Externally-modulated high-power fiber grating ring laser for digital transmission

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Abstract

We have constructed a low-cost, double-cavity erbium-doped fiber ring laser with a fiber Bragg grating and a 2×2 coupler. A high output power of 8.7 dBm and a signal-to-noise-floor ratio of 43 dB were demonstrated. This fiber grating ring laser is used as the light source for the 2.488 Gb/s transmission experiment through a 100 km single mode fiber. To our knowledge, this is the first time a fiber grating ring laser is being used as an externally modulated source for digital transmission. © 1998 Elsevier Science Ltd. All rights reserved.

1. Introduction

Because of the features of high gain and low noise figure in the 1550 nm low fiber loss window, erbium-doped fiber amplifiers (EDFAs) have been extensively used in optical communication systems. Laser sources with wavelengths in the 1550 nm band have attracted considerable interest and have been extensively developed recently. One of the potential candidates is the erbium-doped fiber laser [1–3]. In this letter, based on the previous study [4], we have made an erbium-doped fiber grating ring laser (FGRL) with a high output power and a high signal-to-noise ratio (SNR). Without increase in the cavity loss, the FGRL used a 2×2 coupler instead of an optical circulator (OC) to reduce cost. At room temperature, the output signal was modulated at a bitrate of 2.488 Gb/s with 2^{15}-1 pseudo-random data using a LiNbO$_3$ external intensity modulator. The bit-error-rate (BER) performance and the eye-diagram of the FGRL signal after a 100 km single-mode fiber (SMF) transmission are also measured.

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2. Experimental configuration and theoretic analysis

The FGRL configuration is shown schematically in Fig. 1. Instead of using an expensive OC, the FGRL is constructed with a low-cost 2×2 coupler. Two ports of the coupler at the same side are connected with a regular fiber Bragg grating (FBG) which acts as a reflective mirror. The reflectivity at 1552.6 nm, 3 dB bandwidth and polarization dependent loss of this FBG are 95%, 0.2 nm and less than 0.2 dB, respectively, while the total length of left cavity is about 20 m. To analyze the lasing wavelength in the double-ring cavity, the coupling mode equations of the FBG are as follows:

$$dA/dz = -j(\beta - \pi/\Lambda)A + \kappa B \tag{1}$$

$$dB/dz = \kappa A + j(\beta - \pi/\Lambda)B \tag{2}$$

where A and B stand for the forward and backward propagation modes, respectively. β is the propagation constant, Λ is the periodic interval of FBG and κ is the coupling coefficient which is defined as:

$$\kappa = \pi \Delta n \eta / 2\lambda \tag{3}$$

where Δn is the refractive index difference of the FBG, η is the confinement factor (~ 1 for SMF), and λ is the lasing wavelength corresponding to the Bragg reflection condition in the double-ring cavity and can be expressed as

$$\lambda = 2n\Lambda \tag{4}$$

where n is the fiber refractive index of FBG. For the other two ports of the same side, a 10 m length of alumino-germano-silicate erbium-doped fiber (EDF) was inserted and pumped by a 70 MW, 980 nm laser diode, which is coupled into the ring cavity via a 980/1550 nm wavelength division multiplexing (WDM) coupler. A saturated power at the output of the EDF can reach 11.0 dBm. Three optical isolators are used to ensure unidirectional operation, avoid spatial hole burning in the gain medium, and
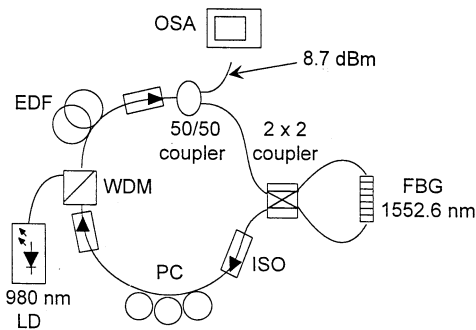

Fig. 1. Experimental setup of the fiber-grating ring laser (FGRL), WDM: 980/1550-nm wavelength division multiplexing; EDF: erbium-doped fiber; FBG: fiber Bragg grating; ISO: optical isolator; OSA: optical spectrum analyzer; PC: polarization controller.

prevent multiple reflections at the connection points. A polarization controller is used to optimize the polarization state of the ring laser. All connectors are angled to eliminate back reflection. The evolution of amplified-spontaneous emission (ASE) is monitored by dynamically inserting a 10/90 coupler at different connection points. The 50/50 coupler serves both output and feedback functions. The output signal is sent into an optical spectrum analyzer (OSA) or power meter for performance monitoring.

