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Using optical Fabry-Perot devices for a wavelength-tunable S-band erbium-doped fiber ring laser with single-frequency operation

Chien-Hung Yeh
National Chiao Tung University
Department of Photonics and Institute of Electro-Optical Engineering
Hsinchu 300, Taiwan
and
Industrial Technology Research Institute
Computer & Communications Research Laboratories
Transmission System Department
Chutung, Hsinchu 310, Taiwan
E-mail: depew.eo89g@nctu.edu.tw

Hung-Chang Chien
National Chiao Tung University
Department of Photonics and Institute of Electro-Optical Engineering
Hsinchu 300, Taiwan

Bing-Chung Cheng
National Chiao Tung University
Department of Photonics and Institute of Electro-Optical Engineering
Hsinchu 300, Taiwan
and
Fu Jen Catholic University
Department of Physics
Taipei 242, Taiwan

Chien-Chung Lee
National Chiao Tung University
Department of Photonics and Institute of Electro-Optical Engineering
Hsinchu 300, Taiwan
and
Yuan Ze University
Department of Electrical Engineering
Chung-Li 320, Taiwan

Sien Chi
Industrial Technology Research Institute
Computer & Communications Research Laboratories
Transmission System Department
Chutung, Hsinchu 310, Taiwan
and
Yuan Ze University
Department of Electrical Engineering
Chung-Li 320, Taiwan

Abstract. We have proposed and experimentally demonstrated a stabilized and tunable S-band erbium-doped fiber ring laser by using a Fabry-Perot laser diode (FPLD) and a fiber Fabry-Perot filter inside the ring cavity. Due to the bandwidth limitation of the FPLD, the effective operating range of the proposed laser is confined to 1490.28 to 1521.22 nm with a tuning step of 0.08 nm. A side-mode suppression ratio of >39.1 dB at 0.05 nm and an output power of >0.4 dBm can be achieved while this laser is tuned from 1490.28 to 1510.27 nm. Zero output wavelength variation and output power fluctuation ≤0.03 dB have also been obtained. [DOI: 10.1117/1.2083407]

Subject terms: S band; fiber ring laser; single frequency; Fabry-Perot laser.

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1 Introduction

Stable and tunable frequency and constant power output are very necessary for the fiber ring lasers applied to wavelength-division multiplexing (WDM) for communications and optical sensor systems. In general, fiber Fabry-Perot (FFP) filters can provide wavelength selection inside the ring cavity of a fiber ring laser. Because of the bandwidth limitation of erbium-doped fiber amplifiers (EDFAs), the operation region of erbium-doped fiber (EDF) ring lasers extends only from C to L band (1530 to 1610 nm)[1,2] and thus must be supplemented with the proposed S-band

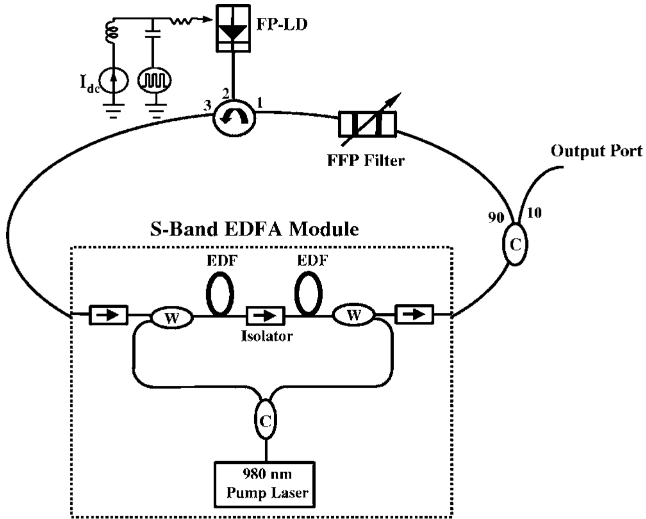

Fig. 1 Proposed experimental setup for the stabilized S-band EDF ring laser with two optical Fabry-Perot devices inside the ring cavity.

