



Using C-band erbium-doped fiber amplifier with two-ring scheme for broadly wavelength-tuning fiber ring laser

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ABSTRACT

In this demonstration, we propose and experimentally investigate a broad and stable wavelength-tuning fiber laser employing a C-band erbium-doped fiber amplifier (EDFA) and coupled-ring cavity scheme. Based on the proposed laser scheme, the wavelength-tuning range can be tuned in S- to C-bands (from 1510.0 to 1562.0 nm) due to the properly control of cavity loss. In addition, the performances of side-mode suppression ratio (SMSR), optical signal to noise ratio (OSNR), and output power and wavelength are also discussed and analyzed over the wavelength-tuning range.

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1. Introduction

Nowadays, wavelength-division-multiplexed (WDM) communication systems play a main role in the future optical transmission. Especially, wideband erbium-doped fiber amplifier (EDFA) and semiconductor optical amplifier (SOA) are the important devices for the WDM applications. Moreover, widely stable and wavelength-tunable amplifier-based fiber lasers are also required due to their potential applications in fiber-optic sensors, optical spectroscopy, microwave fiber access networks, and WDM transmissions, etc. The conventional EDFA has a highly structured gain spectrum in the operating range between 1525 and 1565 nm in C-band [1,2]. In order to achieve broadly tuning range for amplifier-based fiber laser, several broadband fiber ring lasers have been studied and reported [3–5]. Therefore, the amplifier-based fiber lasers should have broadband tuning range with high output power due to their effectively amplification bandwidth. Besides, the wavelength-tuning range was limited by the amplification bandwidth of the fiber amplifier. The EDF-based and SOA-based ring lasers satisfy these requirements; so far, broadband wavelength-tuning range in both C- and L-bands have been reported [6–12].

In this paper, we propose and experimentally demonstrate a wavelength-tunable EDF ring laser having a broadband tuning range over 50 nm from 1510.0 to 1562.0 nm based on C-band EDFA

with coupled-ring cavity scheme using the properly control of cavity loss. Moreover, the performances of wavelength-tuning range, side-mode suppression ratio (SMSR), optical signal to noise ratio (OSNR) and the output power and lasing wavelength have also been analyzed and discussed.

2. Experiments and results

Fig. 1 shows an experimental setup of the proposed wideband wavelength-tunable erbium-doped fiber (EDF) ring laser with two coupled-ring cavities. The proposed fiber laser consists of a C-band erbium-doped fiber amplifier (EDFA), a 1×2 and 2×2 optical couplers (OCs) with 3 dB loss, two polarization controllers (PCs), a “block”, and a tunable bandpass filter (TBF) with 4 dB insertion loss. The “block” consists of an optical circulator (OC) and a fiber reflected mirror (FRM), and is used into ring loop to increase cavity loss. In the experiment, the FRM has a $\sim 99\%$ reflection. Besides, the EDFA is constructed by an EDF (model DF 1500F of Fibercore Ltd.) with ~ 10 m long, a 980/1550 nm WDM coupler and a 980 nm pumping laser with 160 mW, at room temperature. Two PCs are used to control the polarization states and retrieve the maximum output power. The tuning range and 3 dB bandwidth of TBF are 50 nm (from 1510 to 1560 nm) and 0.4 nm. Moreover, the output power and wavelength of the proposed fiber laser are observed and measured by using an optical spectrum analyzer (OSA) with a 0.05 nm resolution.

In the proposed laser, we will discuss and analyze the laser performance without and with the “block” in Fig. 1. In the first

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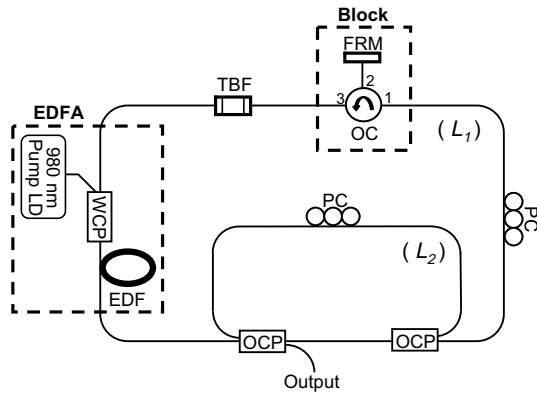


Fig. 1. Experimental setup for the wideband wavelength-tuning EDF ring laser using two coupled-ring cavities.

