Investigation on random distributed feedback Raman fiber laser with linear polarized output

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A random distributed feedback fiber laser with linear polarized output at 1178 nm is presented. Linear polarization is realized by fiber coiling in a half-opened cavity of a polarization maintaining random fiber laser structure. The single linear polarization laser output power reaches ~3 W with polarization extinction ratio >14 dB. Further investigations on the coiling technique and additional feedback are also studied. So far as we know, this is the first reported linear polarized random distributed feedback Raman fiber laser.

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1. INTRODUCTION

The concept of a random laser has drawn a great deal of attention in recent years, as the laser generation mechanism utilizes weak feedback from multiple scattering in an amplifying disordered medium instead of requiring a well-defined resonant cavity [1]. Different types of random lasers are classified by the choice of disordered media materials and contain potential applications in the fields of illumination sources, sensing technology, spectroscopic monitoring, communications, and so on [2]. A random fiber laser (RFL) was first introduced in 2010 based on Raman amplification and distributed Rayleigh scattering feedback [1]. Various features of RFL have been reported, demonstrating high power laser generation and multiwavelength, narrow linewidth, or tunable spectral capability [3–9]. Application fields like sensing and communications request a linear polarized laser, but a random distributed feedback Raman fiber laser with linear polarized output has not yet been reported. In our previous work, we have studied achieving linear polarized laser output by using a Yb-doped fiber in the cavity as a gain medium and utilizing the random distributed feedback from Rayleigh scattering in the long passive fiber [10]. In this paper, we propose a type of linear polarized RFL based on Raman gain in a passive fiber and distributed feedback from Rayleigh scattering. Our system design consists of a 0.5 km long polarization maintaining (PM) passive fiber, which is used as the disordered medium to provide Raman amplification and distributed feedback via Rayleigh scattering. Investigations on the fiber coiling technique are also carried out to study the effectiveness of polarization selection in the PM structure.

2. EXPERIMENTAL SETUP AND RESULTS

We study the performance of a random distributed feedback Raman fiber laser by introducing a half-opened cavity, with a 1120 nm pump laser being injected into the PM structure which provides random distributed feedback through a long PM passive fiber and amplified by Raman gain; see Fig. 1. The pump laser with a maximum power around 25 W is connected to a high reflectivity (HR) PM fiber Bragg grating (FBG) with central wavelength at 1178 nm. The intracavity port of the PM-FBG(HR) is joined with a 0.5 km long PM980 passive fiber (PM single mode fiber with core diameter of 6 μm) acting as a "random mirror" to provide Raman gain and random distributed feedback via backward Rayleigh scattering. The PM-FBG(HR) together with the long passive fiber helps realize a half-opened cavity design which can reduce the threshold of RFL emission [11].

Although the experimental setup is PM, it is difficult to directly realize laser output with a good polarization extinction ratio (PER), and certain techniques to select the polarization in a PM fiber structure should be applied. Polarization selecting methods including fiber coiling, implementation of an orthogonal grating, and special structure designs have been proposed in previous reports applied in conventional fiber lasers [12,13]. For instance, the fiber coiling technique takes advantage of the suppression of higher-order modes and utilizes the particular difference on the bending losses between fast axis polarization modes and the slow ones to realize single polarization output [14–16].

Therefore, in the experimental setup we coil a 2 m length of PM passive fiber around a cylinder with ~2.9 cm outer diameter at the input end using certain techniques to realize linear polarized random laser generation. At the output end we use an 1120/1178 dichroic beamsplitter to extract the RFL from the remaining 1120 nm pump light. The output end is angle cleaved to suppress Fresnel reflection, and an optical spectrum analyzer, an oscilloscope, and an optical power meter are used to measure the laser parameters. The PER of the output 1178 nm laser is also studied using a spatial PER measurement combination of collimator, half-wave plate (with 1178 nm central wavelength), polarization beamsplitter

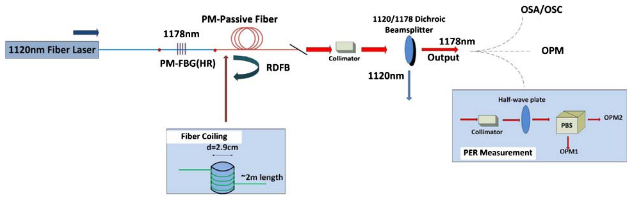

Fig. 1. Experimental setup. RDFB: random distributed feedback; OSA: optical spectrum analyzer; OPM: optical power meter; OSC: oscilloscope; PBS: polarization beamsplitter.

(1178 nm central wavelength) and power meters as introduced in Fig. 1.

Figure 2(a) shows the 1178 nm laser output power dependence on the 1120 nm pump power and its linear fit result. The system generates RFL with a pump threshold near 15 W. In the meantime, we measure the PER to quantitatively judge the performance of linear polarized laser output. From Fig. 2(b) we notice that PER stands >9 dB till 4.7 W output, but there is a clear sign of a rapid decrease in PER as the laser power reaches higher levels. Despite that, realizing ~3 W linear polarized 1178 nm laser output with pump efficiency ~15.7% and PER >14 dB based on a random distributed feedback Raman fiber laser structure is a result worth mentioning.

