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Discussion

An energy-efficient tie-type architecture for stable and wavelength-tunable SOA-based fiber laser

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ABSTRACT

A new and energy-efficient tie-type architecture for stable and wavelength-tunable semiconductor optical amplifier (SOA)-based fiber ring laser is proposed and experimentally investigated. Here, the tie-type laser configuration is constructed by two Sagnac fiber loops. The proposed laser also can extend the lasing wavelength to longer wavelength (L-band) even only the C-band SOA is used. The proposed tie-type architecture has >5 dB higher output optical power at bias current of 80 mA when compared with the single ring SOA-based fiber laser. In this measurement, the output power, wavelength tuning range, side-mode suppression ratio (SMSR) and output stability of proposed fiber laser have also been analyzed and discussed.

1. Introduction

Recently, the stabilized and wavelength-tunable fiber ring laser has received more and more attention since it can be used in many applications, such as optical communication, fiber sensing, optical monitoring, etc. [1–3]. Typically, the fiber ring laser is consisted of laser cavity for frequency selection and gain medium for population inversion. And, the gain media used inside fiber ring laser are erbium-doped fiber amplifier (EDFA), semiconductor optical amplifier (SOA), Raman amplifier (RA) or hybrid optical amplifier [4–7]. In past few years, various resonator designs of fiber lasers have been proposed to achieve stable and single-longitudinal-mode (SLM) output, including the linear cavities [1], ring cavities [8,9], ring cavities with Fabry–Perot etalon [10], compound fiber ring cavities [11] or Gamma-shaped long-cavity [8], and use of a loop mirror in a ring cavity [12]. Besides, using wavelength-selection components, such as the fiber Bragg grating (FBG), Fabry–Perot tunable filter (FPTF) or tunable bandpass filter (TBF), inside the cavities could achieve the tunability in the fiber lasers [13–15]. However, to achieve a larger output power of the previously proposed fiber ring lasers, the pumped power of EDFA, SOA and RA inside the ring cavity required a high energy-consumption [16–18].

In this demonstration, we first propose and experimentally investigate a new and energy-efficient tie-type ring structure for stable and wavelength-tunable SOA-based ring laser. The tie-type laser configuration is produced by two Sagnac fiber loops to reduce the energy consumption of SOA and obtain higher output power simultaneously. In the tie-type configuration, the bi-directional signal passing in the SOA will be more effective in depleting the gain of the SOA. Here, according to the proposed tie-type structure, the driven current of SOA is only 80 mA to produce a higher output power and decrease power consumption. Moreover, the required pumped power of proposed tie-type laser is less than that of traditional single-ring-type [16,17]. Hence, the wavelength-tuning range is observed between 1521.0 and 1563.0 nm and the corresponding output power is also measured between −0.7 and 5.5 dBm. Due to the tuning range limit of tunable bandpass filter (TBF), the lasing wavelength only can be tuned to 1563.0 nm. Hence, we believe that the tuning lightwave can extend to the longer wavelength range (L-band) within the effective gain amplification for the proposed tie-type ring laser scheme. Furthermore, the side-mode suppression ratio (SMSR) and output stability of our proposed fiber laser have been also discussed. As a result, the proposed tie-type laser not only can increase the output power, but also can expand the wavelength region at lower driven current for energy-efficiency.

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2. Experiment and discussions

Fig. 1 presents the proposed tie-type configuration of SOA (produced by Kamelian)-based fiber ring laser for stable wavelength tuning. Here, the tie-type structure was constructed by two Sagnac fiber loops to decrease the energy consumption of SOA and achieve higher output power. As shown in Fig. 1, the SOA was located inside the Sagnac ring-1, and the polarization controller (PC) and a tunable bandpass filter (TBF) were employed inside the Sagnac ring-2. Besides, a 2×2 and 50:50 optical coupler (CP) and a 1×2 and 50:50 CP were used to connect the two Sagnac loops to produce a tie-type scheme. And, the obtained gain and noise figure were respectively 20 dB and 7 dB in C-band (1530–1560 nm) operating range, while the bias current was 250 mA. Moreover, the TBF inside the Sagnac ring-2 could be employed to act as a wavelength-selector for tunability of the proposed fiber laser. In this measurement, the insertion loss, 3-dB bandwidth and tuning range of TBF were 6 dB, 0.4 nm and 30 nm (1520–1560 nm), respectively. Besides, the PC was employed to adjust the polarization status and maintain the maximum output power for the proposed laser configuration.

