A unidirectional room temperature multi-wavelength fiber ring laser without isolator

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A simplified ring cavity for achieving a unidirectional room temperature multi-wavelength erbium-doped fiber ring laser without optical isolator is demonstrated. The fiber ring cavity is built in such a way that the optical fields propagating in two directions suffer different losses caused by one sampled fiber Bragg grating. Furthermore, simultaneous multi-wavelength lasing with 0.8-nm intervals is demonstrated with sinusoidal phase modulation just before the sampled fiber Bragg grating to prevent single-wavelength lasing and unstable wavelength oscillation.

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Erbium-doped fiber (EDF) lasers simultaneously generating multiple wavelengths have been investigated in order to develop simple compact sources for wavelength division multiplexing (WDM) transmission systems[1]. Large homogeneous line broadening[2] of the gain media and gain competition among the various lasing modes at room temperature has been the major barrier to achieve simultaneous and stable oscillation of multiple wavelengths. A common method of reducing the homogenous linewidth is to cool EDF down to cryogenic temperature[1]. However, the use of a cooler, such as liquid nitrogen, is impractical owing to its cost and complexity. To achieve simultaneous multi-wavelength operation at room temperature, several methods have been proposed, such as use of special EDF structure[3], optical feedback, and nonlinear configurations. Recently, it has been demonstrated that an acoustic-optic frequency shifter inserted in the laser cavity can prevent single steady-state oscillation[4]. In addition, a fiber phase modulator[5] can be substituted for the acoustic-optic frequency shifter to decrease cost and insertion loss. However, an optical isolator is needed to be inserted in the EDF ring cavity to ensure the unidirectional operation. The optical isolator always gives rise to the cost and intrinsic loss. What's more, the fiber phase modulator is passed only one time when optical fields circulate every time along the ring cavity.

In this letter, we demonstrate a simple ring cavity structure which has a nonreciprocal loss of the two traveling directions, for obtaining unidirectional room temperature multi-wavelength fiber ring laser based on sinusoidal phase-modulation feedback without optical isolator. Loss is reduced without isolator and further decreased because the unidirectional steady-state oscillation operating clockwise is not influenced by the insertion loss of the fiber around piezoelectric transducer (PZT) and sampled fiber Bragg grating (SBG). The fiber phase modulator is adjacent to the SBG, which makes counter clockwise (ccw) amplified spontaneous emission (ASE) entering the fiber phase modulator pass it two times before returning to EDF every time. It means that the equivalent fiber length around the PZT or modulation amplitude caused by driving signal is increased by one time. The demand on driving signal and PZT is lowered. In a word, this method using the ring cavity structure can dramatically reduce cost and insertion loss.

The experimental setup of the unidirectional fiber ring laser is shown schematically in Fig. 1. It has a ring structure of EDF with only one commercial 5/95 fiber coupler used as output coupler (OC), one port of which is tailed by a piece of fiber several meters long around a PZT and an adjacent SBG to introduce nonreciprocal losses for the two lasing directions (cw for clockwise and ccw for counter clockwise). The PZT wrapped by fiber[5] acts as a phase modulator to prevent single-mode laser oscillation and thus allow multi-wavelength lasing even at room temperature. A commercial fiber coupler with two symmetrical output ports of 4.77% is used to monitor the lasing power in two directions. In addition, a 980-nm laser diode, a 980/1550 nm wavelength division multiplexer and a polarization controller (PC) are employed. Meanwhile, the isolator is inserted in the cavity as shown in Fig. 1 in order to compare the results between without and with isolator. Below lasing threshold, a linear ray-tracing calculation gives the losses for the two directions in the fiber ring laser. We assume that the EDF has a constant gain for the cw and ccw directions without saturation. Losses of the multiplexer and

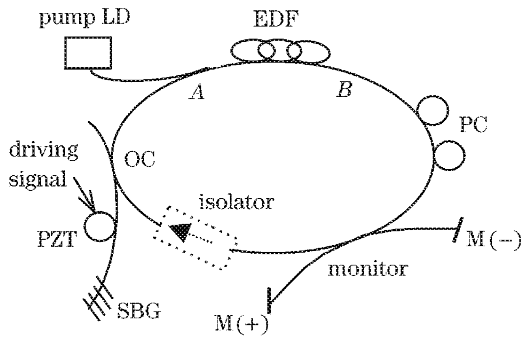

Fig. 1. The experimental setup of the multi-wavelength fiber ring laser. M(−) and M(+) are the monitor outputs of ccw and cw directions, respectively.

