Optics and Laser Technology 107 (2018) 361–365

Contents lists available at ScienceDirect

Optics and Laser Technology

journal homepage: www.elsevier.com/locate/optlastec

Full length article

Single longitudinal mode fiber ring laser

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ARTICLE INFO

Article history:
Received 20 April 2017
Received in revised form 6 September 2017
Accepted 23 May 2018

Keywords:
Fiber lasers
Erbium
Laser stability
Fiber Bragg gratings

ABSTRACT

In this work, a dual-wavelength fiber ring laser working on the SLM regime is proposed and experimentally verified. A proof-of-concept device has been tested employing high precision small-sized SLM fiber lasers to complement the feedback produced by a passive FBG. The ring laser output inherits the spectral benefits of its SLM seed lasers but maintaining some power-related properties of ring cavities. These spectral benefits can also be achieved for a single wavelength, simplifying the requirements regarding power equalization between different wavelengths to obtain the SLM regime. The experimental results exhibit a remarkably good wavelength stability and SLM operation of a fiber ring laser with several meters of cavity length, both with single and multi-wavelength configurations.

1. Introduction

Several works on multi-wavelength fiber lasers have been published in the last years, partly because of their great potential for some applications like microwave photonics systems, fiber-optic sensors, spectroscopy and wavelength division multiplexed systems [1–3]. A configuration of erbium-doped fiber ring laser is an interesting choice to generate a multiple wavelength output due to its good compatibility with other optical fiber components, high gain and low noise figure.

However, mainly due to the long lasing cavity and unstable mode competition caused by the homogeneous gain broadening in the erbium doped fiber (EDF), a multi-wavelength erbium-doped fiber ring laser with single longitudinal mode (SLM) behavior and good stability is difficult to achieve. This can be accomplished by incorporating an additional assembly structure, which introduces complexity to the system and in some cases loss of efficiency in the output power.

Different approaches have been proposed to achieve a SLM regime in multiple-wavelength fiber ring lasers like the use of ultra-narrow fiber Bragg grating filters [4] or a fiber loop mirror with a saturable absorber [5,6] as a passive self-tracking narrow multi-band optical fiber. On the other hand, different techniques have been proposed to solve the problem of the gain competition. In [5], the EDF was cooled to 77 K with liquid nitrogen, thus making this technique impractical in many applications. In [7], three erbium-doped fiber amplifiers were used to supply gain in each lasing wavelength. In [8], a nonlinear fiber inside the cavity was used to stabilize a dual-wavelength fiber laser via the four-wave mixing (FWM). Another option would be to use a nonlinear-broadening homogeneous material gain, such as semiconductor optical amplifiers (SOAs) [9]. But fiber ring lasers based on SOAs exhibit the limitation that the associated output power is low.

In this work, a stable dual-wavelength fiber ring laser with SLM behavior is presented and experimentally demonstrated. In order to achieve the SLM regime in the two oscillating signals, two high quality small-size DBR fiber lasers with different lasing wavelengths are used as seeds in a typical fiber ring laser structure with a fiber Bragg grating (FBG) as filter. A very narrow filtering technique based on the spectral overlap of uniform FBGs [10] has been employed to build the seed SLM linear fiber lasers. The proposed structure maintains the SLM operation even with a single seed laser and is capable of delivering higher output power than isolated seeds. With a proper sizing, this configuration can be very useful to translate power variations produced within the ring cavity to different stable lasing wavelengths simultaneously.

2. Laser configuration

In fiber ring lasers, part of the amplified light is launched again into the active medium trough passive methods, typically allowing light to travel only in one direction. The cavity length of these

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https://doi.org/10.1016/j.optlastec.2018.05.038
0030-3992/

lasers is usually long and their spectral properties are mainly driven by the feedback method (e.g. FBGs) thus, achieving SLM operation can be sometimes challenging. However, Er-doped fibers exhibit gain competition that can be employed to restrict which wavelenghts are active in a laser cavity. Based on these ideas, a DBR seed (or several) can be employed to force the ring cavity to lase with the same properties as the injected seed. The proposed configuration is depicted in Fig. 1 (bottom).

The fiber ring laser employs Er-doped fiber as active medium and the feedback is produced by a highly saturated uniform FBG centered to favor lasing in the Bragg wavelength and avoid peak gain resonances. A circulator is also employed to determine the amplification direction of the cavity. This structure produces a multimode laser whose spectrum is determined by the chosen FBG and narrowed by the gain competition of the Erbium-doped fiber.

A small-sized DBR seed laser using the overlap technique [10] is amplified using a linear stage based on Er-doped fiber to increase its peak power (Fig. 1, top), before launching it into the ring cavity. Since the initial power of the seed laser is higher than the resonance of the ring cavity, the whole cavity inherits the spectral properties of the seed laser, maintaining the SLM regime, but increasing the output power. Although this ring-based structure can be useful for specific applications, it becomes more interesting when different seed lasers are launched into the ring cavity, sharing the latter active medium. This setup is depicted in Fig. 1 (bottom), where two similar DBR seed lasers working at different wavelengths are employed. This way, more complex structures can be simultaneously achieved for all the lasing wavelengths while their spectral properties are individually maintained, even with different powers for each seed laser.