To achieve energy-efficiency in this experiment, the pumped current and temperature of SOA were set at 80 mA and 25 °C respectively. The threshold and maximum operated current of SOA was 35 and 250 mA, respectively. In the measurement, the output wavelength and output power can be observed and measured by using an optical spectrum analyzer (OSA) with a resolution of 0.01 nm and a power meter (PM), respectively.

Fig. 2 shows the output spectra of the lasing wavelengths in the proposed tie-type SOA-based ring laser in the wavelength-tuning range of 1521.0–1563.0 nm with 2 nm tuning-step, when the pumped current for the SOA is 80 mA. And the inset is the output spectrum of original SOA. Due to the tie-type design in the laser scheme, the gain can be extended to the longer wavelength side (1563 nm) even though only the C-band SOA is used (gain peak at 1500 nm). Besides, the background amplifier spontaneous emission (ASE) noise can be highly suppressed and flattened when the lasing wavelength is tuned to the longer wavelength side.

Fig. 3 shows the output power and side-mode suppression ratio (SMSR) of the proposed tie-type laser under the wavelength range of 1521.0–1563.0 nm. Here, we can obtain the minimum output power and SMSR which are -0.7 dBm and 36.8 dB/0.01 nm at the wavelength of 1521.0 nm, respectively. And the maximum output power and maximum SMSR are 5.5 dBm and 49.0 dB/0.01 nm at 1563.0 nm, respectively. The measured output power difference of 6.2 dB can be observed in this wavelength-tuning range. Besides, when the tuning wavelength is tuned to the longer wavelength gradually, the measured output power and SMSR increase, as seen in Fig. 3. Furthermore, due to the bandwidth limitation of the TBF used in the experiment, the study of lasing wavelength >1563.0 nm cannot be performed. However, according to the measured results of Figs. 2 and 3, we believe that wavelength-tuning range of our proposed laser can be extended to L-band by the tie-type Sagnac design.

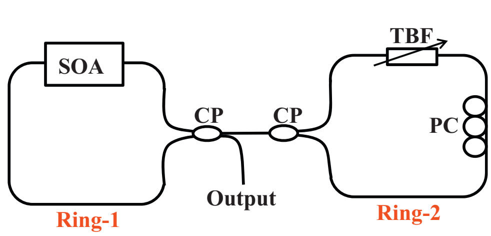

Fig. 1. Proposed tie-type configuration of SOA-based fiber ring laser for stable wavelength tuning.

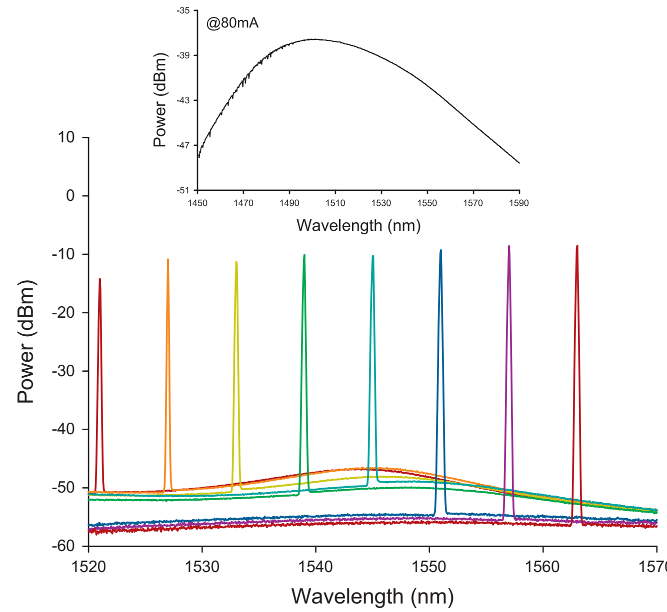

Fig. 2. Output spectra of lasing wavelengths in the proposed tie-type SOA-based ring laser in the wavelength-tuning range of 1521.0–1563.0 nm with 2 nm tuning-step, when the pumped current of SOA is 80 mA.