The reason why the PER value keeps decreasing can be explained as follows. Usually in realizing single linear polarization output, the fiber coil is introduced on the doped gain fiber [14,15]. When the gain fiber is coiled and contains the bending loss difference between fast and slow polarizations, one polarization mode can be eliminated while the other one is amplified due to the fiber gain regime in the meantime. As for this case, the random distributed feedback Raman fiber laser structure is amplified through Raman gain and has no doped gain fiber. The fiber coiling on the passive fiber with no active gain can hardly reach the effectiveness of polarization selection compared with coiling gain fibers. So in the random Raman fiber system, it is reasonable to observe the rapid decrease in PER at high power output and the weaker ability to maintain single polarization.

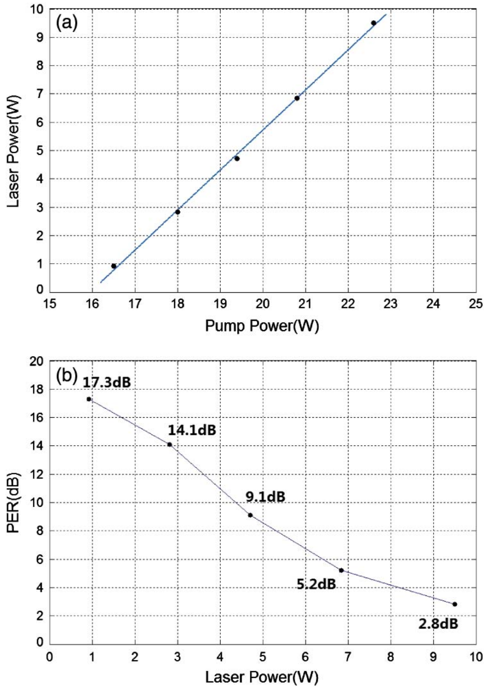

Fig. 2. (a) Laser output power dependence on the pump power and linear fit; (b) PER dependence on laser output power.

The laser output spectra of the linear polarized random distributed feedback Raman fiber laser are measured and shown in Fig. 3. A flattening pattern can be observed as well as the nonlinear spectral broadening effect caused by the long passive fiber. Spectral characteristics of random lasers reported in previous literature [17] describe a flattening process in which the spectrum becomes smooth as the pump power keeps increasing. Recent research also suggests that a fiber laser based on random distributed feedback owns unique features including spectral selectivity with near-Gaussian statistics [18] and the absence of longitudinal modes [1]. The near-Gaussian-type spectra and the flattening pattern we observed in this system coincide with the modeless characteristic of random distributed feedback fiber lasers. Because of the nonlinear spectral broadening effect, the 3 dB linewidth of 9.5 W laser output is about 1.3 nm.

The spectral broadening effect observed in the measured spectrum can be inferred as a cause of the PER decrease mentioned before. In most cases, a PM fiber structure generates laser output containing both fast-axis and slow-axis polarization modes. Usually the two polarizations have different center wavelengths, although the difference is as small as ~0.1 nm [16,19]. Due to the bending loss technique of fiber coiling, the selection of a single polarization is based on eliminating the wavelength of one polarization mode and keeping the other. However as the spectral broadening appears in response to a power increase, both the polarizations start to generate laser output and thus destroy the single polarization performance with PER decrease.

The time domain of the linear polarized random laser is also watched by using an oscilloscope with 1 GHz bandwidth (100 μs resolution). Figure 4 shows the time domain at both 0.9 W laser output (near threshold) and 9.5 W output. Comparing the two time domain characteristics, we can find the process changing from obvious fluctuations to smooth features when the pump power exceeds the threshold value and increases to higher levels. So stability in the time domain is achieved when generating high power laser output, and the phenomenon can be found referenced in previous literature [1].

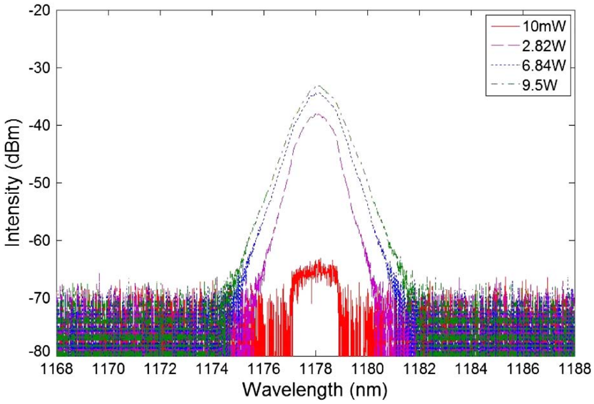

Fig. 3. Spectra under different output laser powers.