EDFA module.[3] However, that is insufficient to stabilize the lasing wavelength and power of a fiber ring laser. Recently, several techniques, such as integrating two cascaded FFP filters of widely different free spectral ranges (FSRs) into the cavity,[4,5] using a compound ring resonator composed of a dual-coupler fiber ring and a tunable bandpass filer,[2] and adding an extra ITU-grid periodic filter in the optical loop,[6] have been reported experimentally.

In this study, a new method, which employs the S-band EDFA module, a Fabry-Perot laser diode (FPLD) and a FFP filter for stabilized and tunable fiber ring lasers at wavelengths of 1490.28 to 1521.22 nm in steps of 0.08 nm, has been proposed and experimentally investigated. The performance of the tunable range, wavelength and power stabilities, and side-mode suppression ratio (SMSR) have also been studied.

2 Experiments

The proposed experimental setup for the stabilized S-band EDF ring laser is shown in Fig. 1. This ring laser is constructed from a 1×2 and 10 : 90 optical coupler, an optical circulator (OC), an intracavity FFP filter, a multi-longitudinal-mode FPLD with 0.08-nm mode spacing, and an S-band EDFA module with two amplifier stages and a power-sharing 980-nm pump laser. The total pump power of this S-band amplifier can be up to 280 mW while the bias current is operated at 356 mA. The S-band erbium-doped fiber inside the EDFA module has a depressed cladding design in order to provide a sharp, high-attenuation, long-wavelength cutoff filter for active fibers. Furthermore, the EDFA module contains two EDF stages with different properties. The fiber in the first stage is 20 m long, and provides both low noise and medium gain by forward pumping. The fiber in the second stage is 30 m long, and generates large output power through backward pumping. The optical isolator is placed between these two stages in order to reduce backward-amplified spontaneous emission (ASE). Both a high gain of 32 dB and a low noise figure of 5.7 dB at 1500 nm can be obtained when an input power of −25 dBm is provided. The saturated output power at 1500 nm can reach 14 dBm for an input signal power of 0 dBm. The central wavelength of the FPLD is 1531.62 nm at a bias current of 20 mA. In addition, the FFP filter has wide tunability, low loss of <0.5 dB, and low polarization-dependent loss (PDL) of ~ 0.1 dB. The FFP filter, with FSR of 45 nm, can be used to select the lasing wavelength in the ring cavity by applying external voltage (0 to 12 V) to the piezoelectric transducer (PZT) of the filter. Moreover, the FPLD is also used inside the ring cavity in the proposed fiber ring laser for wavelength filtering and lasing.

To provide stable single-frequency operation, the central wavelength of the FFP filter passband is tuned to align the longitudinal-mode FPLD for wavelength lasing and tuning. Therefore, the 0.08-nm tuning step is determined by the longitudinal-mode spacing of the FPLD. In this way, the side modes of the FPLD are suppressed and the optical output amplified while the bias current is maintained at 15 mA. The output spectra and powers are observed by using an optical spectrum analyzer (OSA) with 0.05-nm resolution and a power meter (PM). Compared with conventional fiber ring laser operation,[1–3] the FPLD and the optical circulator are removed, but a polarization controller (PC) is placed in the ring cavity in order to control the polarization state and maintain the output wavelength and power stabilization.

3 Results and Discussion

This proposed ring laser could achieve a stabilized-single frequency output. Figure 2(a) shows the ASE of the S-bend EDFA over the wavelength range of 1470 to 1530 nm. Figure 2(b) shows the output spectrum of the FPLD when the bias current is 15 mA over the wavelength range of 1480 to 1540 nm. Actually, the multiwavelength output of the FPLD was distributed at C band, and the central wavelength was 1537.33 nm. Due to the limitation of the output spectrum of the FPLD and the ASE spectrum of the S-band EDFA, the effectively operating range will be limited to 1490 to 1520 nm.