experiment, the proposed fiber laser is without the “block”. The fiber laser has two cavity lengths of major ring (L_1) and sub-ring (L_2) which are 24.4 and 6.2 m long, respectively. Therefore, the two corresponding free spectrum ranges (FSRs) of L_1 and L_2 are 8.37 and 33.0 MHz, respectively. Besides, the TBF is used into the major ring cavity to fine tune the lasing wavelength. Furthermore, Fig. 2 presents the amplified spontaneous emission (ASE) spectrum of the C-band EDFA, which is used in the laser cavity, with 160 mW pumping power of 980 nm LD. The effectively operating wavelength range of the amplifier is between 1525.0 and 1560.0 nm while the power level is above -30 dBm. In accordance with the past studies utilizing single ring schemes [7–9], the wavelength-tuning range was limited by the amplification bandwidth of fiber amplifiers. Besides, compared with the past laser schemes, our proposed coupled-ring scheme would also cause the larger cavity loss due to dual-ring architecture.

When the proposed coupled-ring laser scheme with C-band EDFA is used, the lasing wavelength can be tuned and distributed from 1510.0 to 1562.0 nm, as shown in Fig. 3. It shows that the SMSR and OSNR are between 47.5 and 58.8 dB and 47.1 and 64.7 dB over the tuning range of 1510.0 to 1562.0 nm, respectively. Moreover, Fig. 3 also presents the SMSR of >50.9 dB and OSNR of >60.0 dB in the proposed fiber laser in the wavelengths of 1520.0–1562.0 nm.

Fig. 4 shows the output power, SMSR, and OSNR versus different tuning wavelength in this fiber laser without “block” in Fig. 1 over the wavelength range of 1510.0–1562.0 nm when the pumping power is around 160 mW. The maximal output power of 0.4 dBm occurs at 1551.2 nm, and the output power drops to -5.6 and

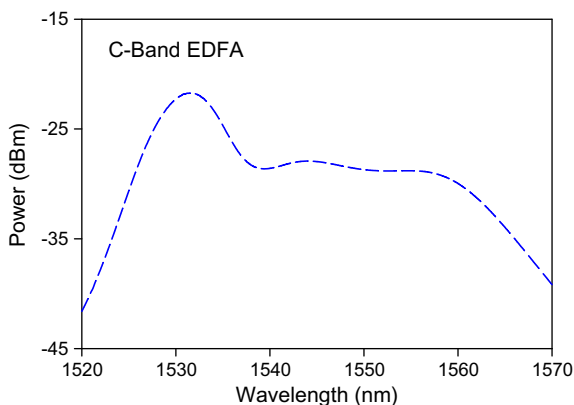


Fig. 2. Output ASE spectrum of C-band EDFA used with 160 mW pumping power.

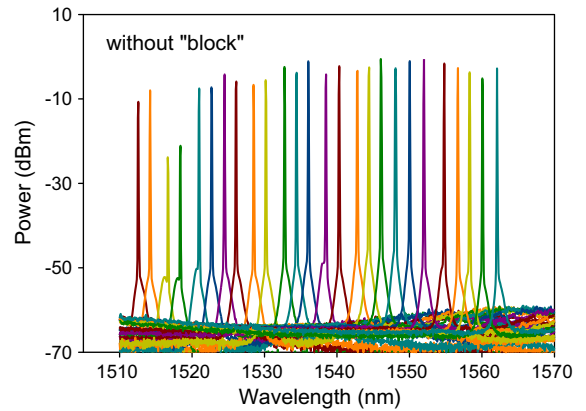


Fig. 3. Output spectra of lasing wavelength in the proposed ring laser over the wavelength range of 1510.0–1562.0 nm employing C-band EDFA with coupled-ring scheme and without “block” in Fig. 1.

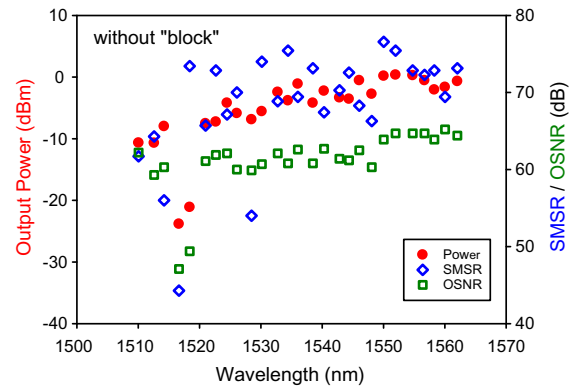


Fig. 4. Output power and SMSR versus different tuning wavelength of the proposed fiber laser while the pumping power is 160 mW in the wavelength range of 1510.0–1562.0 nm.

