Triple-wavelength erbium fiber ring laser based on compound-ring scheme

Chien Hung Yeh*

Information and Communications Research Laboratories,
Industrial Technology Research Institute, Chutung, Hsinchu 31040, Taiwan
**Corresponding author*: depew@itri.org.tw

Fu Yuan Shih, Chang Tai Chen

Department of Electrical Engineering, Yuan Ze University, Chungli 32003, Taiwan

Sien Chi

Department of Photonics & Institute of Electro-Optical Engineering,
National Chiao Tung University, Hsinchu 30010, Taiwan
Department of Electrical Engineering, Yuan Ze University, Chungli 32003, Taiwan

Abstract: A triple-wavelength erbium-doped compound ring fiber laser using the fiber-based triple-ring filter (TRF) is proposed and experimentally investigated. Using the fiber-based TRF laser scheme, the proposed laser can lase three wavelengths simultaneously. The fiber laser retrieve the optical side-mode suppression ratios (SMSRs) of 40.2, 40.4 and 41.6 dB and the output powers of −9, −8.8 and −7.6 dBm at the wavelengths 1555.89, 1556.77 and 1557.66 nm, respectively. The mode spacing of the triple-wavelength fiber laser is nearly 0.9 nm. Moreover, the output power stability of the ring laser has also been measured and analyzed.

OCIS codes: (140.4480) Optical amplifiers; (060.2320) Fiber optics amplifiers and oscillators

References and links

1. J. N. Maran, S. LaRochelle and P. Besnard, "Erbium-doped fiber laser simultaneously mode locked on more than 24 wavelengths at room temperature," Opt. Lett. **28**, 2082–2084 (2003).
2. G. Das and J. Lit, "Wavelength switching of a fiber laser with a Sagnac loop reflector," IEEE Photonics Technol. Lett. **16**, 60–62 (2004).
3. C. S. Kim, F. Farokhrooz and J. Kang, "Electro-optic wavelength-tunable fiber ring laser based on cascaded composite sagnac loop filters," Opt. Lett. **29**, 1677–1679 (2004).
4. T. Miyazaki, N. Edagawa, S. Yamamoto and S. Akiba, "A multiwavelength fiber ring-laser employing a pair of silica-based arrayed-waveguide- gratings," IEEE Photonics Technol. Lett. **9**, 910–912 (1997).
5. Y. G. Liu, X. Feng and S. Yuan, "Simultaneous four-wavelength lasing oscillations in an erbium-doped fiber laser with two high birefringence fiber Bragg gratings," Opt. Express **12**, 2056–2061 (2004).
6. A. Bellmare, M. Karasek, M. Rochette and S. LaRochelle, "Room temperature multi-frequency erbium-doped fiber lasers anchored on the itu frequency grid," J. Lightwave Technol. **18**, 825–831 (2000).
7. J. Vasseur, M. Hanna, J. Dudley and J. Goedgebuer, "Alternate multiwavelength mode-locked fiber laser," IEEE Photonics Technol. Lett. **16**, 1816–1818 (2004).
8. S. Yamashita and K. Hotate, "Multiwavelength erbium-doped fiber laser using intracavity etalon and cooled by liquid nitrogen," Electron. Lett. **32**, 1298–1299 (1996).
9. Q. H. Mao and J. Lit, "Multiwavelength erbium-doped fiber lasers with active overlapping linear cavities," J. Lightwave Technol. **21**, 160–169 (2003)
10. C. H. Yeh, F. Y. Shih, C. T. Chen, C. N. Lee and S. Chi, "Stabilized dual-wavelength erbium-doped fiber dual-ring laser," Opt. Express **15**, 13844–13848 (2007).

1. Introduction

Erbium-doped fiber (EDF) lasers lasing multiple wavelengths simultaneously have considerable interest in wavelength division multiplexing (WDM) communication systems. To overcome the limitation of primarily homogeneous gain-broadening of erbium ion at room

#88644 - $15.00 USD Received 16 Oct 2007; revised 26 Nov 2007; accepted 2 Dec 2007; published 18 Dec 2007

temperature, various methods have been proposed [1]–[5]. The most straightforward method is to use an independent gain segment for each wavelength, where EDF lasers may be achieved by pumping with appropriate wavelength multiplexing and demultiplexing [4]. However, most of the approaches lead to inhomogeneity in a single EDF, when various elements such as acoustooptic frequency shifters [6], comb or interferometer filters [7], and Sagnac loop reflectors are introduced [2]. To improve the stability of the multiwavelength EDF lasers, many different techniques of reducing mode competition, such as cooling the EDF at 77 K [8], introducing active overlapping linear cavities [9], and using the polarization hole burning principle [5] have been proposed. Moreover, using dual-ring fiber scheme to lase dual-wavelength is also reported [10].