Figure 3 shows the optical spectra of the ring laser for different external voltages (0 to 12 V) applied to the PZT of a FFP filter. Thereby, the single-mode lasing wavelength can be tuned from 1490.28 to 1521.22 nm in 0.08-nm steps. From Fig. 3, the ring laser has lower ASE at 1503.08 nm.

Figure 4(a) and 4(b) show the output power and the SMSR versus the lasing wavelength in the tunable range with 0.08-nm tuning steps. The maximum output power of 2.4 dBm is observed at 1497.54 nm. As seen in Fig. 4(a) and 4(b), the SMSR and output power are larger than 39.1 dB (at 0.05 nm) and 0.4 dBm, respectively, for the tuning range from 1490.28 to 1510.27 nm. When the laser was operated at wavelength 1502.84 nm, the SMSR rose to 48.7 dB at 0.05 nm. In addition, the stabilized output of this ring laser can be observed without using any PC. As a result, an SMSR of >33.3 dB at 0.05 nm and an output power of >-3.4 dBm can be retrieved while this ring laser is tuned from 1490.28 to 1515.60 nm in steps of 0.8 nm, with the FPLD operated at 25°C.

Repeatability and accuracy in tuning of a desired specific wavelength can be achieved by adjusting the bias cur-

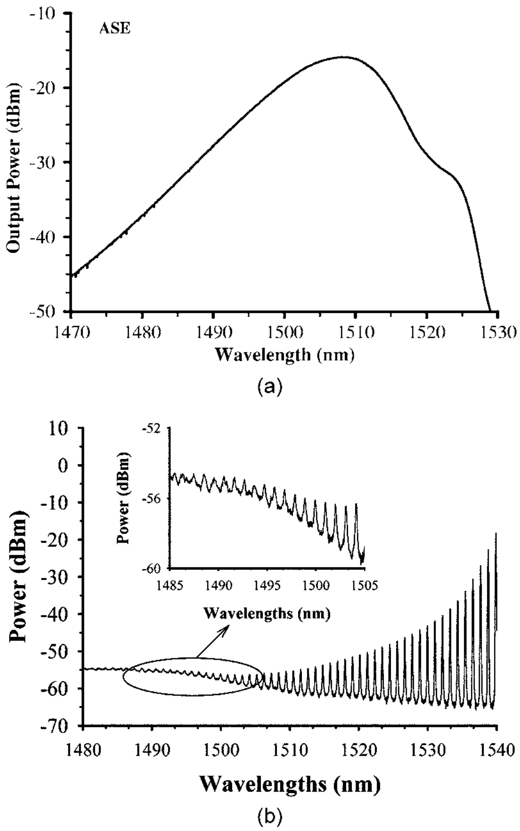

Fig. 2 (a) The ASE spectrum of the S-band EDFA module. (b) The output spectrum of the FPLD with 15-mA bias current.