When a 3-post OC is used to replace the low-cost 2×2 coupler, the laser cavity has only one optical path of about 2.5 dB insertion loss; a similar optical path can be constructed by connecting the FBG to only one end of the coupler [1]. However, a high loss cavity is not suitable for high power application. In the current design, the 3.0 dB loss of the coupler is not much larger than the approximately 2.5 dB total loss of an OC. In our structure, the periodic grating is introduced in a loop section of a fiber. The loop junction is made by a 3 dB coupler with over 30 dB directivity. Most of the ASE region is in 'un-lasing' condition since they do not satisfy the Bragg reflection condition, as expressed in Eq. (4), the resultant output is a superposition of the incident ASE through two paths, one without any cross-coupling over the loop junction and the other one with two cross-couplings. On the other hand, if the wavelength of ASE satisfies the Bragg reflection condition, it will lase in the ring cavity. The incident wavelength is reflected by the periodic structure of FBG and then travels with two possible paths in the loop junction with each path has one cross-coupling. As a result, the two paths are symmetric and the superposition of the two waves yields a strong output. In other words, the actual laser cavities are two optical paths resulting from the reflection at both ends of the FBG. By carefully adjusting the polarization controller, we find that nearly a single longitudinal mode operation of the FGRL can be achieved.

3. Results and discussion

By using an OSA with 0.1-nm resolution, the output spectrum of the FGRL is depicted in Fig. 2. The transmission characteristic of the FBG is also shown in the inset of Fig. 2. A maximum ring laser output power of 8.7 dBm from the output port of Fig. 1 is obtained. It is only 2.3 dB lower than the EDF saturated power (11 dBm). A high SNR of 43 dB can be achieved which is mainly attributed to the narrow 3 dB bandwidth of this notch reflective type FBG. Thus, most of the lasing power was accumulated within a 0.2 nm region. The measured 3 dB bandwidth of FGRL is less then 0.1 nm limited by the resolution of OSA. The laser instability is mainly caused by thermal fluctuation and acoustic vibration. Both of them may change the lengths of the ring cavity and the FBG periodic length. The method [5] used for thermal control could be used to exhibit long-term stability of the FGRL.

Though various fiber ring lasers have been proposed for optical communication applications, a system experiment with a fiber ring laser has rarely been demonstrated. The measurement of optical spectrum and other parameters may not require a stable laser source. Fig. 3 shows the eye diagram of a stabilized FGRL. In this experiment,
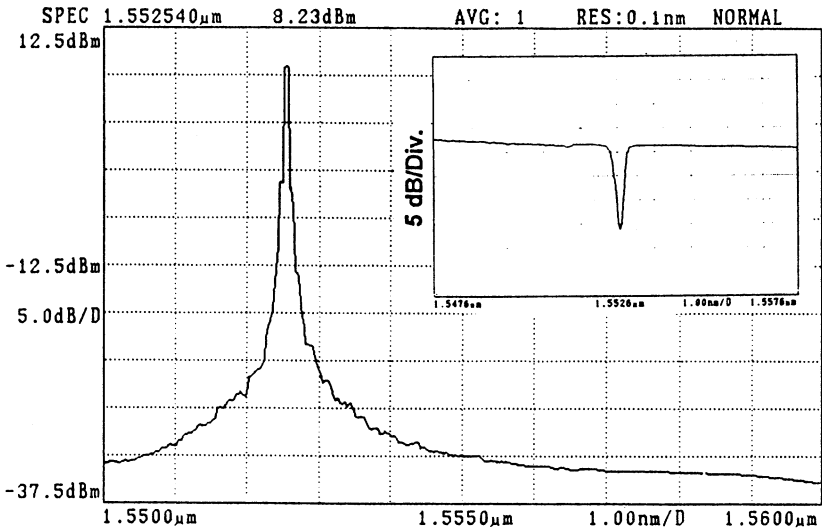
Fig. 2. Output spectrum of the fiber grating ring laser. Also shown by the inset figure is the transmission characteristic of this regular fiber Bragg grating (FBG).
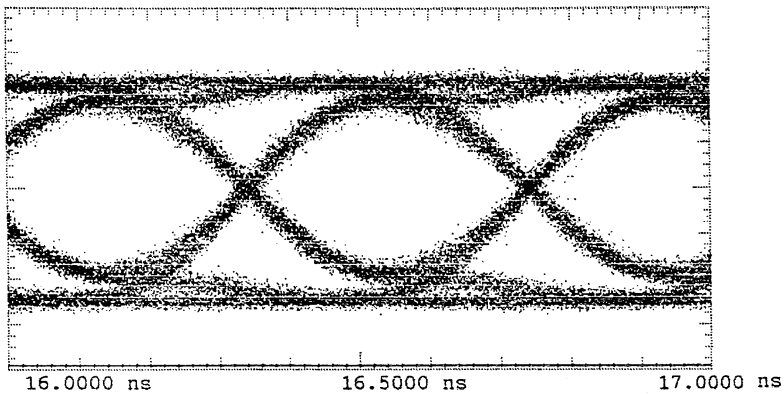

