Random Laser with Er/Yb-codoped Fiber Grating

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Abstract— A random fiber laser is demonstrated based on a 25-mm-long multi-phase shifted fiber Bragg grating, which was fabricated in a highly Er/Yb-codoped fiber with the beam-scanning method. By inserting twenty phase errors with random amplitudes between 0 and 2π along the grating and end-pumping the Er/Yb co-doped fiber with a 980-nm laser diode, we achieved low threshold (28 mW) and almost either single or dual-wavelength random lasing operations of changeable wavelengths depending on the power of pump laser.

1. INTRODUCTION

Low threshold random fiber lasers based on optical fiber Bragg grating (FBG) technology have been reported recently by taking advantages of the effective light localization effect introduced by FBGs and high efficient gain from pumped erbium-doped fibers (EDFs) [1, 2]. Lizárraga realized the first FBG-based random fiber laser by using a randomly spaced identical FBG array recorded along a 150-cm-long Er/Ge co-doped fiber [1]. Gagne reported more compact random fiber lasers based on single FBGs, which were recorded on Er-doped fibers and of multiple phase errors randomly distributed along the whole length (20–30 cm) [2]. In this paper, we report a much more compact random fiber laser by using a 25-mm-long multi-phase-shifted FBG, which was fabricated in a highly Er/Yb-codoped fiber and pumped with a 980-nm laser diode. It is the shortest random fiber laser to the best of our knowledge if only the effective part of the fiber is under consideration. Typical random laser radiation based on the light localization behavior of the grating with randomly phase errors is realized.

2. FIBER GRATING FABRICATION

The multi-phase-shifted FBG was fabricated by using a frequency-doubled Argon laser (244 nm) with the phase mask and beam-scanning method. The highly Er/Yb-codoped fiber has a mode field diameter of 7 µm and a high peak absorption coefficient of ~ 500 dB/m at 980 nm. A 25-mm long FBG with 20 phase shifts of random amplitude between 0.2π and 1.9π and nearly equal separation around 1.19 mm was therefore fabricated in the middle of the 40 mm-long-Er/Yb-codoped fiber. Figure 1 shows the reflection and transmission spectra of the recorded multi-phase-shifted FBG measured by using a tunable laser (AQ4321D) with resolution of 1 pm and an optical spectrum analyzer with resolution of 10 pm. The reflection spectrum has a 3-dB bandwidth around 0.95 nm centered at 1542.98 nm and reflectivity of 99.9%. Several obvious narrow transmission peaks attributed to the phase shifts are observed in the broadband reflection background.

3. LASER DESIGN AND VERIFICATION

The experimental setup is shown in Fig. 2. A 980 nm pump laser with a maximum output power of 200 mW was used to pump the multi-phase-shifted FBG through a 980/1550 nm wavelength

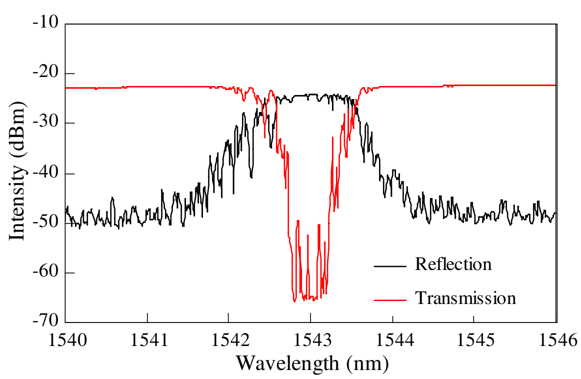

Figure 1: Reflection and transmission spectra of the phase shifted FBG.

division multiplexer (WDM). The laser output is backward in respect to the pump laser so that the residual pump laser can be avoided from the output. Angle-polished connectors or fusion splicing were used to avoid any unwanted back reflections. The multi-phase-shifted FBG was placed into water to prevent it from temperature changes arising from high power pumping because the pump generated heat can be absorbed quickly by water during the experiment. Both optical power meter and OSA were used for measurement.