In this paper, we propose and investigate a simple configuration of triple-wavelength fiber laser by using fiber-based triple-ring filter (TRF) scheme. Besides, compared with the past study; the proposed fiber-based TRF scheme is simple to be constructed with cost-effective. The performances of the triple-wavelength fiber ring laser operated at optimal driving condition and the output stabilities are also discussed.

2. Experiments and Results

Figure 1 illustrates an experimental setup of the proposed triple-wavelength fiber compound ring laser structure. The proposed triple ring laser consists of an erbium-doped fiber amplifier (EDFA), three 3 dB optical couplers (OCPs), an optical circulator (OC) and three polarization controllers (PCs). In Fig. 1, the three OCPs and OC can construct the triple-ring filter (TRF) scheme. The EDFA is constructed by an EDF with 10 m long, a 980/1550 nm WDM coupler, an optical isolator (OIS) and a 980 nm pumping laser with 80 mW, in room temperature. The triple-ring scheme is completed with the TRF which serves as an in-line mode selector. Each ring has the laser light propagate in a clockwise direction oriented by the OC. Moreover, the output power and wavelength of the proposed fiber laser are analyzed and measured by an optical spectrum analyzer (OSA) of 0.05 nm resolution.

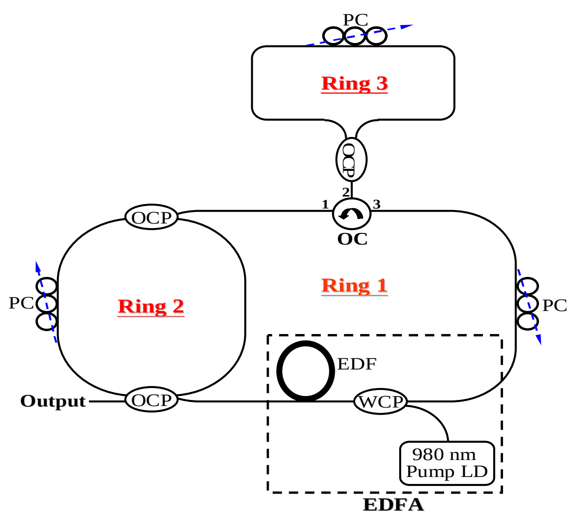

Fig. 1. Stable triple-wavelength fiber ring laser scheme using triple-ring filter.

Due to the homogeneous broadening of EDF, the number of lasing mode in the proposed ring laser will be less than four in room temperature generally. If we want to get more lasing modes based on EDF, some methods have been proposed, such as cooling the EDF in 77 K, introducing active overlapping linear cavities, and using the polarization hole burning principle [5], [8], [9]. The proposed fiber-based TRF is served as a mode-filter. Maximum selectivity occurs when the cavity lengths of L_1 (ring 1), L_2 (ring 2) and L_3 (ring 3) are incommensurate, producing by the vernier effect. Due to the fiber-based TRF method, the proposed fiber laser architecture can lase three wavelengths simultaneously at room temperature. For each ring, ring, the FSR is inversely proportional to its length, and so $FSR_L = v/L$ (v is the fiber mode group velocity). The effective FSR of the triple-ring cavity is FSR = $A_c\ FSR_{L1} = B_c\ FSR_{L2} = C_c FRS_{L3}$, where A_c, B_c and C_c are the integers which don't have common factors. Thus, owing to the vernier effect, the value of effective FSR becomes the least common multiple number of the FSR_{L1}, FSR_{L2} and FSR_{L3}. Thus, the mode suppression can be achieved and governed by the length of the triple-ring cavities. Therefore, the three rings (ring 1 to 3) have the ring length (L_i, i = 1, 2 and 3) of 30, 6 and 2 m long, which give the FSRs of 6.8, 34.1 and 102.2 MHz, respectively. Based on the optimal cavity lengths of three fiber ring loops (ring-1 to ring-3), the proposed laser scheme can lase triple-wavelength without using any active or passive filter component inside cavity. And three in-line polarization controllers are used to control the intracavity polarization states.