Fig. 3. The Eye diagram of the fiber-grating ring laser.

a 2.488 Gb/s electrical signal with a pseudo-random binary sequence of 2^{15}-1 and a Ti : LiNbO$_3$ Mach–Zehnder modulators followed by a boost EDFA are used. The ring laser configuration is put into a stable chamber with temperature control of 23°C and humidity control of 50%. The measured short-term BER performance of the modulated signal after passes through a 100 km single-mode fiber versus received optical power, with BER of 10^{-9} at 23 dBm, is shown in Fig. 4. The error floor may be
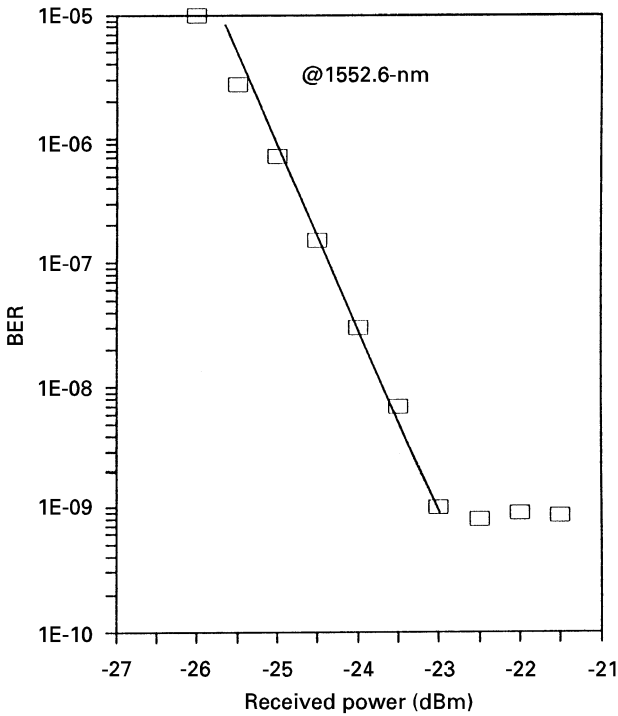
Fig. 4. Bit error rate at 2.488 Gb/s versus received optical power of the fiber-grating ring laser.

due to dual-path lasing operation in the cavity and/or unavoidable environmental vibration. It is expected that the multiple-ring cavity method in a recent study [6] will facilitate really single-frequency operation and further improve the BER performance. Because of high-power characteristic of this FGRL configuration, further work is required to construct the multi-wavelength laser sources by cascading several FBGS with different central reflective wavelengths between the two ports of the 2×2 coupler at the same side.

4. Conclusion

In summary, a new, simple and low cost erbium-doped FGRL has been constructed by adding a regular FBG into a double-ring cavity constructed by a 2×2 coupler. A high output power of 8.7 dBm and a narrow 3 dB bandwidth of less than 0.1 nm are achieved. A system experiment with 2.488 Gb/s transmission of 100 km SMF by externally modulating the FGRL is also demonstrated. In a stable temperature and humidity condition, measured sensitivities of BER for 10^{-9} is -23.0 dBm for 2.488 Gb/s digital transmission. The features of the FGRL are suitable for an externally modulated laser source.

Acknowledgements

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