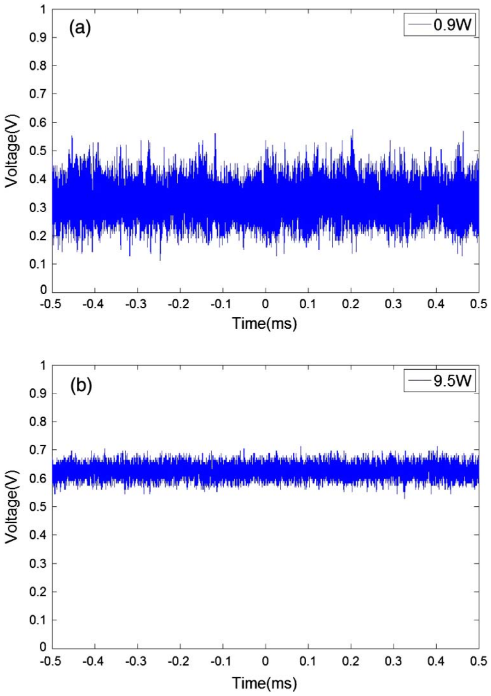

Fig. 4. Time domain at (a) 0.9 W laser output and (b) 9.5 W laser output.

3. DISCUSSION

To further discuss the performance of fiber coiling in single polarization selection, we coil at the input end of the PM passive fiber with different coiling lengths under the same diameter, and compare their PER value under different laser output powers; see Fig. 5. By increasing the fiber coiling length, the pump efficiency experiences a slight reduction due to larger induced bending losses. Comparing the coiling lengths changing from 1.7 to 3.2 m, we can find that the polarization performance resembles the result mentioned before in Section 2, which suggests good single polarization performance with a large PER value in the low power output regime, and we observe a PER decrease when the output power exceeds a certain higher level. However, there is a small improvement for PER value under the same output power level, as the longer coiling introduces larger loss and better polarization selection ability.

Afterward, the difference of single polarization output based on different fiber coiling positions in the cavity is studied. As the formerly discussed fiber coilings are all from the input end of the PM passive fiber, we therefore measure the PER value for 3.2 m fiber coiling length at the output end of the PM passive fiber. We notice that at identical output power levels the PER values measured in the case of the output end fiber coiling technique is much smaller than that coiled at the input end (with PER no more than 3 dB while giving >2 W laser output). Previous literature [4] has suggested that there exists a saturation of forward output power in random distributed feedback Raman fiber laser. While the pump power increases, the value of L_{RS} at which Raman gain is equal to losses [$gs \cdot Pp(L_{\mathrm{RS}}) = \alpha s$] can be reduced due to pump wave depletion. So, after the point where gain equals losses, the following passive fiber act just like a kind of loss medium with no effective contribution to Raman gain. In contrast, passive fiber near the input introduces effective contributions to the total Raman gain. That can explain why fiber coiling at the input end is much more efficient than that at the output end.

To ensure the achieved high power linear polarized laser output is due to the fiber coiling technique in the random distributed feedback Raman fiber laser regime, we measure the PER of laser output without any coiling being introduced. The PER value stands no more than 5 dB while generating 1 W or higher output. This comparison between the fiber coiling case and the no coiling case shows the effective influence of fiber coiling on the selection of single polarization random lasers.

We also study the end face feedback effect on the random laser performance. As mentioned before using the fiber coiling technique at the input end of the PM passive fiber, the system can generate laser power output of several watts with PER around 10 dB. Here we vertically cleave the output end of the passive fiber instead of angle cleaving (<0.01% reflection) to induce additional reflection feedback of about 4%. Studying the laser output, we find out that the threshold is reduced from ~15 to ~5 W, and the single polarization performance is deteriorated with a PER value always <3 dB. It is obvious that the linear polarized laser output achieved in this paper is a production based on random distributed feedback.

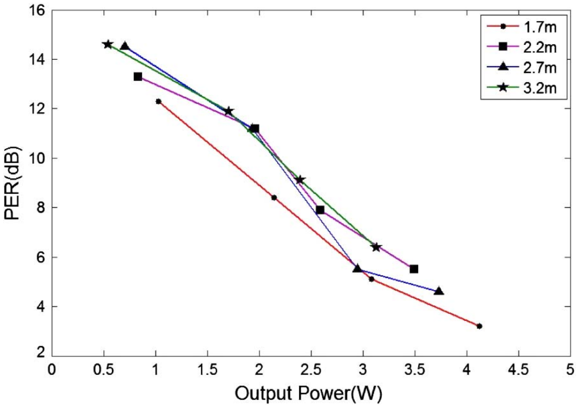

Fig. 5. PER value under different powers at different fiber coiling lengths.

4. CONCLUSION

A linear polarized random distributed feedback Raman fiber laser with high PER operating at 1178 nm is introduced in this paper, which has large application potential in the fields of illumination, sensing, and communications. We realize the linear polarized laser output by introducing a certain fiber coiling technique in a half-opened cavity of a PM-RFL structure. The single linear polarization laser output power reaches ~3 W with PER >14 dB. To our knowledge, this is the first reported linear polarized random distributed feedback Raman fiber laser. The next step of our research will pay attention to deeper investigation on the fiber coiling radius together with the coiling direction, which introduce certain strain distributions, and the improvement of configuration design.

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