

Tunable S-band erbium-doped triple-ring laser with single-longitudinal-mode operation

C.-H. Yeh^{1*}, T.-T. Huang², H.-C. Chien³, C.-H. Ko² and S. Chi^{2,3}

¹Information and Communications Research Laboratories,
Industrial Technology Research Institute, Chutung, Hsinchu 310-40, Taiwan
²Department of Electrical Engineering, Yuan Ze University, Chungli 320-03, Taiwan
³Department of Photonics and Institute of Electro-Optical Engineering,
National Chiao Tung University, Hsinchu 300-10, Taiwan
[*depew@itri.org.tw](mailto:depew@itri.org.tw)

Abstract: We propose and demonstrate a tunable and stable single-longitudinal-mode (SLM) erbium fiber laser with a passive triple-ring cavity structure in S-band operation. The proposed laser is fundamentally structured by using three different lengths of ring cavities, which serve as the mode filters. When a mode-restricting intracavity fiber Fabry-Perot tunable filter (FFP-TF) is combined, the proposed resonator can guarantee a tunable and stable SLM laser oscillation. Moreover, the performances of the output power, wavelength stability, tuning range, and side-mode suppression ratio (SMSR) are studied.

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1. Introduction

Tunable and stable single-mode fiber ring lasers are very attractive source for many applications, such as high-resolution spectroscopy, passive component test, fiber sensors. Unfortunately, the fiber laser has the possibility of multimode operation with mode hopping because of very long cavity length and very narrow longitudinal mode spacing. Therefore, the fiber ring lasers were mainly used by the fiber Bragg grating (FBG) or etalon filters in the gain cavity of fiber lasers for a single-frequency operation. The research on single-longitudinal-mode (SLM) operation using saturable absorbers [1]-[3] has been reported to

overcome the limited spectral width of the mode selection filters [4]. Additionally, the longitudinal lasing mode was unstable when the fiber ring cavity and the filter are highly sensitive to the temperature drift and other external disturbances. To prevent the unstable operation, the fiber lasers of various schemes have been reported so that length of tunable filter and fiber ring cavity was stabilized [5], [6], or a saturable absorber was used to suppress multimode operation [1]-[3]. To facilitate SLM operation, a large free spectrum range (FSR) was also required. This has been the focus of many recent researches. With a compound-ring resonator, a large FSR is obtainable by exploiting the Vernier effect. In addition, it can have some flexible features to be used in a fiber ring laser, such as tuning the lasing wavelength by the Fabry-Perot (FP) etalon and achieving unidirectional propagation by the Mach-Zehnder interferometer (MZI). Recently, an S-band erbium-based amplification technology has been reported [7]. However, only a few S-band ring lasers were studied [7], [8] in the related researches.

In this paper, we propose and demonstrate experimentally a tunable fiber laser with SLM oscillation by an S-band EDFA, a fiber Fabry-Perot tunable filter (FFP-TF) and the passive triple-ring cavity in S-band operation. In addition, the behavior and performance of the output power, wavelength stability, tuning range, and side-mode suppression ratio (SMSR) are studied.

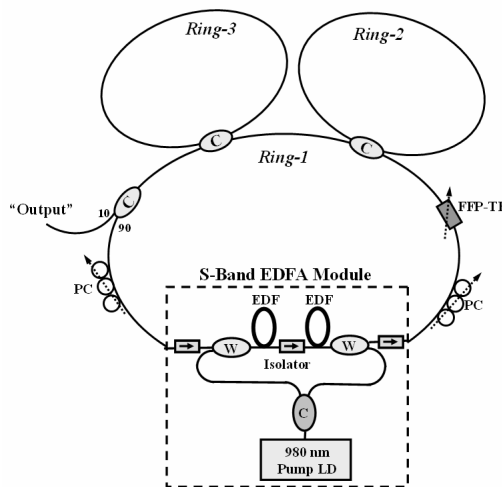


Fig. 1. Proposed experimental setup of an S-band erbium fiber laser with a multiple-ring cavity structure.