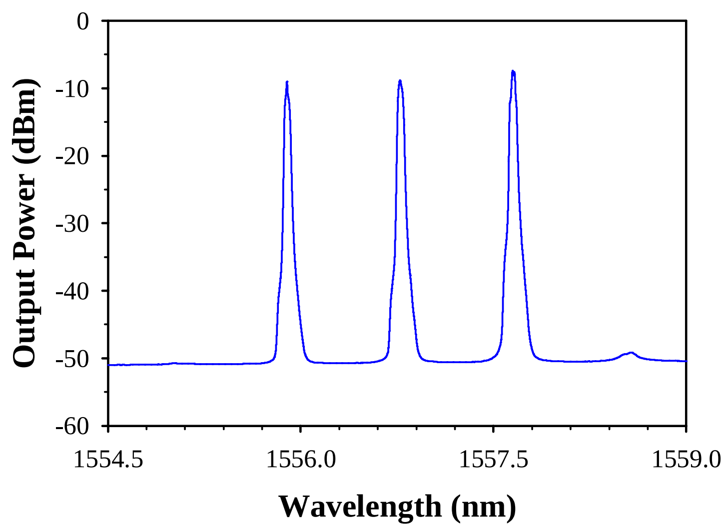

Fig. 2. Output triple-wavelength of the proposed laser at 80 mW pumping power.

In the triple-ring fiber laser, since the proposed TRF scheme is polarization-dependent, the output power can be controlled by changing the eigenstate of the polarization in the ring. Therefore, by rotating the three PCs to align the maximum output power of eigenstate of the polarization can always be retrieved. When a 980 nm pumping power operates at 80 mW, the triple-wavelength spectrum of fiber laser is shown in Fig. 2. The lasing three wavelengths of the triple-wavelength laser are 1555.89 (λ_1), 1556.77 (λ_2) and 1557.66 nm (λ_3) and the output powers are –9 (P_1), –8.8 (P_2) and –7.4 dBm (P_3), respectively. The mode spacing ($\Delta\lambda$) of the laser is 0.9 nm ($\Delta\nu \cong 112.5$ GHz), as seen in Fig. 2. Based on the proposed fiber-based TRF scheme, the FSR_{Li} (i = 1, 2, and 3) of each ring would be the least common multiple number for the FSR of triple-ring cavity. In addition, maybe the lasing wavelength of the TRF laser scheme is decided by the gain competition of erbium. The output power difference (ΔP) of the triple-wavelength is 1.6 dB at 80 mW pumping level. Figure 2 also shows that the SMSRs of the triple-wavelength are 40.2, 40.4 and 41.6 dB, respectively. Besides, Figure 3 also presents the output spectra versus the different pumping power operated at 20 to 80 mW in the proposed TRF fiber laser. When the pumping power is below 20 mW, the triple-wavelength will be not observed. Since the pumping power is 20 mW, the SMSR, output power of the triple-wavelength laser are 30.6, 29.6 and 30.1 dB and –19, –20 and –19.5 dBm, respectively. To realize the output power difference (ΔP) of the triple-wavelength laser, we define $\Delta P = P - P_{ref}$, where P and P_{ref} are the maximum and minimum output power of the triple-wavelength under different pumping power level. Figure 4 shows the output power difference (ΔP) versus

#88644 - \$15.00 USD Received 16 Oct 2007; revised 26 Nov 2007; accepted 2 Dec 2007; published 18 Dec 2007

different 980 nm pumping power of 20 to 80 mW. Moreover, it shows the minimum and maximum power differences of nearly 1 and 1.8 dB at the pumping levels of 20 and 36 mW, respectively.

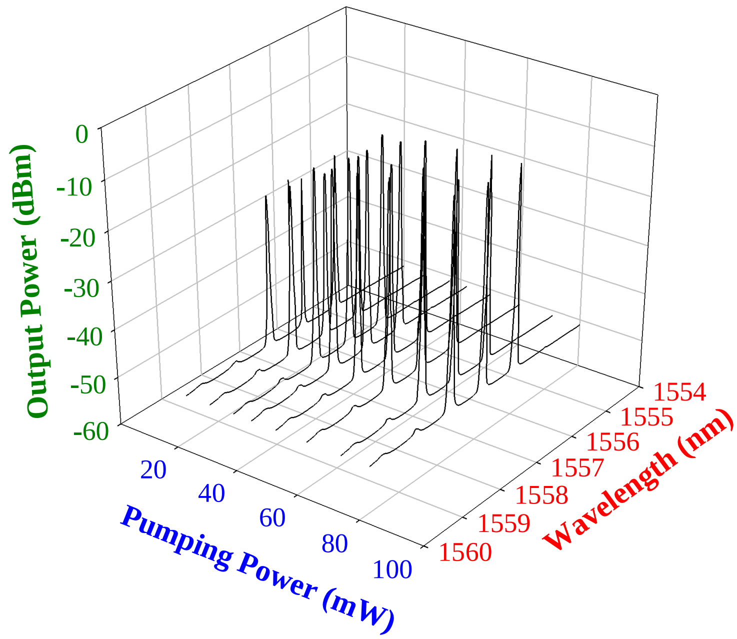

Fig. 3. Output spectra versus the different pumping power operated at 20 to 80 mW for the fiber laser.