3. Experimental characterization of the seed laser

Different seed lasers have been manufactured according to the structure depicted in Fig. 1, (top). For each laser, two FBGs of $L = 8$ mm have been inscribed into commercial Er-doped fiber (I-25 from Fibercore) using the phase mask technique with a continuum UV laser emitting at 244 nm. One of the FBGs was partially post-exposed to adjust its central wavelength and reach the SLM regime [10]. After finishing the DBR structure, 2 m of Er-doped fiber (I-25) were spliced after the small-sized DBR structure to increase its peak power (Fig. 1, top). One of these manufactured seed lasers has been experimentally characterized before launching it into the ring cavity.

In Fig. 2, several experimental properties of a SLM seed laser are depicted. The SLM operation (a) has been measured with a high resolution optical spectrum analyzer (BOSA-C from Aragon Photonics with a spectral resolution of 0.08 pm) and also employing a heterodyne detection system. In Fig. 2(b), a single peak is shown, proving the SLM operation.

The heterodyne setup has been changed to the delayed self-heterodyne detection scheme [11], in order to measure the Full Width at Half Maximum (FWHM) linewidth of the emitted wavelength. A phase modulator (Photline MPZ-LN20) has been employed to perform the 5 GHz modulation. A 150 km length standard optical fiber has been employed as the delayed line. An EDFA has been introduced in the setup to amplify the signal of the delayed line. According to [11], the real linewidth is the square root of two times the measured FWHM, so the achieved linewidth was around 1 kHz as shown in Fig. 2(c). This narrow linewidth is comparable to previous results achieved with similar Er-doped fibers [10], suggesting a very stable SLM operation of the fiber laser.

The output laser signal has been directly connected to an OSA (HP70952B, that exhibits a wavelength resolution of 60 pm) to study the power behavior of the manufactured laser. Maintaining the pump current constant, the generated output optical power has been monitored during 60 min using the OSA. The power stability measured each 30 s (Fig. 2e) is depicted, achieving a drift of 0.44 dB with a 90% confidence interval. For the pump current employed during the stability test, the output laser exhibited an optical signal-to-noise ratio (OSNR) higher than 48 dB (Fig. 2d).

4. Experimental characterization of the ring laser

After the characterization of an isolated SLM seed laser, the ring configuration depicted in Fig. 1 (bottom) has been mounted employing 4 meters of Er-doped fiber (I-25 from Fibercore). Two seed lasers have also been connected to the cavity while the chosen FBG ($L = 24$ mm) centered at these wavelengths ($\lambda_c \approx 1551.5$ nm) that exhibits a high bandwidth ($BW_{3dB} \geqslant 2$ nm).

4.1. Wavelength measurements

The wavelength evolution of the most common operation situations has been analyzed using the high resolution optical spectrum analyzer (BOSA-C) and verified using the heterodyne method. For each of the presented results, two similar graphs are

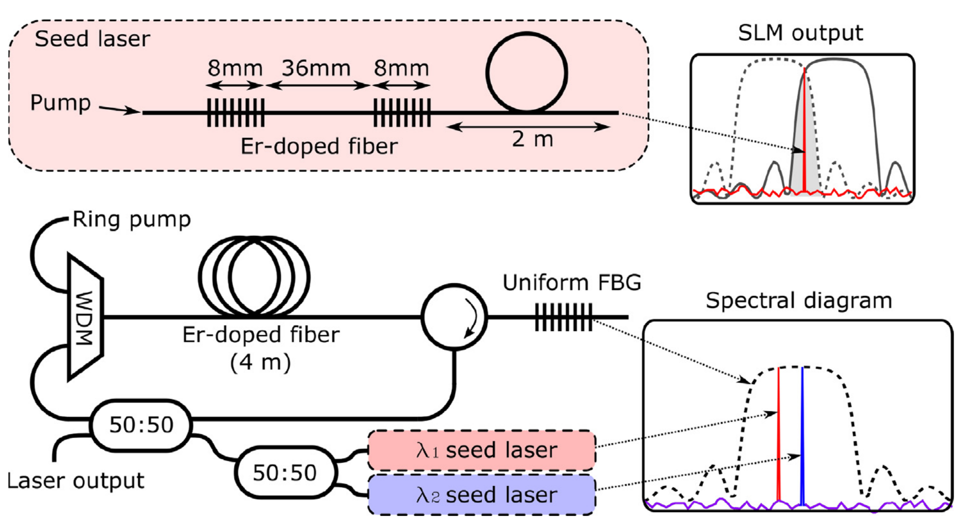

Fig. 1. A SLM laser is amplified through 2 m of Er-doped fiber, obtaining a seed laser (top). Proposed ring configuration (bottom): different seed lasers are launched into the same active medium to obtain a common output.