Random Distributed Feedback Fiber Laser Employing Erbium-doped Fibers

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Abstract— A low-threshold, narrow bandwidth random fiber laser by using a short erbium-doped fiber (EDF) to provide high-efficiency gain in a FBG-formed half-opened cavity is demonstrate. Typical random laser radiation based on the resonance between the FBG reflector and distributed random Rayleigh scattering of the long-distance SMF is realized. Single- and dual-wavelength random lasing operations are realized by using one- and two-FBGs respectively, with low threshold pump power of only 10 mW, which is about two orders lower in magnitude than that of the previously reported conventional random fiber lasers amplified through distributed Raman effect.

1. INTRODUCTION

Random lasers operate without a traditional cavity but randomly distributed scattering centers, leading to the unique advantage of simple technology, i.e., without the need to engineer a precise cavity [1]. Optical fiber-based random lasers, also called random fiber lasers, have attracted lots of attention in recent years because the fiber waveguide provides one-dimensional random distributed feedback (RDFB) that can improve the laser performance significantly [2]. Normally, random fiber lasers are based on the distributed feedback of Rayleigh scattering amplified through stimulated Raman scattering (SRS) effect in a long-distance (tens of km) single-mode fiber (SMF) [2]. Their applications in sensing [3] and communications [4] have also been investigated. Improved laser performance was also achieved by using stimulated Brillouin scattering (SBS) as the gain mechanism, instead of the normally used SRS effect, because SBS has much higher gain efficiency and narrower gain bandwidth [5]. Random fiber lasers based on a randomly spaced identical FBG array recorded in rare earth-doped active fiber has also been reported with improved performance, arising from the efficient gain of the active fiber, the strong feedback and narrow reflection bandwidth of the FBGs [6].

2. LASER DESIGN AND VERIFICATION

Figure 1 shows the schematic diagram of the proposed EDF-based random fiber laser with a half-opened cavity. 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 containing one or two FBGs, a 2-m-long highly-doped EDF and a 30 km-long SMF (type G.652). 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 through WDM 1 into the EDF, which is followed by the long SMF. The FBG reflector is at the left of WDM 1 to reflect the selected wavelength(s) back into the EDF and the long SMF. We use one and two FBGs to achieve the single- and dual-wavelength laser operations, respectively. FBG 1 has central wavelength of 1550 nm, linewidth of 0.24 nm and reflectivity of 90%. FBG 2 has central wavelength of 1551 nm, linewidth of 0.27 nm and reflectivity of 97%. WDM 2 is used to filter out the residual pump power from the laser output. The Angled polished connectors

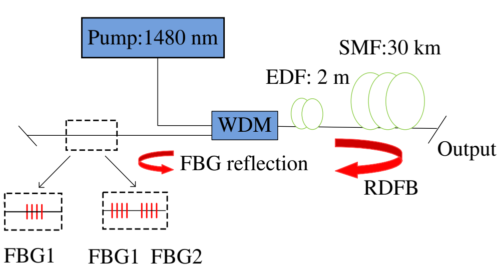

Figure 1: Proposed EDF-based random laser WDM, wavelength-division multiplexer; EDF, erbium-doped fiber; SMF, single-mode fiber; FBG, fiber Bragg grating; RDFB, random distributed feedback.

are used at the both output ends to eliminate the Fresnel reflection of the fiber ends. The laser output is measured by using an optical spectrum analyzer (OSA) with resolution of 0.02 nm and an optical power meter (OPM).

The lasing operation is supposed to be grounded on the EDF gain and the resonance between FBG reflection and RDFB through backward Rayleigh scattering in the long-distance SMF. When the EDF is pumped to generate population inversion of erbium ions, amplified spontaneous emission (ASE) is generated and then wavelength-selectively reflected by the FBG reflector and randomly backward scattered by Rayleigh scattering effect of the long SMF. With increasing power of the pump laser, resonance happens when the gain overcomes the total cavity loss.

3. LASER CHARACTERIZATION

For the single- and dual-wavelength random fiber lasers with one or two FBG(s), the output spectra, as shown in Figs. 2(a) and (b), indicate a dramatic change when the pump power reaches 10 mW. Based on previous studies [2], the generation of stochastic spikes is related to the combined effect of distributed Rayleigh scattering and cascade SBS, while nonlinear spectral broadening (NSB) arising from nonlinear interactions, such as frequency mixing and cross-phase modulation, can make the spikes broadened and superposed and further suppress the SBS process. For the single-wavelength random fiber laser, well-localized and stabilized laser spectra with narrow linewidth were observed when the pump power reaches 100 mW. For the dual-wavelength random fiber laser, the intensity increases with pump power and then stabilized and smoothened output spectrum is finally achieved when the pump power reaches about 200 mW, which is just twofold of that for the single-wavelength random fiber laser, indicating nearly the same pump power consumption for each lasing wavelength to reach the stabilized state. In addition, two new spectral peaks appear outside the two main peaks and grow up with the pump power. The wavelength separations of neighboring peaks are the same, meaning that four-wave mixing (FWM) effect in the long-distance fiber plays the key role for the generation of the new spectral peaks. It also indicates the possibility of achieving multi-wavelength random fiber laser based on this FWM effect.

