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Research Note

Erbium-doped fiber dual-ring laser with stable single-longitudinal-mode and 55-nm tuning range

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ABSTRACT

In the investigation, we propose and demonstrate a stabilized and wavelength-selectable erbium-doped fiber (EDF) compound-ring laser with single-longitudinal-mode (SLM) oscillation covering both C-band and L-band ranges. Here, the dual-ring-cavity (DRC) scheme with an unpumped EDF-based saturable absorber (SA) is proposed in the EDF laser to guarantee SLM output. The proposed DRC of EDF laser can produce the mode-filter and ultra-narrowband auto-tracking filter effects to suppress the densely multi-longitudinal-mode (MLM) and extend the effective gain of EDF in a wavelength range of 1525.0–1580.0 nm. In addition, the observed output stabilities of power and wavelength in the proposed EDF DRC laser are also experimented and discussed.

1. Introduction

At the present time, the erbium-doped fiber (EDF) ring laser is the promising and technique for the favorable applications in the optical fiber communication, high-resolution spectroscopy, fiber sensor, fiber-wireless transmission, light detection and ranging (LIDAR) [1–6]. Using EDF-based lasers could accomplish the beneficial features of broadly wavelength output range and narrow linewidth [7]. However, the conventional EDF ring laser configuration would result in the multi-longitudinal-mode (MLM) oscillation and unstable wavelength output usually, due to the mode hopping effect and a longer fiber length of laser cavity [8]. Hence, to obtain the stable and tunable single-longitudinal-mode (SLM) wavelength output would be important technology in the EDF-based lasers for the furthermore applications. Here, to achieve the stable SLM output of EDF ring laser, utilizing the multiple fiber ring structure [9], unpumped EDF- and thulium-doped fiber (TDF)-based saturable absorbers (SAs) [7,10,11], narrow linewidth optical filter [12], Mach-Zehnder interferometer [13], and optical injection method [14] in the laser cavity have also been demonstrated. Moreover, in order to achieve broadband wavelength output of EDF-based laser, use of the C + L bands erbium-doped fiber amplifier (EDFA), parallel EDFA structure, and hybrid fiber amplifier for acting as gain medium have been proposed and discussed [15–18].

In this work, we propose and investigate a wavelength-tunable EDF ring laser scheme with stable SLM output. In the experiment, the dual-ring-cavity (DRC) configuration with a short-length of unpumped EDF SA is proposed to suppress the other side-mode for completing SLM oscillation. Moreover, the proposed DRC of EDF laser also can extend the output wavelength from C-band to L-band, while a C-band EDFA is utilized in laser cavity for acting as gain medium. Therefore, the output powers and optical signal to noise ratios (OSNRs) of the proposed EDF laser are in the ranges from −2.0 to 2.7 dBm and 33.0 to 37.2 dB respectively, in the tuning wavelengths of 1525.0 to 1580.0 nm. Here, around 55 nm tuning range can be obtained based on the proposed EDF DRC laser. And the measured linewidth of output wavelength is nearly 13 kHz. In addition, the output stabilization and SLM performance are also executed and discussed.

2. Experiment and results

Fig. 1(a) presents the proposed EDF ring laser with DRC scheme. The laser setup is consisted of a commercial C-band EDFA module, two 2 × 2 50:50 optical couplers (CPRs), two polarization controllers (PCs), a C-band tunable bandpass filter (TBF), a reflective fiber mirror (RFM) with the reflectivity of 98%, and an unpumped EDF of 2 m, respectively. The operation range of fiber-based RFM with the reflectivity of ≥95% is between 1520 and 1600 nm. The insertion loss and polarization dependent loss of RFM are 0.4 and 0.04 dB. The saturation power and effective gain of C-band EDFA,

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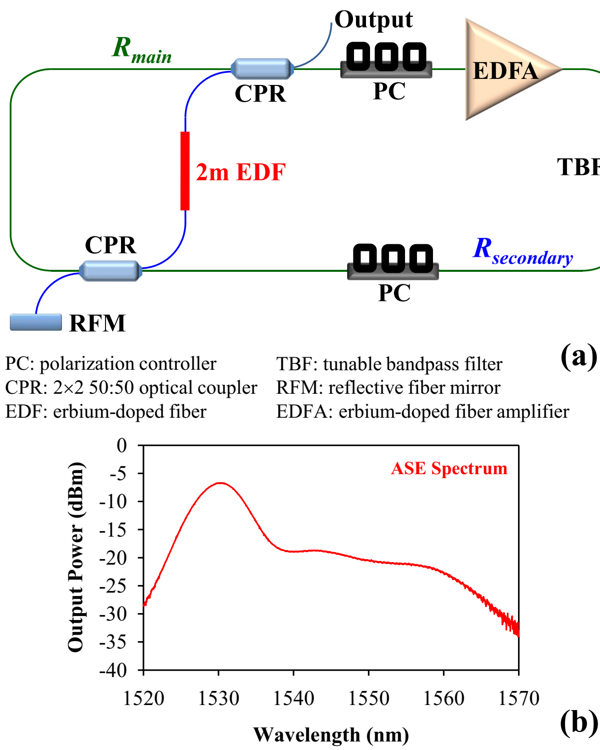

Fig. 1. (a) Experimental setup of proposed EDF DRC laser. (b) Original ASE spectrum of C-band EDFA.

which is used for acting as gain medium, are 13 dBm and 25 dB in the operation range of 1528.0–1562.0 nm. Moreover, Fig. 1(b) also presents the output amplified spontaneous emission (ASE) spectrum of EDFA. Here, to accomplish the wavelength selection, a C-band TBF is applied in the laser cavity for tuning. The 3 dB bandwidth, tuning range and insertion loss of C-band TBF are 0.2 nm, 40 nm (1525.0–1565.0 nm) and 6 dB, respectively. In addition, two PCs are used to maintain the single-polarization status for mitigating mode-competition and also provide maximum output power.

