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Abstract. A dual-wavelength erbium fiber laser with single-longitudinal-mode characteristic is proposed and demonstrated. The system uses a 7-m-long highly doped erbium-doped fiber as the primary gain medium while two fiber Bragg gratings (FBGs) act as a wavelength selection mechanism. The sensing capability of the FBGs gives this source the possibility to be also used in a dual-sensor multiplexing scheme. The system is very stable and suitable for sensor multiplexing. [DOI: 10.1117/1.OE.53.3.036106]

Keywords: Erbium-doped fiber; fiber Bragg grating; multiwavelength lasing; single-longitudinal mode.

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1 Introduction

Fiber Bragg gratings (FBGs) have emerged as promising sensing elements for strain, temperature, and other parameters. The most significant limitation of the FBG sensors is the inability to discriminate between strain and temperature on a single measurement of Bragg wavelength shift. A number of schemes have been proposed to overcome this limitation.[1,2] These schemes can be classified into two classes: single grating schemes, which utilize a single fiber grating to achieve simultaneous measurement of strain and temperature; and combination schemes, which utilize two or more gratings, or grating in combination with other fiber elements, to discriminate strain and temperature.

In Ref. 3 is demonstrated a novel sensor that uses the difference in strain and temperature response of FBGs and a long period fiber grating to discriminate between strain- and temperature-induced wavelength shifts. Some authors[4–7] have reported fiber laser-based grating sensors in which the wavelength or intensity is measured to determine the measurands. The optical signal-to-noise ratio (OSNR) can be significantly increased because powers of the order of milliwatts can be obtained.

Multiwavelength single-longitudinal-mode (SLM) lasers have attracted considerable interest in recent years for their numerous applications, such as wavelength-division-multiplexing systems, fiber optic sensors, spectroscopy, and microwave photonic systems.[8–11] To achieve SLM operation, several approaches have been proposed. These include the use of multiple ring-cavities,[12] saturable absorbers,[8,13] the use of FBGs as self-injection feedback elements,[14] random-distributed feedback based on Rayleigh backscattering,[15] or phase-shifted FBGs.[16]

In this article, we combine the FBG sensor and fiber-laser concept together to propose and experimentally demonstrate a novel SLM dual-wavelength erbium-doped fiber laser (EDF) at room temperature. This configuration is simpler than the ones used in Refs. 17 and 18, where there were circulators used to insert the FBGs' reflected signals into the cavity. Here, unidirectional operation is ensured, and therefore the spatial hole-burning effect is avoided.

In the experiment, we achieved single-wavelength and dual-wavelength lasing, and the dual-wavelength is selected by the FBGs. The output power of the proposed multiwavelength EDF laser is quite stable and its power fluctuation is measured to be <1.2 dB. The OSNRs achieved were higher than 40 dB. Experimental results of the output power variation with time for this structure, as well as an output power and wavelength stability analysis with the temperature for one of the FBGs, were carried out.

2 Experimental Setup

The experimental setup of the proposed EDF laser is shown in Fig. 1. The designed laser consists of an amplifying fiber cavity wherein a double FBG reflection for each wavelength is utilized. For this purpose, we included a couple of FBGs and tunable FBGs for each wavelength. The nontunable FBGs were connected first, because their bandwidths are narrower than the tunable FBGs, so most of the amplified spontaneous emission was filtered at first reflection. The FBGs are centered at 1535 and 1550 nm with a reflectivity of 98% and 98.3%, respectively. The tunable FBGs were tuned at the same wavelength, 1535 and 1550 nm, with a reflectivity of 98.3% and 99.7%, respectively.

In order to achieve independent control of the system's equalization, the order of connection of the tunable and nontunable FBGs was the following: the λ_1 wavelength was tuned at 1550 nm and the tunable wavelength λ_2 to 1535 nm, the λ_2 wavelength was tuned at 1535 nm, and the tunable wavelength λ_1 to 1550 nm. In this way, the variable attenuator 1 (VA1) controlled the gain at λ_2 and at the same mode the variable attenuator 2 (VA2) only affected to λ_1. In particular, in order to achieve power equalization of both channels, the attenuation of VA1 was set to 0.8 dB, while the losses induced by VA2 were fixed to 0.2 dB.