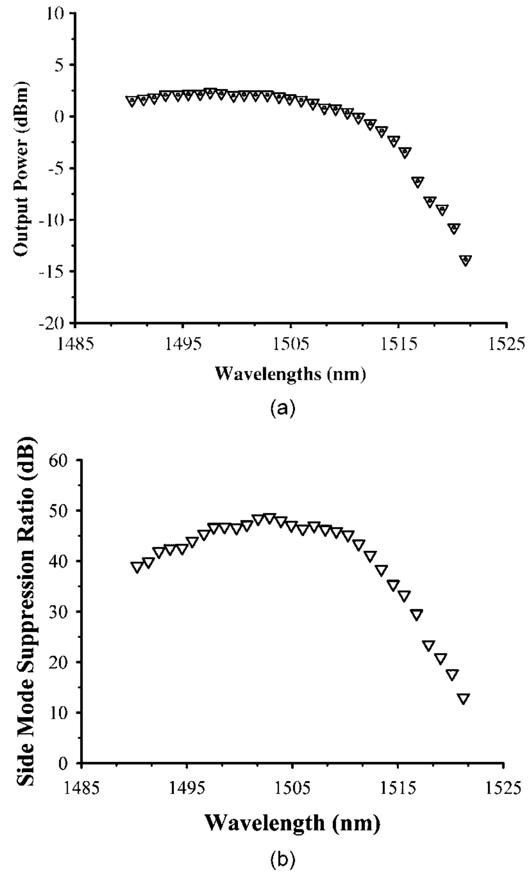

Fig. 4 (a) The output power and (b) the SMSR versus the lasing wavelength with 0.8-nm tuning steps over the tunable range.

rent and temperature of the FPLD. Then, controlling the lasing wavelength injected from the FFP filter into the FPLD so as to dominate the gain competition[7] and lock the desired mode[8] will produce single-frequency output with 0.08-nm tuning step in the S-band window. When the bias current or temperature is increased, the central wavelength will shift slightly to longer wavelength according to the characteristic of the FPLD.[8,9] Therefore, we can obtain continuous stabilized single-frequency light-wave output by the method mentioned.

To investigate the performance of power and wavelength stability, the short-term stability of the proposed structure was measured and compared with that of the conventional architecture.[3] The lasing wavelength is 1510.27 nm initially, and the observation time is more than 900 s. In Fig. 5, the power fluctuation for the proposed configuration is seen to be less than 0.03 dB. Simultaneously, the proposed ring laser can dramatically reduce the wavelength variation. During 2-h observation, the stabilized output of the pro-

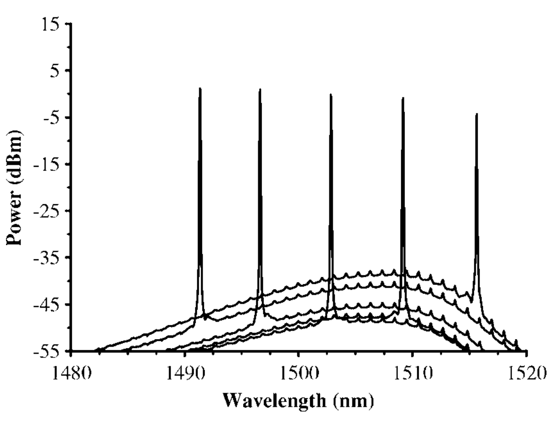

Fig. 3 The output spectra of the proposed laser with the external voltage applied to the PZT of FFP filter over the wavelength range from 1490.28 to 1521.22 nm in steps of 0.8 nm.

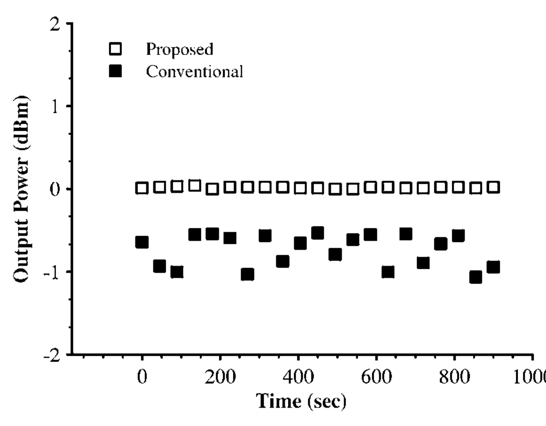

Fig. 5 The output power fluctuation for the proposed ring laser. The lasing wavelength is 1510.27 nm initially, and the observation time is more than 900 s.

posed ring laser was maintained. The threshold current of the FPLD was 11 mA, and its bias current can be adjusted between 11 and 20 mA for wavelength tuning. When the bias current is greater then 20 mA, the side mode of the ring laser cannot be suppressed, due to the gain saturation of the FPLD. External injection into the FPLD can lock the mode for stabilized single-frequency output. Compared with the conventional fiber ring laser, this laser has more stable output. However, its performance will be limited by the gain profile of the EDF and the bandwidth of the FPLD.