2. Experiment setup

Figure 1 shows the proposed configuration and experimental setup of an S-band erbium fiber laser with a triple-ring cavity resonator. Ring-1 is composed of an S-band EDFA, a 90:10 optical coupler, an optical circulator, an S-band FBG, and two polarization controllers (PCs). This S-band amplifier, with a saturated output power of 16.1 dBm at 1498 nm, has a depressed-cladding design and a power-sharing 980 nm pump laser to generate EDF gain extension effect [7]. The phase conditions [9] of the main and the subring resonant modes can be described by $\beta L_m = 2k\pi$ and $\beta L_i = 2l\pi$ if the main and the subring cavity lengths are L_m and L_i ($i = 1-N$, N is the number of subring cavities), respectively. Here β is the propagation constant in each ring cavity and k and l are positive integers. Moreover, the main and subring cavities have FSRs of FSR_m and FSR_s , respectively. Owing to Vernier effect, the value of effective FSR becomes the least common multiple number of both FSR_m and FSR_s . As a result, the mode suppression can be achieved and governed by the length of the main-ring and sub-ring cavities we choose. The laser mode oscillates only at a frequency that satisfies the resonant conditions of the main cavity and all of the subring cavities simultaneously. In our

proposed laser scheme, the ring-1 was the main ring, and ring-2 and -3 were the subrings. It is important to use the two PCs to align the state of polarization of the ring-1 cavity to guarantee a SLM oscillation. The FFP-TF not only determines a lasing wavelength but also serves as a mode-restricting component to provide the first restriction on the possible laser modes. Ring-2 and ring-3 are composed of a 2×2 and 50:50 optical coupler with different cavity length, respectively. Due to the combination of a FFP-TF and triple-ring cavity, a SLM selection in this fiber laser is successfully achieved. The wavelength mode oscillates only at a frequency, which satisfies the resonant conditions of the triple-ring cavities simultaneously. The polarization state of proposed laser should be maintained by adjusting the PCs as that of the ring cavity 1. These cavities have the free spectral ranges (FSRs) $FSR = c/nL$, where c is the speed of light in vacuum, $n = 1.468$ is the average refractive index of the single-mode fiber and L is the total cavity length. In the proposed laser architecture, the total lengths of the ring-1 to ring-3 are 75 m, 1.2 m, and 0.6 m, corresponding to the FSRs of nearly 2.72, 170.3, and 340.6 MHz, respectively. The output power and wavelength of proposed triple-ring laser are measured by an optical spectrum analyzer (OSA) with a 0.05 nm resolution.

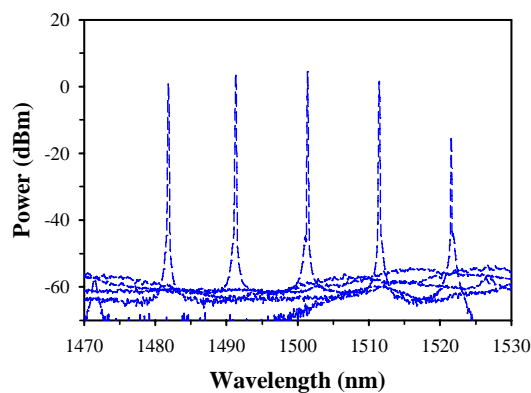


Fig. 2. Optical spectra of this S-band EDF ring laser while the various external-voltage applied on the PZT of FFP-TF in the tuning range of 1481 to 1521 nm.

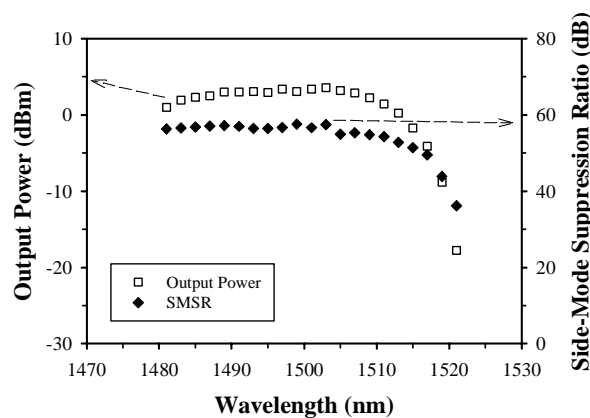


Fig. 3. Output power and SMSR versus the tuning wavelength in this ring laser.