A 7-m-long highly EDF (Er-30 by Liekki, with an absorption of 30 dB/m at 1530 nm) is used, acting as the active medium. Because of the high concentration of erbium, the

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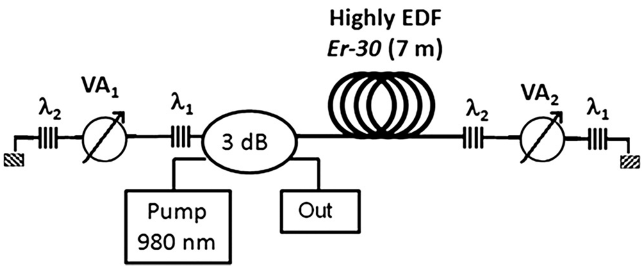

Fig. 1 Experimental setup of a linear cavity fiber laser, where a 50% coupler is used to couple the light from a 980-nm source and to deliver the 1550-nm laser output to an optical spectrum analyzer (OSA).

fiber length needed for the cavity was shorter than in other cases.[19] This configuration was also composed by a 980-nm pump source and a 50% coupler to incorporate the two FBGs into the laser cavity and to extract the laser output monitored by an optical spectrum analyzer (OSA).

As is well known, EDF is a mainly homogeneous broadened gain medium; it is difficult to get simultaneous multiwavelength oscillation at room temperature. So, the key technique for achieving multiwavelength output is to reduce the gain competition in the EDF. In the cavity, the loss of each wavelength can be changed by turning variable attenuators (VAs). Because of the existence of gain competition, usually a wavelength oscillates and the other one is suppressed. However, when the cavity loss at the two wavelengths is equal, the competition is reduced and dual-wavelength output can be achieved.[14]

As a consequence, VAs have been connected to each FBG in order to correctly adjust the cavity losses on each wavelength to achieve oscillation of the system at the desired wavelengths. All the free terminations in the system have been immersed in refractive index matching gel to avoid undesirable reflections.

3 Experimental Results

Figure 2 shows the output spectra of the proposed dual-wavelength EDF fiber laser scheme corresponding to the reflection bands of both FBGs, when pump power is 70 mW. The measured power of both channels was around −22 dBm, giving OSNRs of around 45 dB.

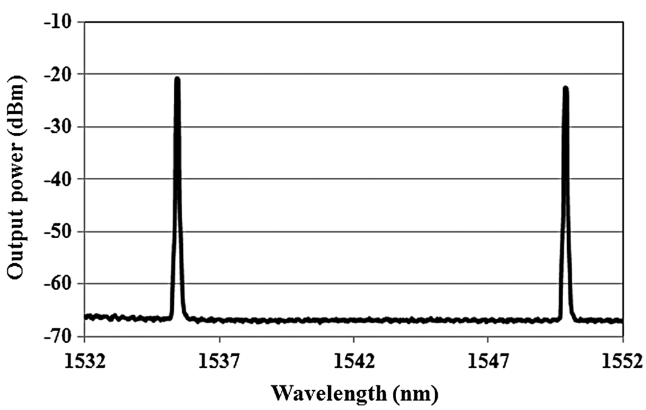

Fig. 2 Output optical spectrum measured by the OSA for the proposed dual-wavelength erbium fiber laser for a pump power of 70 mW.

When both lasing wavelengths are oscillating simultaneously with similar output powers by using the VAs to adjust the cavity losses, the laser presents a SLM operation behavior as is shown in Fig. 3. This figure represents the optical spectrum measured with a high-resolution Brillouin optical spectrum analyzer (BOSA-C Aragon Photonics, Zaragoza, Spain), with a resolution of 0.08 pm. The wavelengths correspond to the two lasing wavelengths. Both lasing signals operate in SLM regime.

To further verify the output power stability of the two wavelengths, the output spectrum was measured by using an OSA along 10 and 120 min, as shown in Fig. 4. As shown in Fig. 4(a), power fluctuations of FBG centered at 1550 nm vary from 1.2 dB when the laser operation is in multiple-longitudinal mode to 0.6 dB when it works in SLM operation. As represented in Fig. 4(b), the instability measured during 120 min was 1.18 dB for the emission line centered at 1535 nm when the laser operation is SLM.

The power and wavelength stability of this structure versus temperature variations were also analyzed. Thus, one of the FBGs was placed inside a climatic chamber and temperature cycles from 25°C to 70°C were performed in order to study its behavior. As shown in Fig. 5, the averaged wavelength increment was ∼10 pm/°C for the FBG of 1550 nm, which indicates that this structure measures correctly temperature variations, as expected. Measured power instabilities were lower than 1 dB for this FBG.