Due to the limited resolution (=0.05 nm) of the OSA, we cannot measure the real linewidth of output wavelength. In our experiment, we use the delayed self-homodyne technique[10] to verify that the output lightwave was single mode; however, the linewidth of the lasing wavelength cannot be determined by that method. To obtain the real linewidth of the light wave, the heterodyne detection technique[11] should be used.

4 Conclusion

A stabilized and tunable S-band EDF ring laser using an FPLD and an FFP filter inside the ring cavity has been proposed and experimentally demonstrated. Due to the bandwidth limitation of the FPLD, the effective operational range is confined to 1490.28 to 1521.22 nm with a step of 0.08 nm. The side-mode suppression ratio (SMSR) of >39.1 dB at 0.05 nm and the output power of >0.4 dBm can be achieved while this ring laser is tuned from 1490.28 to 1510.27 nm. An output wavelength variation of zero and output power fluctuation of $\leqslant 0.03$ dB have also been obtained. Therefore, this proposed stabilization technique is expected to benefit S-band ring laser applications.

Acknowledgments

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Chien-Hung Yeh received his BS and MS degrees from the Department of Physics, Fu Jen Catholic University, Taiwan, in 1998 and 2000, respectively. He received his PhD degree in the Institute Electro-Optical Engineering, National Chiao Tung University, Taiwan, in 2004. His current research interests include optical fiber laser technologies, optical switching, EDFAs, applications of optical amplifiers for WDM transmission, optical monitoring technologies for fiber communications, and Ethernet passive optical networks. He is now working in the Transmission System Department, Computer & Communications Research Laboratories, Industrial Technology Research Institute, in Taiwan.

Hung-Chang Chien received his BSEE and MSEE degrees from National Chung-Cheng University, Taiwan, in 1999 and 2001, respectively. He is currently a PhD student in the Department of Photonics & Institute of Electro-Optical Engineering, National Chiao Tung University, Taiwan. His research interests are optical fiber communications and optical fiber amplifiers.

Bing-Chung Cheng received the MS degree from the Physics Department, Fu Jen Catholic University, Taiwan, in 1994. He is currently a PhD student in the Department of Photonics & Institute of Electro-Optical Engineering, National Chiao Tung University, Taiwan. His research interests are optical fiber communications and optical solitons.

Chien-Chung Lee received the MS degree in electro-optical engineering from National Central University in 1991 in Taiwan. Also in 1991, he joined the Telecommunication Laboratories (now renamed Chunghwa Telecomm Labs), Ministry of Transportation and Communications, in Taiwan. Since that time he has been working on fiber-in-the-loop technologies, including fiber measurement and optical CATV transmission. His current research interests include in-service surveillance technologies for optical networks, and applications of EDFA for WDM transmission and analog video HFC networks. He received his PhD from the Institute of Electro-Optical Engineering, National Chiao Tung University, Taiwan, in 2001.

Sien Chi received his BSEE degree from the National Taiwan University and his MSEE degree from the National Chiao Tung University, Taiwan, in 1959 and 1961, respectively. He received his PhD in electrophysics from the Polytechnic Institute of Brooklyn, New York, in 1971, and he joined the faculty of National Chiao Tung University, where he was a professor of electro-optical engineering from 1972 to 2004 and the vice-president of the university from 1999 to 2002. He was the chair of the International Symposium of Optoelectronics in Computers, Communications and Control in 1992, which was co-organized by National Chiao Tung University and SPIE. He joined the faculty of the Department of Electrical Engineering, Yuan Ze University, in Taiwan, in 2004. His research interests are optical fiber communications, optical solitons, and optical fiber amplifiers. He is a fellow of the Optical Society of America and the Photonics Society of Chinese-Americans