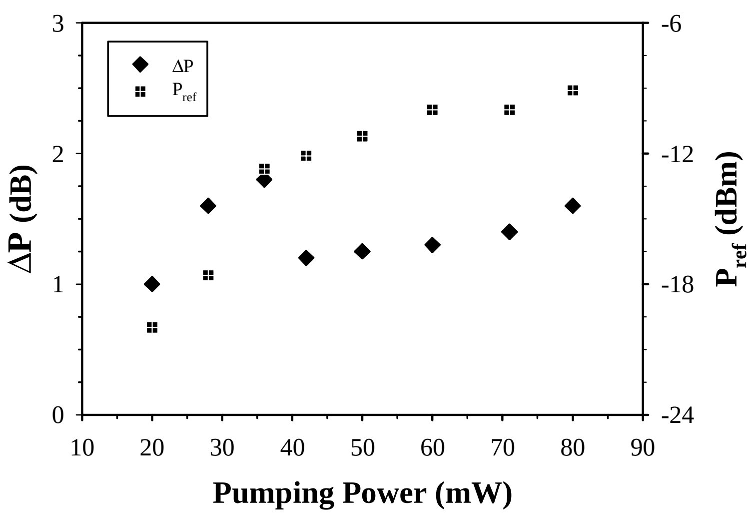

Fig. 4. Output power difference (ΔP) and minimum power (P_{ref}) of triple-wavelength versus different pumping level, which is operated at 20 to 80 mW for the proposed fiber laser.

#88644 - $15.00 USD Received 16 Oct 2007; revised 26 Nov 2007; accepted 2 Dec 2007; published 18 Dec 2007

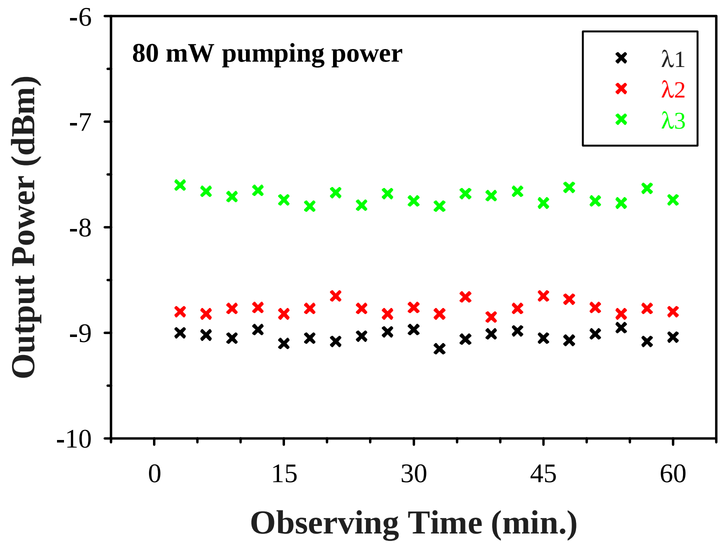

Fig. 5. Observing short-term stability of the output power for the proposed laser under the observing time of 60 minutes.

In order to realize and investigate the output power stability of the laser, a short-term stability in the triple-wavelength laser is measured and shown in Fig. 5. The lasing three wavelengths are 1555.89, 1556.77 and 1557.66 nm and the observing time is over 60 minutes. The maximum output power fluctuations are 0.1, 0.16 and 0.14 dB in the observing time, respectively, as shown in Fig. 5. And the wavelength variations of the lasing three wavelengths (λ_1 to λ_3) are also observed to zero during the same observation time. However, the output stability of proposed triple-wavelength fiber laser will be affected by any environmental perturbations. After two hours observing and recording, the stabilized output of the ring laser is still maintained. The proposed fiber laser not only observes triple-wavelength output, but also retrieves the good output stability in a long-term observing time. As a result, the proposed ring laser has the advantage of simply architecture, low cost and stable output.

3. Conclusion

We have proposed and investigated a stable triple-wavelength fiber laser for more than an hour. The proposed fiber laser does not use any fiber Bragg gratings or etalon filters within the intracavity. By using a TRF within the ring cavity, the fiber laser can lase at three wavelengths simultaneously. This triple-wavelength output exhibits a good performance having the optical side-mode suppression ratio (SMSR) over 40.2 dB and output power of > –9 dBm when the pumping power is 80 mW. Moreover, the output power stability has also been studied.

#88644 - $15.00 USD Received 16 Oct 2007; revised 26 Nov 2007; accepted 2 Dec 2007; published 18 Dec 2007