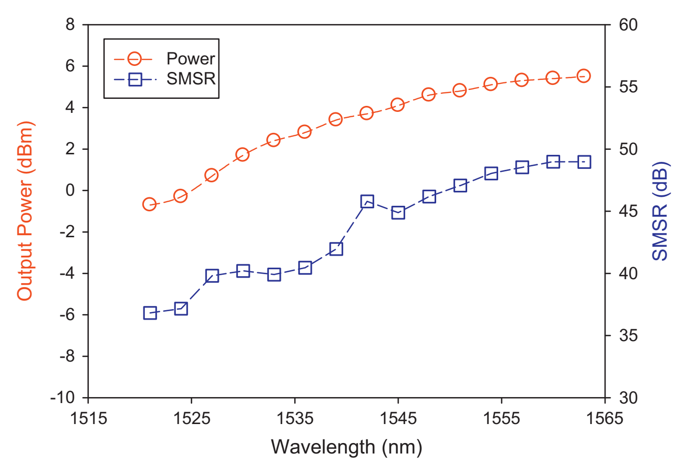

Fig. 3. Output power and SMSR of the proposed tie-type laser under the wavelength range of 1521.0–1563.0 nm.

Fig. 4 shows the output power of the proposed fiber laser versus different pumped currents of SOA, when the lasing wavelength is selected at 1551.0 nm. Here, the driving current of SOA is operated between 0 and 80 mA. Obviously, when the driving current of the SOA is increased gradually, the measured output power of fiber laser is also increased. The measured output power of 5.5 dBm can be achieved when the SOA is driven at 80 mA. The driving current for achieving transparent gain in the SOA is at 35 mA. However, we observe that the laser starts lasing at single line wavelength when the SOA is operated at 20 mA ($<$ threshold current of SOA) as shown in Fig. 4. According to the proposed tie-type laser configuration, the threshold pumped current of the wavelength-tuning laser can drop to 20 mA for wavelength lasing. As a result, the proposed laser scheme can extend the lasing range under a lower pumped current.

In the experiment, we also demonstrate and analyze the output stabilities of power and wavelength in the proposed fiber laser. Initially, the measured lasing wavelength was selected at 1551.0 nm with output power of 4.8 dBm. A short-term

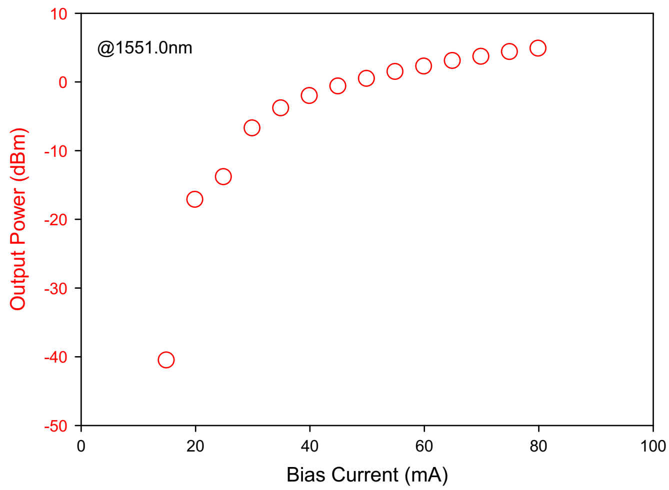

Fig. 4. Output power of the proposed fiber laser versus different pumped currents of SOA, when the lasing wavelength is selected at 1551.0 nm.

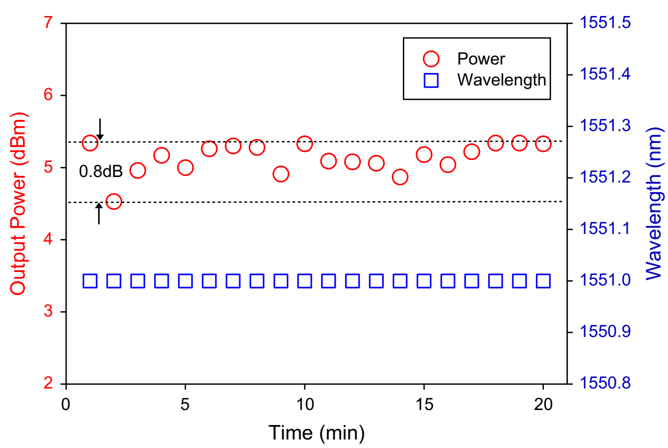

Fig. 5. Output stabilities of power and wavelength in the proposed fiber laser after 20 min observing time.

observation of stability is performed in this measurement. As shown in Fig. 5, the observed wavelength variation ($\Delta\lambda$) is negligible ($\sim$0 nm) and the measured power difference (ΔP) of $<$0.8 dB is obtained during the observing time of 20 min at 1551.0 nm. Furthermore, after 1 h observation, the output stabilities of the laser are still maintained.

