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Author(s)	Dong, Xinyong; Yuan, Junwei; Zhu, Lei; Shum, Perry Ping; Su, Haibin
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Erbium-doped Fiber Laser with Distributed Feedback from a Fiber Grating Array

Xinyong Dong^{1,2,3}, Junwei Yuan³, Lei Zhu³, Perry Ping Shum^{2,4}, and Haibin Su^{1,2}

¹School of Materials Science and Engineering, Nanyang Technological University, Singapore

²CINTRA, Research Techno Plaza, 50 Nanyang Drive, Singapore

³Institute of Optoelectronic Technology, China Jiliang University, Hangzhou, China

⁴School of Electrical & Electronic Engineering, Nanyang Technological University, Singapore

Abstract— An erbium-doped fiber laser with low coherence, low threshold, high efficiency and narrow linewidth is demonstrated for the first time based on distributed feedback from a fiber Bragg grating (FBG) array. The FBG array contains tens of FBGs with identical Bragg wavelength but very weak reflectivity of $\sim 5\%$, inscribed along a normal single-mode fiber with random separations. Low pump threshold power of 3.0 mW and high slope efficiency of 24% are achieved, which are comparable with that of normal erbium-doped fiber lasers but much better than that of conventional random fiber lasers based on distributed Rayleigh scattering.

1. INTRODUCTION

Random fiber lasers have no classical resonator, but random distributed feedback (RDFB), which make the structure very simple. In recent years, ultra-long Raman fiber lasers based on RDFB from distributed Rayleigh scattering have become a very attractive concept [1–6]. However, high pump power up to Watt level is needed because the scattering efficiency is very low [3]. Moreover, laser spectrum line-width is relatively broad (1 nm or more) [4–6]. To improve the laser performance, a number of techniques have been proposed [7–10]. By using half-opened laser cavity with fiber Bragg gratings (FBGs), one can reduce the pump threshold power roughly by half [7, 8]. By using narrow band filters or reflectors, one can reduce the line-width to ~ 0.1 nm [9, 10]. In 2009, N. Lizarraga et al. reported a random laser based on an Er/Ge co-doped single-mode fiber (SMF) with randomly spaced Bragg gratings being recorded on it [11]. The threshold of the laser is reduced to about 10 mW, and the line-width is about 0.02–0.04 nm. But Erbium-doped fiber (EDF) generates heat when it is working as gain medium, then the reflecting wavelength of the FBGs will move, making the laser output unstable. In 2014, our team reported an EDFL based on RDFB through Rayleigh scattering in a long-distance (5–30 km) SMF [12], where similar results were obtained but less thermal problem. However, the SMF is too long to make the device portable, and it introduce transmission loss.

In this work, we demonstrate a low-threshold, narrow line-width, high efficiency RDFB-based EDFL by using a randomly distributed Bragg grating array with very weak individual reflectivity of $\sim 0.5\%$. High efficiency lasing operation is realized, with low threshold pump power of only 3 mW. The slope efficiency is 24%, which is about tenfold higher than that of the previously reported conventional random fiber lasers amplified through distributed Raman scattering effect [9].

2. LASER DESIGN

Figure 1 shows the schematic diagram of the proposed EDFL based on RDFB from a grating array. It consists of a 1480 nm pump laser with a maximum output power of 400 mW, two 1480/1550 nm wavelength division multiplexers (WDMs), a FBG reflector with central wavelength of 1549.6 nm, line-width of 0.24 nm and reflectivity of 90%, a 2-m-long highly-doped EDF and a weak FBG array. The EDF has a mode field diameter of 6 μm and a high peak absorption coefficient of ~ 11 dB/m at 1480 nm. The pump laser is launched into the EDF through the WDM1. The WDM2 is used to filter out the residual pump power from the laser output. Angled polished connectors are used at the both output ends to eliminate the influence of Fresnel reflection at the fiber ends on the laser operation.

The weak FBG array including twenty identical weak Bragg gratings, was recorded on a SMF (type G.652) by using a frequency-doubled Argon laser with a conventional phase mask technique [13]. The length of each grating is about 5 mm, and the distances between two neighboring gratings are randomly distributed in the range of 4 to 5 m (the total length of the weak FBG array is ~ 100 m). The total and individual reflectivity of the FBGs are about 10% and 0.5%, respectively.

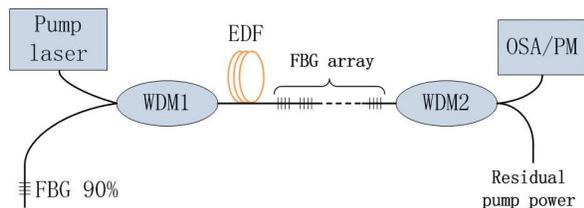


Figure 1: Schematic diagram of the proposed EDFL based on RDFB from a grating array. WDM, wavelength division multiplexer; EDF, erbium-doped fiber; FBG, fiber Bragg grating.

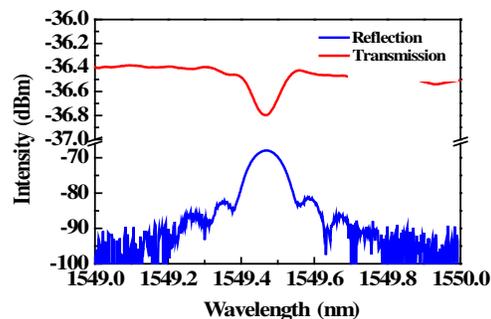


Figure 2: Measured transmission and reflection spectra of the weak FBG array.

A measured transmission and reflection spectra of the FBG array are shown in Fig. 2. The central wavelength and 3-dB bandwidth are 1549.47 nm and 0.1 nm, respectively.