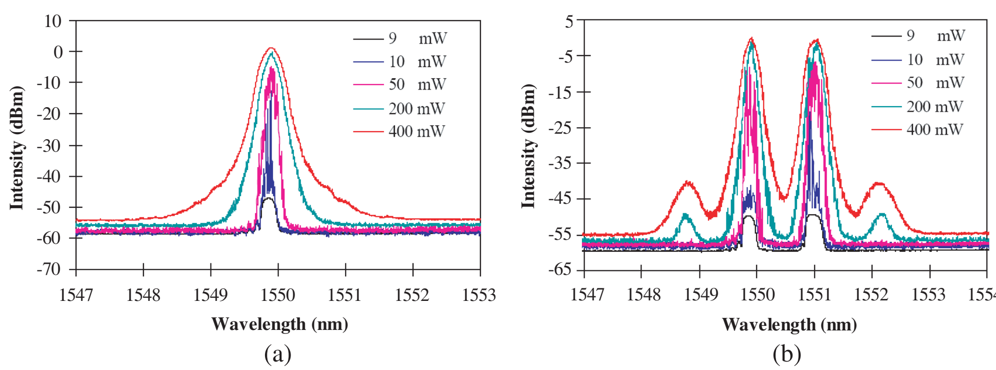

Figure 2: Output spectra of the (a) single- and (b) dual-wavelength random fiber laser for different pump powers.

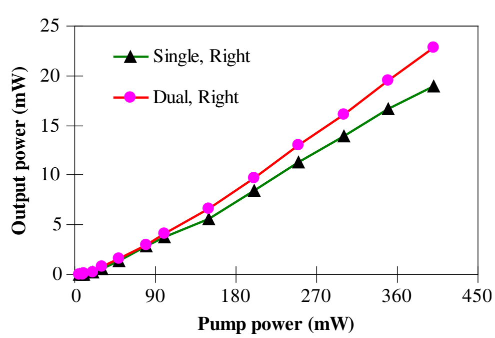

Figure 3: Output power against pump power for single- and dual-wavelength random fiber lasers.

Figure 3 shows the comparison of laser output power against pump power between the singleand dual-wavelength random fiber lasers. It can be seen that the two lasers show the same threshold and similar output characteristic. The output powers grow nearly linearly, under maximum pump power of 400 with pump power. The maximum output powers are 19 mW and 23 mW for the single- and dual-wavelength random fiber lasers, respectively. So the pump efficiencies are up to 5.7% and 6.4% for single- and dual-wavelength output, respectively. The dual-wavelength laser has slightly higher efficiency than that of the single-wavelength one.

4. CONCLUSIONS

A low-threshold, high-efficiency and narrow linewidth random fiber laser has been demonstrated for the first time by using an erbium-doped fiber as gain medium in a FBG-formed half-opened cavity design. Due to the wavelength-selective feedback of the FBG reflector and the high-efficient gain from the pumped EDF, the threshold power of the achieved random fiber laser is as low as 10 mW, which is two orders lower in magnitude than that of the reported conventional random fiber laser amplified by distributed Raman effect. The maximum pump efficiency of single- and dual-wavelength lasers are up to 5.7% and 6.4%, which is comparable to that of normal erbium-doped fiber lasers.

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REFERENCES

1. Ambartsumyan, R., N. Basov, P. Kryukov, and V. Letokov, "Laser with nonresonant feedback," *Sov. Phys. JETP*, Vol. 3, 167–169, 1966.
2. Turitsyn, S. K., S. A. Babin, A. E. El-Taher, P. Harper, D. V. Churkin, S. I. Kablukov, J. D. Ania-Castañón, V. Karalekas, and E. V. Podivilov, "Random distributed feedback fibre laser," *Nature Photon.*, Vol. 4, 231–235, 2010.
3. Babin, S. A., A. E. El-Taher, P. Harper, E. V. Podivilov, and S. K. Turitsyn, "Tunable random fiber laser," *Phys. Rev. A*, Vol. 84, 021805, 2011.
4. Martins, H. F., M. B. Marques, and O. Frazão, "Temperature-insensitive strain sensor based on four-wave mixing using Raman fiber Bragg grating laser sensor with cooperative Rayleigh scattering," *Appl. Phys. B*, Vol. 104, 957–960, 2011.
5. Jia, X. H., Y. J. Rao, F. Peng, Z. N. Wang, W. L. Zhang, H. J. Wu, and Y. Jiang, "Random-lasing-based distributed fiber-optic amplification," *Opt. Express*, Vol. 21, 6572–6577, 2013.
6. Pang, M., S. Xie, X. Bao, D. P. Zhou, Y. Lu, and L. Chen, "Rayleigh scattering-assisted narrow linewidth Brillouin lasing in cascaded fiber," *Opt. Lett.*, Vol. 37, 3129–3131, 2012.
7. Lizárraga, N., N. P. Puente, E. I. Chaikina, T. A. Leskova, and E. R. Méndez, "Single-mode Er-doped fiber random laser with distributed Bragg grating feedback," *Opt. Express*, Vol. 17, 395–404, 2009.