 nm RRFL is realized based on forward pumping structure. To the best of our knowledge, RRFL with ~1.05 µm wavelength is realized for the first time. The lasing threshold of 1053 nm RRFL is around 0.66 W, beyond which the laser power increases linearly and the slope efficiency is about 182%. In further work, better cavity design could make 1053 nm RRFL become an excellent seed source for high-power laser drivers.

References

[1] D. S. Montgomery, "Two decades of progress in understanding and control of laser plasma instabilities in indirect drive inertial fusion," Physics of Plasmas, vol. 23, 055601, 2016.

[2] C. Labaune, "Incoherent light on the road to ignition," Nature Physics, vol. 3, pp. 680–682, 2007.

[3] Sergei K. Turitsyn, Sergey A. Babin, Atalla E. El-Taher, Paul Harper, Dmitriy V. Churkin, and Sergey I. Kablukov, et al. "Random distributed feedback fibre laser," Nature Photonics, vol. 4, pp. 231–235, 2010.

[4] Ilya D. Vatnik, Dmitriy V. Churkin, Sergey A. Babin, and Sergei K. Turitsyn, "Cascaded random distributed feedback Raman fiber laser operating at 1.2 μ m," Optics Express, vol. 19, pp. 18486–18494, 2011.

[5] Xueyuan Du, Hanwei Zhang, Xiaolin Wang, Pu Zhou, and Zejin Liu, "Short cavity-length random fiber laser with record power and ultrahigh efficiency," Optics letters, vol. 14, pp. 571–574, 2016.

[6] Hanwei Zhang, Long Huang, Jiaxin Song, Han Wu, Pu Zhou, and Xiaolin Wang, et al. "Quasi-kilowatt random fiber laser," Optics letters, vol. 44, pp. 2613–2616, 2019.

[7] Zehui Wang, Ping Yan, Yusheng Huang, Jiading Tian, Chao Cai, and Qirong Xiao, et al. "An Efficient 4-kW Level Random Fiber Laser Based on a Tandem-Pumping Scheme," IEEE Photonics Technology Letters, vol. 31, pp. 817-820, 2019.

[8] Mengqiu Fan, Zinan Wang, Han Wu, Wei Sun, and Li Zhang, "Low-threshold, high-efficiency random fiber laser with linear output," IEEE Photonics Technology Letters, vol. 27, pp. 319–322, 2015.

[9] Han Wu, Zinan Wang, Wei Sun, Qiheng He, Zedong Wei, and Yun Jiang Rao, "1.5 μ m Low Threshold, High Efficiency Random Fiber Laser with Hybrid Erbium-Raman Gain," Journal of Lightwave Technology, vol. 36, pp. 844–849, 2018.

[10] Xueyuan Du, Hanwei Zhang, Xiaolin Wang, and Pu Zhou, “Tunable random distributed feedback fiber laser operating at 1 μm,” Applied Optics, vol. 54, pp. 908–911, 2015.

[11] Babin, Sergey A., Atalla El-Taher, Paul Harper, Evgeniy V. Podivilov and Sergei K. Turitsyn, “Tunable random fiber laser,” Physical Review, vol. 84, 021805, 2011.

[12] Lei Zhang, Huawei Jiang, Xuezong Yang, Weiwei Pan, and Yan Feng, “Ultra-wide wavelength tuning of a cascaded Raman random fiber laser,” Optics letters, vol. 41, pp. 215–215, 2016.

[13] Brandon Redding, Michael A. Choma, and Hui Cao, “Spatial coherence of random laser emission,” Optics letters, vol. 36, pp. 3404–3406, 2011.

[14] Mengqiu Fan, Zhaoyu Zon, Xiaocheng Tian, Dangpeng Xu, Dandan Zhou, and Rui Zhang, et al. “Comprehensive Investigations on 1053 nm Random Distributed Feedback Fiber Laser,” IEEE Photonics Journal, vol. 9, pp. 1–9, 2017.

[15] Mengqiu Fan, Shengtao Lin, Ke Yao, Yifei Qi, Jiaojiao Zhang, and Junwen Zheng, et al. “Spectrum-tailored random fiber laser towards ICF laser facility,” Matter and Radiation at Extremes, vol. 8, 025902, 2023.

[16] Bing Han, Shisheng Dong, Yang Liu, and Zinan Wang, “Cascaded Random Raman Fiber Laser With Low RIN and Wide Wavelength Tunability,” Photonic Sensors, vol. 12, 220414, 2022.