-23.8 dBm at 1530.2 and 1516.7 nm, respectively. Then, the output rises to -8.0 dBm at 1514.2 nm gradually. The output powers of Fig. 4 are between -23.8 and 0.4 dBm ($\Delta P_{\max} = 24.2$ dB) in the tuning range. Fig. 4 also shows the minimum output power, SMSR and OSNR at the wavelength 1516.7 nm simultaneously. The spectrum distributions of output power, SMSR and OSNR are similar under different tuning wavelength, as shown in Fig. 4. The output power, SMSR and OSNR can be kept larger than -7.5 dBm, 50.1 dB and 60.0 dB, respectively, in the wavelengths of 1520.1–1562.0 nm, as illustrated in Fig. 4. The lasing signals are generated in the 1510–1525 nm in the proposed fiber scheme, which suppresses the effectively gain to shorter wavelengths due to cavity loss. According to the past researches [5,7], the output power and SMSR spectra would drop gradually in both sides of their tuning range in accordance with their amplification bandwidth. As illustrated in Fig. 4, the output spectra in the wavelength-tuning range does not drop gradually in both sides, when the C-band EDFA is used in the proposed coupled-ring laser scheme. Due to the tuning range limitation of TBF used in this experiment, we believe that the tuning range could be predicted to exceed the original tuning range while a broadband optical filter is employed.

In the next experiment, when the “block” is added in the proposed laser scheme in Fig. 1, the two cavity lengths of major ring (L_1) and sub-ring (L_2) would become to 32.5 and 6.2 m long, respectively. Therefore, the two FSRs of L_1 and L_2 are 6.28 and 33.0 MHz approximately. In this experiment, the cavity length is

increase while the “block” is added in the cavity; it means the cavity loss is also increased. The reflection of FRM in operating wavelength range has slightly variation among the wavelengths. Based on the various output reflection of FRM inside cavity, it could compensate the loss and retrieve the uniformly output over the whole tuning range. Fig. 5 shows the output spectra of the proposed laser in the wavelengths of 1510.0–1562.0 nm. Compared with Figs. 3 and 5, Fig. 5 shows the smaller but comparatively even output power in the same tuning range. Fig. 5 also presents the SMSR and OSNR are between 43.5 and 58.6 dB and 56.9 and 64.8 dB over the tuning range of 1510.0–1562.0 nm, respectively. The fiber reflected mirror (FRM) is produced by WT&T Inc., and its model number is FM-2c. The operating wavelength range and maximum optical power of FRM are between 1500 and 1680 nm and 20 dBm, respectively. Besides, the FRM would induce slightly loss variation among the operating wavelengths. As a result, if a piece of fiber absorber or an attenuator is used instead of such the “block”, it may have the similar experimental results.

Fig. 6 shows the output power, SMSR, and OSNR versus different tuning wavelength for this fiber laser with “block” in Fig. 1 over the wavelength range of 1510.0–1562.0 nm when the pumping power is 160 mW. The maximal output power of -4.6 dBm occurs at 1560.5 nm and drops to -14.1 dBm at 15326.1 nm. Then, the output rises to -11.5 dBm at 1514.1 nm. The output powers of the proposed laser are between -14.1 and -4.6 dBm ($\Delta P_{\max} = 9.5$ dB) in the wavelength-tuning range. Compared with Fig. 4, it shows the smaller power variation in the same tuning range. The spectrum distributions of the output power and OSNR are similar, as shown in Fig. 6. With the increase of the tuning wavelength, its SMSR will also increase gradually, as seen in Fig. 6. The output power, SMSR and OSNR can be maintained larger than -12.2 dBm, 43.5 dB and 56.9 dB, respectively, in the wavelengths of 1510.0–1562.0 nm. In this paper, we only present the broadly wavelength-tuning range of proposed fiber laser scheme. However, according to the past study of Ref. [13], the proposed fiber laser may obtain single-longitudinal-mode (SLM) output under optimal cavity design to reduce the longitudinal modes by satisfying the least common multiple for the dual-cavity length. As a result, based on the coupled-ring architecture with properly cavity loss, the proposed fiber laser not only can obtain wider wavelength-tuning range but also retrieve uniform output power.