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monitoring coupler are ignored. For an identical output of ASE with A and B being the start points of the ccw and cw directions respectively, it is obvious that 5% ASE at B clockwise circulates to A and 5% ASE at A counter-clockwise circulates to B. Without the SBG, the losses in two directions should be equal to each other. Owing to the employment of SBG, about $0.9R(\lambda)$ ASE at A is reflected to itself ($R(\lambda)$ is the wavelength-dependent reflectivity of the SBG). So the ratio of the returning power at A to that at B is $(0.9R(\lambda)+0.05)/0.05$, i.e., $1+18R(\lambda)$, which will promote lasing in the cw direction and suppress lasing in the ccw direction.

When the signal for driving the PZT is paused, the output power at port M(+) is obtained and shown in Fig. 2. It is shown that the fiber ring laser tends to oscillate in few longitudinal modes defined by the SBG. Furthermore, these lasing modes are unstable because of the small fluctuation of the fiber length and mode competition at room temperature.

On the other hand, the laser operates in several wavelengths simultaneously when the PZT is driven by the 12.5-kHz, 5-V sinusoidal signal. The laser spectrum is observed through an optical spectrum analyzer. The lasing wavelengths are coincident with the reflected wavelengths from the SBG. In order to understand the unidirectional behavior of the fiber ring laser without isolators, we replace the 5/95 coupler with one 3-dB coupler, then the ratio of the returning power at A to that at B is $1+R(\lambda)$, which is smaller than 2. A maximum output difference of 10 dB at corresponding lasing wavelengths between the two monitoring output ports is obtained. We attribute the non-unidirectional lasing to the very small difference between the losses in the two directions and the effect of inhomogeneous broadening of the gain medium. In order to increase the nonreciprocal loss for the two directions and obtain unidirectional lasing, the 5/95 coupler is used. This increases the ratio of returned power between the two lasing directions from $[1+R(\lambda)]$ to $[1+18R(\lambda)]$. Unfortunately, the maximum output difference between monitor ports is still about 10 dB. Through analysis, it is obtained that a majority of output power from port M(−) arises as the result of the back-reflections from monitor port M(+) through the direct-arm of the monitor coupler (the monitor coupler is used only to prove the unidirectional operation of the

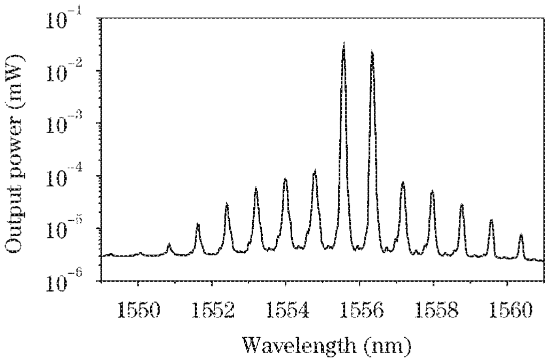

Fig. 2. Laser output measured from the monitor port M(+) at pump power of 29.7 mW.

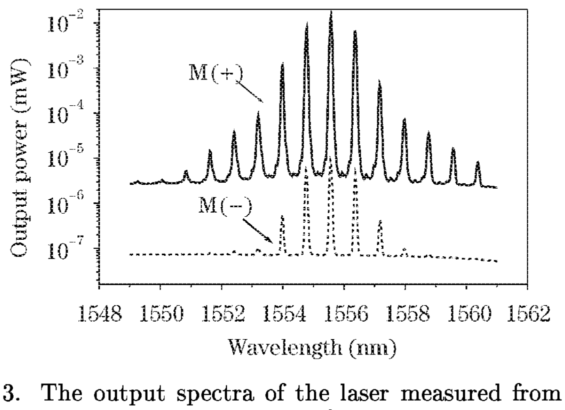

Fig. 3. The output spectra of the laser measured from the monitor coupler at pump power of 28.4 mW. The solid line represents the cw direction lasing and the dashed line the ccw direction lasing.