3. LASER CHARACTERIZATION

The lasing operation is grounded on the EDF gain and the resonance between FBG reflection and the backward RDFB provided by the weak FBG array. When the EDF is pumped to generate population inversion of erbium, amplified spontaneous emission (ASE) is generated. Then the selected wavelength reflected by the FBG reflector and the weak FBG array. With increasing power of the pump laser, resonance happens when the gain overcomes the total cavity loss.

The laser output was measured by using an optical spectrum analyzer (OSA) with resolution of 0.02 nm and an optical power meter (OPM). Fig. 3 shows measured output spectra of the laser at different pump powers. Fig. 4 shows the output power against pump power. The threshold power of the fiber laser is about 3 mW, which is much smaller than the value, 10 mW, reported in the EDFL based on RDFB through Rayleigh scattering in a long-distance SMF [12]. The slope efficiency is 24% in our experiment, which is more than tenfold higher than that of the previously reported conventional random fiber lasers amplified through distributed Raman scattering effect [9]. The main reason for the low threshold and high slope efficiency is the RDFB provided by the weak FBG array is much stronger than that provided by Rayleigh scattering in a fiber.

Normally, the fiber lasers based on RDFB have poor stability in both output power and spectrum. For example, the emission peak wavelength and even the number of emission peaks are changing with pump power and time for the previously reported random laser based on randomly spaced FBGs written on an Er/Ge co-doped fiber [11]. Here in our case, the laser only has one emission peak and the peak wavelength is quite stable at around 1549.48 nm when the pump power is raised to over 34.1 mW. This great improvement in laser performances may mainly relate to the fact that all the twenty weak FBGs have the same central wavelength and they were not recorded

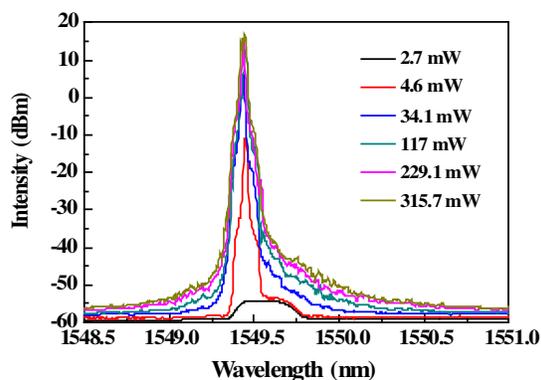


Figure 3: Measured output spectra of the RDFB-based EDFL at different pump power.

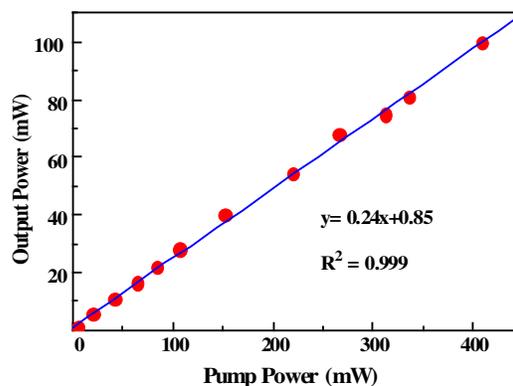


Figure 4: Output power against pump power of the proposed RDFB-based EDFL.

on the active fiber, i.e., the EDF, so their reflection wavelengths are not affected by temperature of the active fiber, which may rise with pump power. There is a small wavelength shift of 0.12 nm, from 1549.60 to 1549.48 nm, when the pump power is increased from just above the threshold to 34.1 mW. That may be caused by the little mismatch between the peak reflection wavelength of the FBG reflector (1549.60 nm) and that of the FBG array (1549.47 nm).

The laser stability with time was also tested. Fig. 5 shows the output spectra recorded every one minute when the pump power is 201 mW. The output lasers have almost same profiles at the whole measurement process, which is much better than that of the random laser based on randomly spaced FBGs written on an Er/Ge co-doped fiber [11]. This is due to the central wavelength of the weak FBG array recorded on the SMF is more stable than that of the FBG array recorded on the EDF with the work time increasing.

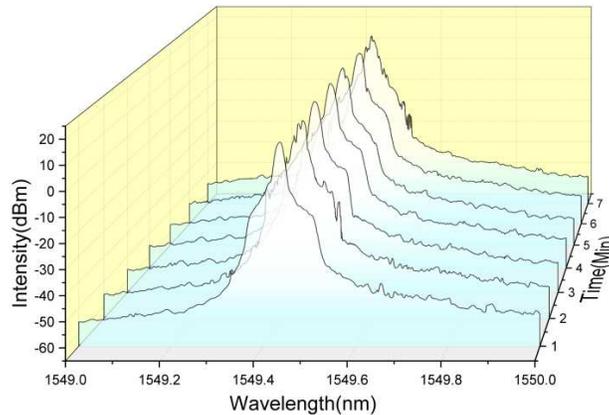


Figure 5: Laser output spectra with time at the pump power of 201 mW.

4. CONCLUSION

A low-threshold, high-efficiency and narrow line-width EDFL has been demonstrated for the first time by using a random distributed Bragg grating array feedback. The laser output spectrum was studied in different pump power. Due to the wavelength-selective feedback of the FBG reflector, the strong RDFB provided by the weak FBG array and the high-efficient gain from the pumped EDF, the threshold power of the achieved EDFL is as low as 3 mW, the slope efficiency in our experiment is up to 24%, which is comparable to that of normal EDFL. We also proved the stability of the laser is better than that of the random laser based on an Er/Ge co-doped SMF with randomly spaced Bragg gratings.

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