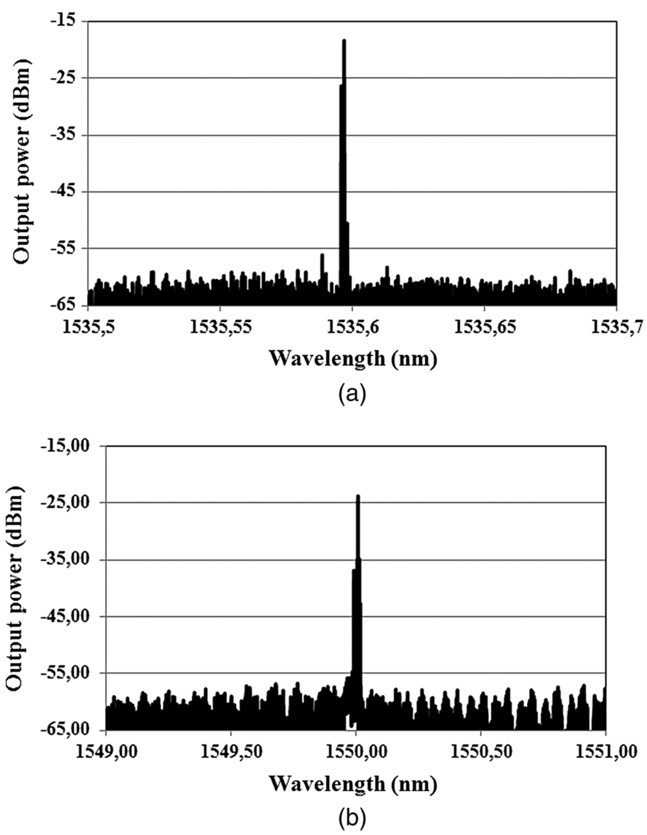

Fig. 3 Output optical spectrum measured by the Brillouin optical spectrum analyzer for the dual-wavelength erbium fiber laser configuration when the tunable laser was tuned close to the first (a) and second (b) wavelength laser emission.

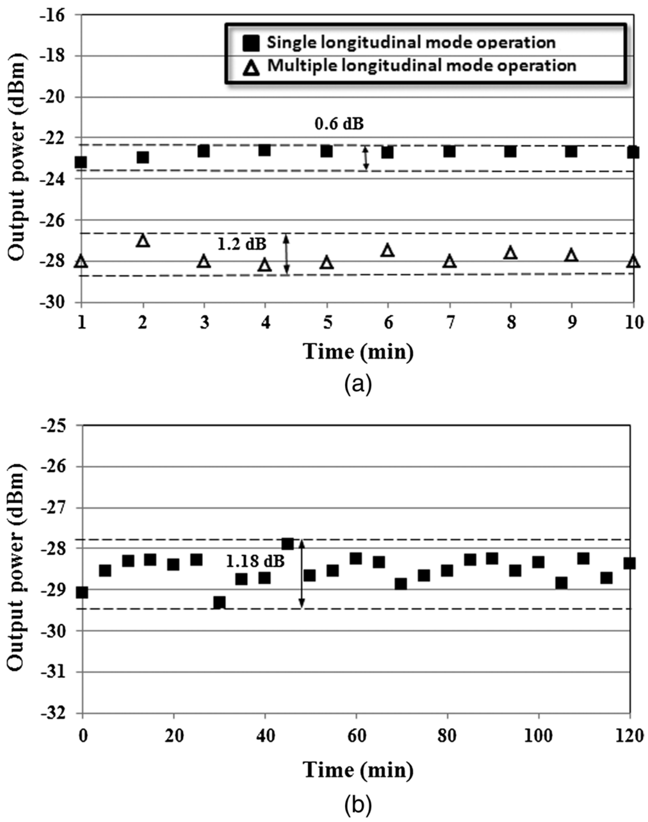

Fig. 4 (a) Output power fluctuation for the emission line centered at 1550 nm when the laser works in single-longitudinal-mode (SLM) and multiple-longitudinal-mode (MLM) operation. (b) Fluctuation for the emission line centered at 1535 nm during 120 min when the laser operation is SLM.

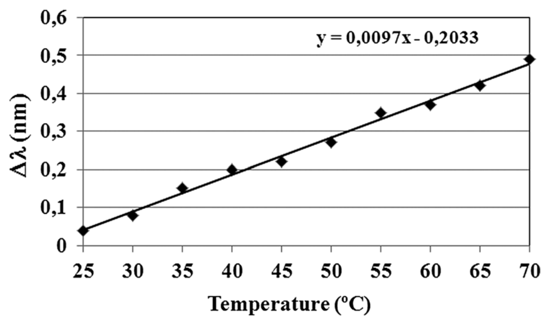

Fig. 5 Wavelength variation with temperature for the fiber Bragg grating at 1550 nm.

4 Conclusions

A new SLM and stable dual-wavelength EDF laser scheme has been demonstrated. The laser employs FBGs to select the operation wavelengths. By adjusting the VAs to equalize the emission peaks amplitudes, the laser can switch and operate in single-wavelength and dual-wavelength oscillation. The topology of the laser allows a low-noise configuration. As a result, it is experimentally demonstrated that both emission lines work in SLM operation, showing an OSNR as high as 45 dB and a power stability that varies from 1.15 to 1.2 dB for both emission lines. Finally, temperature measurements have been carried out with the structure, showing a good linearity and stability.

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