The measured laser output spectra as a function of pump power are shown in Fig. 3. We measured it twice by changing the pump direction (namely injecting the pump laser from another end of the Er/Yb-codoped fiber). The threshold pump powers are 28 and 35 mW, respectively. It can be seen that the laser output spectra for the both pumping directions contain two lasing peaks when the pump power is low, a strong one on the long wavelength side and a weak one on the short wavelength side. With increasing the pump power, the weak one grows up faster than the strong one and finally exceeds the initially strong one when the pump power reaches $\sim$ 100 mW. With further increasing the pump power, the laser output experiences different evolutions for the two pump directions: for the left end pumping case, the initially strong one shrinks quickly and disappears finally so only one peak is operating; for the right end pumping case, the two peaks keep operating together till the pump power reaches the maximum. Since each peak of the laser output may contain several randomly embedded local spatial modes and the radiation intensity of each local spatial mode depends on the local pump power, we believe that the differences in both pump threshold and spectrum evolution are related to the asymmetrical distribution of random phase errors and attenuation of the pump power along the length of the grating. The relatively broad laser linewidth and minor spectral splitting [as can be observed in Fig. 3(b)] provide the evidences that the final laser output spectrum is the sum of lots of local spatial modes that may have slightly different emission wavelengths. The laser modes for the both pumping directions have an optical signal to noise ratio (OSNR) as high as 65 dB.

The measured output powers as a function of pump power are shown in Fig. 5. For the laser pump from left end or right end of the Er/Yb-codoped fiber, it can be divided into three or two parts depends on the number of the laser peaks. The output powers grow nearly linearly with pump power increasing in different ranges, respectively. The maximum output powers of the laser for pump from left and right end are 1.18 and 1.5 mW, respectively. So the pump efficiencies are 0.7% and 0.9%, respectively. The difference of the efficiency is because the numbers of laser emission that pump from left or right ends are different. As the fusion splice between the WDM and Er/Yb-codoped fiber exhibit losses, while the reflection of the grating is high that lead to a

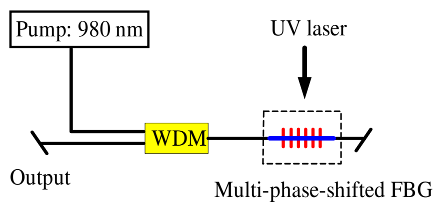

Figure 2: Schematic diagram of the experimental setup. WDM, wavelength division multiplexer; FBG, fiber Bragg grating.

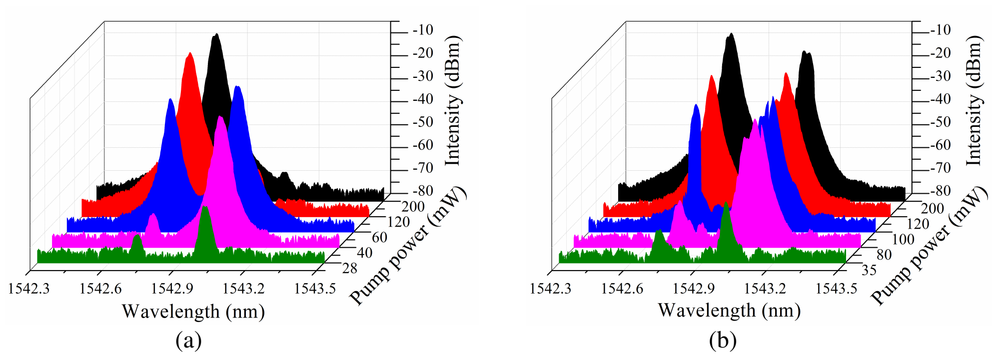

Figure 3: Laser output spectra with different pump power. (a) and (b), pump from left and right end of the Er/Yb-codoped fiber.

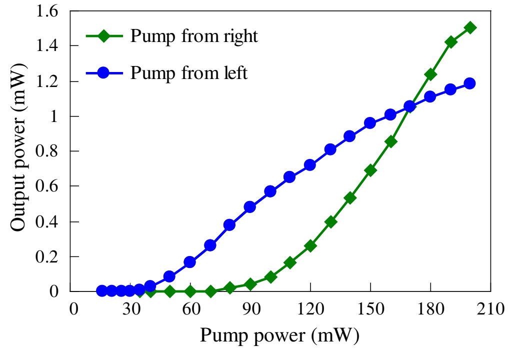

Figure 4: Laser power as a function of pump power when pumped from the left or right end of the Er/Yb-codoped fiber.

high intra-cavity flux, the efficiency is not very high.

4. CONCLUSION

To conclude, we present an ultra-short random fiber laser based on the fiber Bragg grating with multi-phase-shifts. The proposed random fiber laser exhibits the pump threshold of about 28 mW and 35 mW when pump from left and right end of the fiber. Depending on the pump power, the random laser shows almost both single and dual-wavelength operation. This proposed random fiber laser may find potential applications for sensing applications.

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