Fig. 7 shows the output power versus the different pumping power level at the lasing wavelength of 1562.2 nm initially, when the pumping power is between 7 and 160 mW without and with “block”. The output powers are between -15.5 and -1.0 dBm

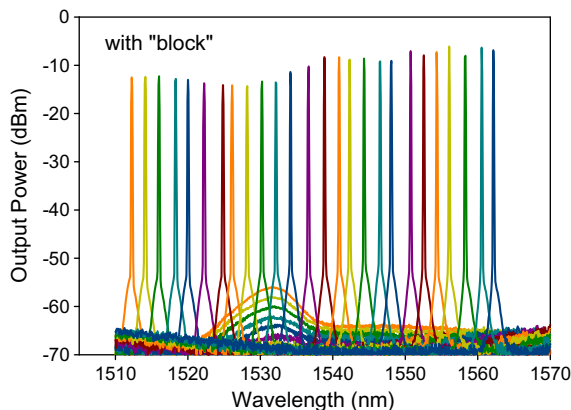


Fig. 5. Output spectra of lasing wavelength in the proposed ring laser over the wavelength range of 1510.0–1562.0 nm employing C-band EDFA with coupled-ring scheme and “block” in Fig. 1.

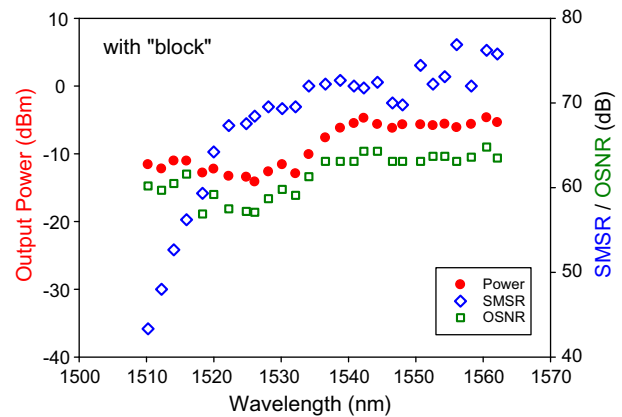


Fig. 6. Output power and SMSR versus different tuning wavelength of the proposed fiber laser while the pumping power is 160 mW in the wavelength range of 1510.0–1562.0 nm with “block” into cavity.

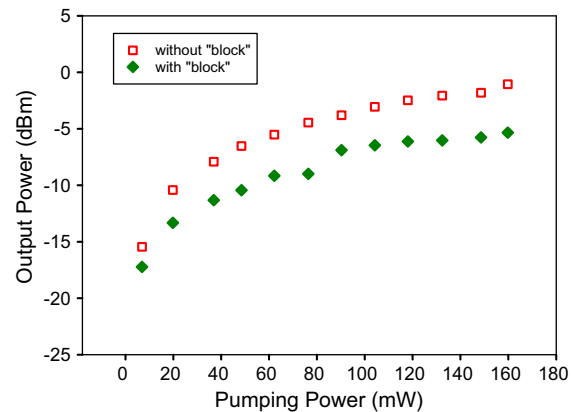


Fig. 7. Output power versus the different pumping power under 7–160 mW at 1562.2 nm initially with and without “block”.

and -17.2 and -5.3 dBm, respectively, when the proposed laser scheme is without and with “block” in the pumping range. When the “block” is used in Fig. 1, the output power will cause some decrease due to the larger cavity loss. The lasing power will start to saturate at ~ 120 mW pumping power without and with “block” into ring cavity, as shown in Fig. 7. The dual-cavity laser scheme results in the larger cavity loss. Thus, the power conversion efficiency is not good by the observed result. And the threshold pumping power for this fiber ring laser is ~ 20 mW with and without the “block”.

3. Conclusion

In conclusion, we have proposed and experimentally investigated a broad and stable wavelength-tuning fiber laser employing a C-band erbium-doped fiber amplifier and coupled-ring cavity scheme. In accordance with the coupled-ring laser scheme, the wavelength-tuning range can be tuned in S- to C-bands (from 1510.0 to 1562.0 nm) due to the proper control of the laser cavity loss. In this experiment, the output power can be achieved from -14.1 to -4.6 dBm at least, respectively, in the wavelength-tuning range. Therefore, proper cavity loss control in the laser not only can extend the tuning range, but also can obtain the better output efficiency. In addition, the performances of SMSR, OSNR, and output power and wavelength are also discussed and analyzed over the wavelength-tuning range.

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