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Single-longitudinal-mode fiber ring laser using fiber grating-based Fabry–Perot filters and variable saturable absorbers

Junqiang Sun *, Xiuhua Yuan, Xinliang Zhang, Dexiu Huang

Wuhan National Laboratory for Optoelectronics, Institute of Optoelectronic Science and Engineering, Huazhong University of Science and Technology, Luo Yu Road No. 1037, Wuhan 430074, PR China

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Abstract

A single-longitudinal-mode (SLM) fiber ring laser is demonstrated by incorporating a fiber Bragg grating (FBG)-based Fabry–Perot (F–P) filter and a variable saturable absorber in a fiber ring cavity. An ultra-narrow bandpass filter is established by the combined mode filtering of the FBG-based F–P filter and the variable saturable absorber. No accurate control for cavity length is required, and stable single longitudinal-mode operation without mode hopping is conveniently achieved.

Keywords: Single-longitudinal-mode; Fiber ring laser; FBG-based F–P filter

1. Introduction

Stable single-longitudinal-mode (SLM) erbium-doped fiber lasers (EDFLs) are very important light sources for many applications such as high-resolution spectroscopy, photonic generations of microwave signals, fiber sensing systems [1], and dense wavelength-division-multiplexing (DWDM) backup source with ITU-T grids [2]. Approaches to implement SLM operation in EDFLs can be categorized as two styles. One approach is a short-length cavity to enlarge longitudinal-mode spacing [3,4]. However, these lasers normally suffer from a low pump absorption and hence low slope efficiency, and thus particular Er^{3+} doped fiber should be designed to alleviate this issue. More importantly, a short cavity results in broad spectral linewidth. Another approach is a long ring cavity to offer higher output power without special requirements for the gain media [5,6]. However, the fiber ring laser unavoidably generates an enormous number of densely spaced longitudinal modes around the central lasing wavelength due to the required intracavity optical components, connecting fibers and a rather long cavity length. Consequently, laser output is usually unstable with a large linewidth owing to multimode oscillation, mode competition and hopping. To achieve SLM operation, several techniques have been proposed to ensure a long-term stable performance in EDFLs, for instance, introducing a passive multiple-ring cavity or a compound ring resonator composed of a dual-coupler fiber ring to guarantee SLM laser oscillation [7,8], integrating two cascaded Fabry–Perot of widely different free spectral ranges into the ring cavity [9], using an unpumped erbium-doped fiber as a narrow-bandwidth autotracking filter [10,11], and employing an external light injection [12] or utilizing a fiber Bragg grating (FBG) as self-injection feedback to control the lasing frequency [13].

Fiber Bragg grating can be considered as a good candidate for lasing mode discrimination since it holds superior advantages of low insertion loss, passiveness, and high selectivity. Adopting fiber Bragg grating as an optical filter offers the most straightforward and low-cost approach. There are three ways to design FBG-based narrow bandwidth filters. One is to introduce a precise π-phase shift in the middle of the FBG that creates a narrow passband in the center of the FBGs stop band [14]. The drawback

* Corresponding author. Tel.: +86 2787792242x804; fax: +86 2787792225.
E-mail address: jqsun@mail.hust.edu.cn (J. Sun).

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of this kind of filter is its higher insertion loss in the passband [15] and higher control accuracy required during its fabrication. The second type is to vary the sampling period of the sampling fiber Bragg grating [16], and thus the narrow passband is generated within its reflection peak. But the longer length of this filter causes the inconvenience of its packaging. The third type is the FBG-based Fabry-Perot (F–P) filter [17]. When two highly reflective FBGs of identical wavelength form a resonator, the multiple reflections between them will create multiple resonant peaks in the stop band of the single FBG. The number of the resonant peaks is determined by the separation between FBGs and the bandwidth of the resonant peak is dominated by the reflectivity of the FBG. Since FBGs of the high reflectivity (>99%) can be easily fabricated, the FBG-based F–P filter with the bandwidth of the resonant peak of less than a picometer can be realized [18].

In this paper, a novel SLM fiber ring laser is proposed and demonstrated experimentally. Realization of single longitudinal-mode operation is guaranteed by the combined interactions of a FBG-based Fabry-Perot filter and a variable saturable absorber. Since the laser is constructed with all-fiber optical components, it is compatible with optical fiber transmission and sensing systems. Our laser configuration demonstrated in this paper can be operated without strict control of the cavity length and stable single longitudinal-mode performance without mode hopping is conveniently achieved.