Figure 2 shows the output lasing wavelengths of this S-band EDF ring laser under various external-voltage (0 to 12 V) applied on the PZT of FFP-TF. Based on applying different

voltage on PZT, then the various output wavelengths can be retrieved. The tuning range of our proposed ring laser over 40 nm from 1481 to 1521 nm is observed. The threshold pump powers of the single-ring and double-ring lasers were nearly 120 and 135 mW. Figure 3 represents the output power and SMSR versus the tuning wavelength in this ring laser. The maximal output power of 3.6 dBm occurs at around 1503 nm, and the output powers drop to 1.4 and -8.6 dBm while operating at 1511 and 1519 nm, respectively. In Fig. 3, the SMSR and output power can be kept larger than 54.3 dB and 0 dBm in a wide tuning range over 32 nm from 1481 to 1513 nm. When the lasing wavelength operated at around 1499 nm, the SMSR will increase dramatically to 57.6 dB due to the strong gain competition and ASE compression. Figure 3 also shows the output power of > 3 dBm and the SMSR of > 55 dB in the wavelengths of 1489 to 1505 nm, and the power variation of ± 0.25 dB over the operating range is retrieved simultaneously. As a result, the tuning range over 40 nm of 1480 to 1522 nm can be achieved and the SMSR of 54.3 dB and the output power of 0 dBm can be kept in the operating region from 1481 to 1513 nm in the proposed S-band erbium-based ring laser.

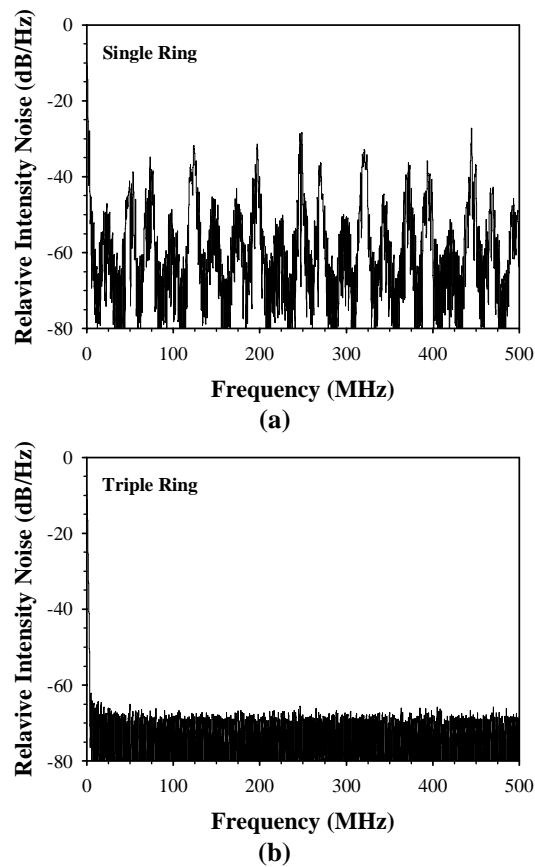


Fig. 4. Detected homodyne frequency spectrum of the proposed laser (a) with only single-ring cavity and (b) with triple-ring cavities.

The single-frequency operation of the fiber laser and its influence can be verified by a self-homodyne detection method. The optical circuit for a measurement is composed of a photodetector (PD) with 3 dB bandwidth of 12 GHz and a Mach-Zehnder interferometer with a 25 km long standard single-mode fiber (SMF). Therefore, Fig. 4(a) shows the detected self-homodyne frequency spectrum of the proposed laser only with one ring cavity that is noisy and unstable due to the mode hopping. The behavior of mode hopping is enhanced by the

environment disturbances of temperature and vibration. Then, the frequency spectrum improves after passing through the ring-1 and ring-2 with the FSRs of 170.3 and 340.6 MHz are added, as shown in Fig. 4(b). A stable SLM operation with side-mode suppression to 500 MHz can be achieved by the proposed structure, as shown in Fig. 4(b).

To investigate the performances of power and wavelength stabilities, the short-term stability of the proposed structure is measured. The lasing wavelength is 1501 nm initially and the observing time is over 900 s. From observed results, the output central wavelength variation and the power fluctuation of the proposed ring laser are smaller than 0.02 nm and 0.05 dB, respectively. In addition, during a 1-h observation, the stabilized output of the ring laser is still maintained and observed by the self-homodyne detection method.

4. Conclusion

In summary, we have proposed and demonstrated experimentally a tunable and stable SLM erbium fiber laser with a passive triple-ring cavity structure in S-band operation. The proposed laser is structured by using three different lengths of ring cavities, which serve as the mode filters. When a mode-restricting intracavity FFP-TF is combined, the proposed resonator can guarantee a tunable SLM laser oscillation. Output power of > 0 dBm, power stability of ≤ 0.05 dB, wavelength variation of ≤ 0.02 nm and side-mode suppression ratio (SMSR) of > 54.3 dB / 0.05 nm have been experimentally demonstrated for this single-frequency fiber laser over an operating range of 1481 to 1513 nm. Proposed fiber laser effectively also can suppress the side-mode frequencies in a RF bandwidth of 500 MHz.

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