In the experiment, two CPRs, a RFM and an unpumped EDF-based SA are utilized to produce the DRC structure, as shown in Fig. 1(a). Here, the proposed DRC architecture has two fiber rings, which mean the R_{main} and $R_{secondary}$ respectively, as illustrated in Fig. 1(a). The produced dual fiber rings can generate two different free spectrum ranges (FSRs), which represent the FSR_{main} and $FSR_{secondary}$, respectively. The FSR can be denoted by the expression, $FSR = c/(n \times L)$, where the c is the speed of light in vacuum, L is the length of fiber ring, and n = 1.4682 is the effective refractive index of single-mode fiber. Furthermore, the fiber lengths of R_{main} and $R_{secondary}$ are 21 and 18 m, which have the corresponding FSRs of 9.7 and 11.4 MHz, respectively. In the laser configuration, an effective FSR can be generated by using the proposed DRC scheme and also satisfy the least common multiple of the two fiber rings for serving as the mode-filter based on the Verniner affect [9]. Moreover, an unpumped EDF-based SA of 2 m, which is also added in the DRC scheme, can introduce the ultra-narrowband auto-tracking filter effect on account of the spatial-hole-burning, which is caused by saturation effects of a standing wave [7,19]. As a result, the densely MLM oscillation of EDF laser could be suppressed to achieve the SLM operation.

Fig. 2 shows the measured wavelength spectra of the proposed EDF DRC laser. When the C-band TBF is employed, the output range can be tuned in the wavelengths of 1525.0–1565.0 nm, as plotted in blue line of Fig. 2. However, to realize the available tuning range

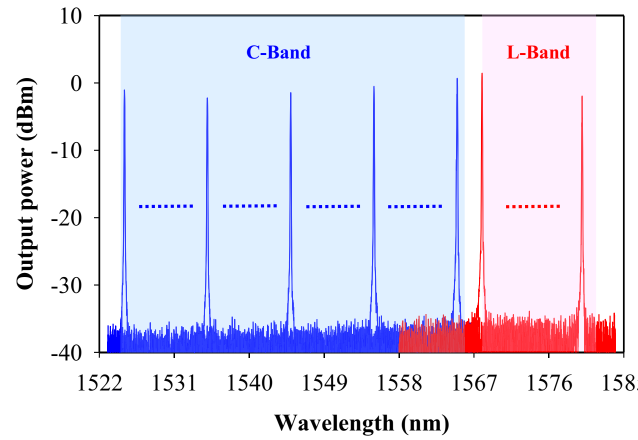

Fig. 2. Output wavelength spectra of proposed EDF DRC laser in the different wavelengths.

of the proposed EDF DRC laser, an L-band TBF is applied to replace the C-band in this measurement. The tuning range of L-band TBF is from 1568.0 to 1612.0 nm. Hence, the re-measured wavelength spectra can be obtained in the tuning range from 1568.0 to 1580.0 nm, as illustrated in red line of Fig. 2. When the central wavelength of TBF exceeds the 1580.0 nm, no output wavelength can be observed due to the insufficient gain of proposed EDF laser. As illustrated in Fig. 2, the maximum amplified spontaneous emission (ASE) of EDFA around 1530.0 nm can be suppressed significantly for each output wavelength. As mentioned above, the proposed DRC structure of EDF laser can expand the effective gain from the C- to L-bands for widely tuning.

Fig. 3 indicates the measured output powers and optical signal to noise ratios (OSNRs) of the proposed EDF DRC laser in the wavelength range of 1525.0 to 1580.0 nm. The observed output powers and OSNRs are in the ranges from −2.0 to 2.7 dBm and 33.0 to 37.2 dB, respectively. Moreover, the maximum output power and OSNR of proposed EDF laser are observed at the wavelength of 1570.0 nm, as shown in Fig. 3. As seen in Fig. 1(b), the output ASE spectrum and effective gain range of C-band EDFA is from 1528.0 to 1562.0 nm. While a DRC scheme is employed, the maximum gain of nearly 1530.0 nm can be suppressed moving to the shorter L-band range for tuning due to the mode-filter effect, as illustrated in Figs. 1(b) and 3.

Then, to realize the output SLM performance of proposed EDF DRC laser, we employ the delayed self-homodyne method for measurement. Here, a Mach-Zehnder interferometer (MZI) configura-

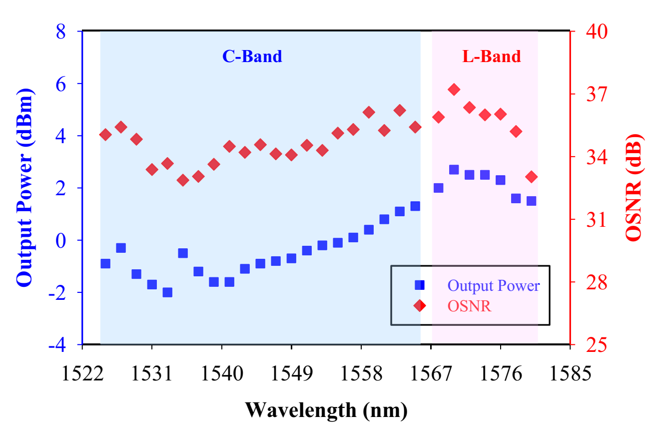

Fig. 3. Measured output power and OSNR of proposed EDF DRC laser in the wavelengths of 1525.0 to 1580.0 nm, respectively.