2. Experimental setup

The experimental setup of the single-longitudinal-mode erbium-doped fiber ring laser is shown in Fig. 1. This fiber laser is constructed with a basic ring cavity configuration including two segments of erbium-doped fibers (EDFs) pumped by 980 nm laser diodes (LDs), a FBG-based F–P filter, a uniform FBG, a circulator and in-line polarization controllers. The total length of the ring cavity is about 27 m. The FBG-based F–P filter, which is fabricated by separating two uniform FBGs with a length of standard single fiber, has one transmission peak in its reflection band and acts as a longitudinal-mode selective component to restrict the laser oscillation to a few longitudinal modes. The uniform FBG is utilized to align its reflection band to the ultra-narrow pass band of the F–P filter and reflects the transmission light from the F–P filter. The variable saturable absorber is realized with an incompletely pumped EDF amplifier. As the launched pump power is less than that of what is required to make the EDF to be transparent, the EDF at the end section will serve as a saturable absorber that can be regarded as a tracking filter. Moreover, the length of the saturable absorber can be controlled by changing the launched pump power level. Thus, the tracking filter characteristics can be adjusted by changing the launched pump power. To minimize lasing instability originating from the residual 980 nm pump light and amplified spontaneous emission (ASE) noise, counter-propagating pumped configuration is being adopted in the fiber ring laser. The circulator is employed to help the implementation of the ultra-narrow bandpass filtering and sustain the unidirectional oscillation. Polarization controllers (PCs) are positioned in the cavity to offer the appropriate polarization states for enhancing the laser performance. The laser output is extracted from an 8:2 optical coupler. The laser spectrum is monitored by an optical spectrum analyzer (OSA) with the highest spectral resolution of 0.01 nm. Single-longitudinal-mode lasing and electrical beating signal are verified by detecting the output laser with a high-speed photodetector and a radio frequency (RF) electrical spectrum analyzer (ESA).

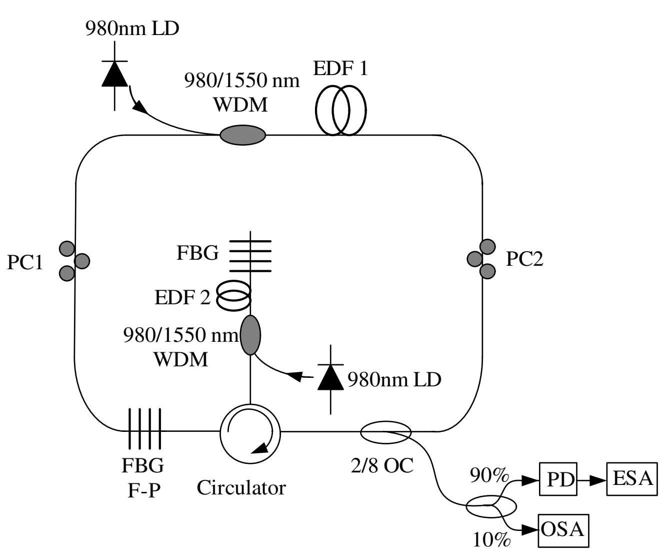

Fig. 1. Proposed single-longitudinal-mode erbium-doped fiber ring laser. OC: optical coupler; PC: polarization controller; FBG: fiber bragg grating; PD: photon detector; OSA: optical spectrum analyzer; and ESA: electrical spectrum analyzer, EDF: erbium-doped fiber; WDM: wavelength division multiplexer.

3. Experimental results and discussions

The fiber for fabricating FBGs is the standard single mode fiber, SMF-28, hydrogen-loaded 7 days under the pressure of 140 atm. The F–P filter consists of two 3 mm long uniform fiber gratings separated by a 0.45 mm long unexposed fiber. The center-to-center distance of two FBGs is 3.45 mm that gives the free spectral range(FSR) of 0.34 nm. The stop bandwidth of the uniform FBGs ≈0.3 nm at −3 dB so only one transmission peak is contained in the FBG-based F–P filter. Fig. 2 illustrates the transmission spectrum of the FBG-based F–P filter (solid) and reflection spectrum of FBG (dash) measured using the EDF spontaneous emission spectrum. One narrow pssband of the F–P filter within the reflection of the FBG are observed. However, the resonant peak cannot be fully resolved due to the limited resolution of 0.01 nm of the optical spectrum analyzer (OSA) used. Additionally, power fluctuations of the EDF spontaneous emission and