Here, to realize the benefit and performance of proposed tie-type laser, we also perform the experiment using the traditional SOA-based single ring laser scheme for comparing, as shown in Fig. 6. In this measurement, we fixed a lasing wavelength at 1551.0 nm by using a TBF inside cavity loop. The same SOA and TBF are used. Then, we first varied the different pumped currents of the SOA to realize the characteristics of output power in single ring configuration. Fig. 7 presents the output power of the traditional ring laser versus different pumped current of SOA, when the lasing wavelength was selected at 1551.0 nm. Here, the driving current of SOA is operated between 80 and 200 mA. As shown in Fig. 7, if we want to get a 4.8 dBm output power, the SOA driving current of 200 mA is required. And compared with our proposed tie-type configuration, the tie-type laser only needs 80 mA driving current to obtain 4.8 dBm output power at the same lasing wavelength. In the tie-type configuration, the bi-directional signal passing in the SOA will be more effective in depleting the gain of the SOA. Hence $>$5 dB higher output optical power can be achieved at the bias current of 80 mA.

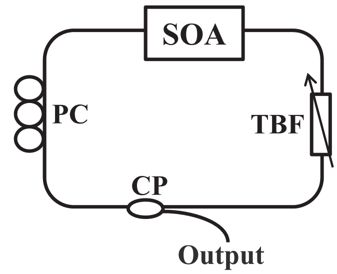

Fig. 6. Experimental setup of traditional SOA-based single ring laser scheme.

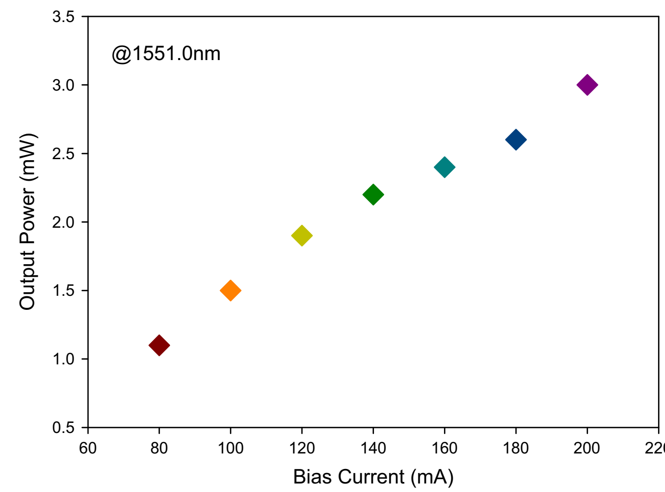

Fig. 7. Output power of the traditional ring laser versus different pumped currents of SOA, when the lasing wavelength was selected at 1551.0 nm.

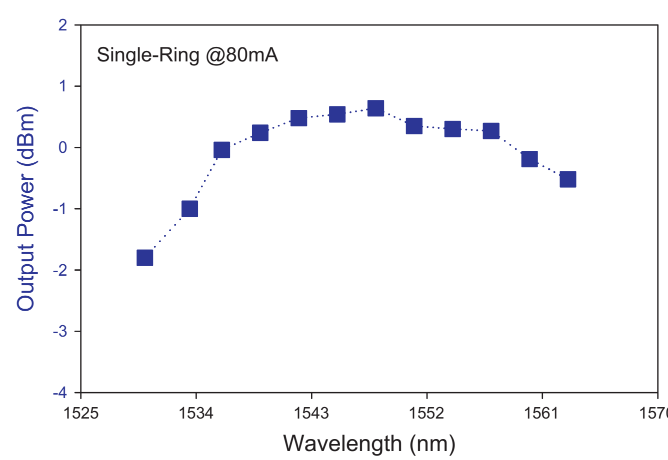

Fig. 8. Measured output power is between -1.9 and 0.6 dBm for the wavelengths of 1530.0–1563.0 nm in the traditional single ring scheme.