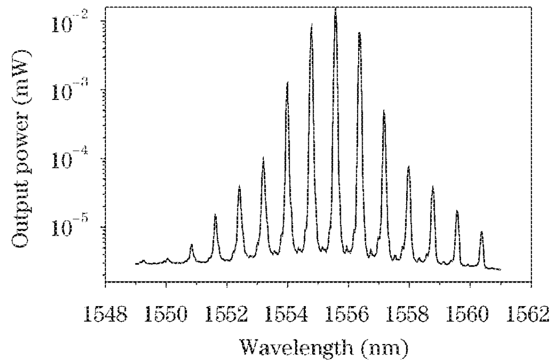

Fig. 4. The output spectrum of the laser measured from the monitor port M(+) with isolator at pump power of 28.4 mW.

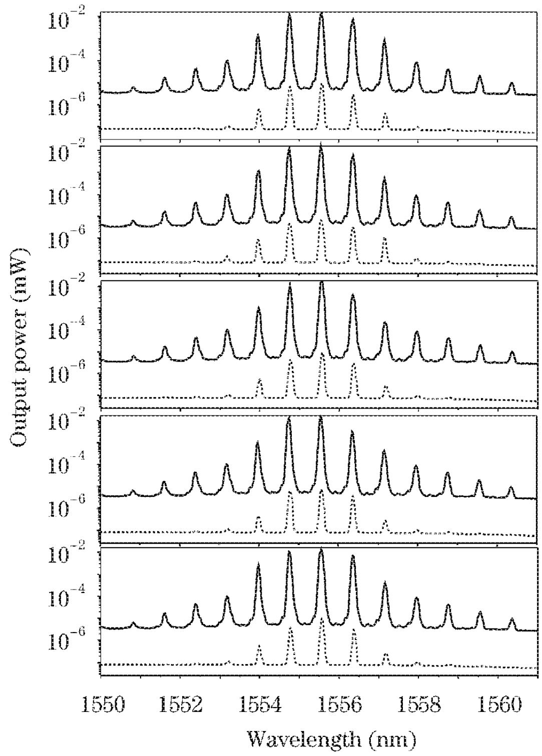

Fig. 5. Repeated scanning outputs from the monitor coupler with sinusoidal phase-modulation feedback at pump power of 29.7 mW. The solid lines represents the cw direction lasing and the dashed lines the ccw direction lasing.

fiber ring laser, and it is really unnecessary, on account of power output from unused port of OC in Fig. 1, when the laser is applied). When we prevent the back-reflections from the monitor ports by a large angled cleave of the fiber ends, the output difference at corresponding lasing wavelengths between monitor ports is about 30 dB almost independent on lasing wavelengths and pump power, as shown in Fig. 3. It is better than the results reported in Ref. [6]. The output power of the ccw direction from the monitor coupler is mainly due to ASE. The powers corresponding to five central wavelengths are 1.16, 7.69, 14.4, 6.44, and 0.447 μW, respectively. The spectrum demonstrates the presence of 3 lines with output power variation of less than 6 dB. The unevenness of spectrum is mainly caused by the reflectivity of SBG, the length of EDF, and the cavity loss, which are to be considered in our further work in order to obtain the flat output spectrum.

Figure 4 shows the output spectrum from port M(+) with isolator. Comparing Figs. 3 and 4, we can see that the ring cavity without isolator as shown in Fig. 1 is feasible. To examine the stability of the unidirectional room temperature multi-wavelength fiber ring laser without isolator, we repeat five scanning outputs. The results are shown in Fig. 5. It is demonstrated that the unidirectional and multi-wavelength properties are retained very well.

In conclusion, we have investigated the properties of an erbium-doped fiber ring laser with a very simplified structure. This structure gives rise to unidirectional lasing without the need of optical isolator and multi-wavelength lasing at room temperature by means of introducing the sinusoidal phase-modulation feedback.

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References

1. N. Park and P. F. Wysocki, IEEE Photon. Technol. Lett. **8,** 1459 (1996).
2. E. L. Goldstein, L. Eskildsen, V. da Silva, M. Andrejco, and Y. Silberberg, J. Lightwave Technol. **13,** 782 (1995).
3. J. Hübner, P. Varming, and M. Kristensen, Electron. Lett. **33,** 139 (1997).
4. A. Bellemare, M. Karásek, M. Rochette, S. LaRochelle, and M. Têtu, J. Lightwave Technol. **18,** 825 (2000).
5. K. J. Zhou, D. Y. Zhou, F. Z. Dong, and N. Q. Ngo, Opt. Lett. **28,** 893 (2003).
6. Y. Shi, M. L. Sejka, and O. Poulsen, IEEE Photon. Technol. Lett. **7,** 290 (1995).