Next, we also measure the output power of single ring laser under different lasing wavelengths when the pumped current was set at 80 mA, as shown in Fig. 8. The measured output power is between -1.9 and 0.6 dBm for the wavelengths of 1530.0–1563.0 nm. And the measured output powers at both ends would drop gradually, due to the decrease of effective gain amplification, as seen in Fig. 8. As the output optical power starts to drop at wavelength of 1552.0 nm, we believe that the single ring laser could not be operated in the L-band. By comparing the measured results of Figs. 3 and 8 our proposed tie-type laser not only can increase the output power, but also can expand the wavelength region at much lower driving current.

3. Conclusion

In summary, we have proposed and experimentally investigated a new and energy-efficient tie-type ring structure for stable and wavelength-tunable SOA-based fiber ring laser. The tie-type laser configuration was produced by two Sagnac fiber loops. Due to the tie-type design in the laser scheme, the gain can be extended to the longer wavelength side (1563 nm) only if the C-band SOA is used (gain peak at 1500 nm). Besides, the background ASE can be highly suppressed and flattened when the lasing wavelength is tuned to the longer wavelength side. The wavelength-tuning range is observed between 1521.0 and 1563.0 nm and the corresponding output power is also measured between -0.7 and 5.5 dBm. In the tie-type configuration, the bi-directional signal passing in the SOA will be more effective in depleting the gain of the SOA. Hence >5 dB higher output optical power can be achieved at the bias current of 80 mA when compared with the single ring SOA-based fiber laser. Furthermore, the side-mode suppression ratio (SMSR) and output stability of our proposed fiber laser have been also discussed. A short-term observation of stability is performed, and the observed wavelength variation is negligible ($\sim$0 nm) and the measured power difference of <0.8 dB is obtained during the observing time of 20 min at 1551.0 nm. Therefore, our proposed tie-type laser not only can increase the output power, more energy-efficiently, but also can expand the wavelength region at a much lower driven current.

References

[1] M.A. Ummy, N. Madamopoulos, A. Joyo, M. Kouar, R. Dorsinville, Optics Express 19 (2011) 3203.
[2] C.H. Yeh, C.W. Chow, Y.F. Wu, S.S. Lu, Y.H. Lin, Laser Physics 22 (2012) 256.
[3] C.H. Yeh, C.W. Chow, Y.F. Wu, Y.H. Lin, B.C. Cheng, J.H. Chen, Laser Physics Letters 8 (2011) 672.
[4] S.-K. Liaw, C.-K. Huang, Y.-L. Hsiao, Laser Physics Letters 5 (2008) 543.
[5] H. Ahmad, K. Thambiratnam, A.H. Sulaiman, N. Tamchek, S.W. Harun, Laser Physics Letters 5 (2008) 726.
[6] R. Sonee Shargh, M.H. Al-Mansoori, S.B.A. Anas, R.K.Z. Sahbudin, M.A. Mahdi, Laser Physics Letters 8 (2011) 139.
[7] A. Ahmad, M.A. Mahdi, M.I. Md Ali, A.K. Zamzuri, Laser Physics Letters 5 (2008) 202.
[8] H. Chen, Optics Letters 30 (2005) 619.
[9] S. Roh, S. Chung, Y.W. Lee, I. Yoon, B. Lee, IEEE Photonics Technology Letters 18 (2006) 2302.
[10] C.H. Yeh, C.W. Chow, Y.F. Wu, F.Y. Shih, C.H. Wang, S. Chi, Optical Fiber Technology 15 (2009) 344.
[11] J. Zhang, J.W.Y. Lit, Journal of the Optical Society of America A 11 (1994) 1867.
[12] I.N. Duling III, Optical Letters 16 (1991) 539.
[13] M.A. Ummy, N. Madamopoulos, P. Lama, R. Dorsinville, Optics Express 17 (2009) 14495.
[14] C.-H. Yeh, C.-C. Lee, S. Chi, IEEE Photonics Technology Letters 15 (2003) 1503.
[15] C.-H. Yeh, F.-Y. Shih, C.-H. Wang, C.-W. Chow, S. Chi, Laser Physics Letters 5 (2008) 821.
[16] G.-R. Lin, Y.-C. Lin, Laser Physics Letters 8 (2011) 880.
[17] S.L. Girard, H. Chen, G.W. Schinn, M. Piché, Proceedings of the CLEO, 2007, Paper JTuA66.
[18] Lei Xu, Bing C. Wang, Varghese Baby, Ivan GleskPaul R. Prucnal, Proceedings of the LEOS, 2001, Paper WC4.