La-Codoped Bismuth-Based Erbium-Doped Fiber Ring Laser With 106-nm Tuning Range

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***Abstract*—Ultrawide-band tunable fiber ring lasers using 84.6-cm-long lanthanum-codoped bismuth-based erbium doped fiber and a narrow-band tunable microelectromechanical system filter are reported. The fiber ring lasers can be continuously tuned from 1520 to 1626 nm, covering both the C- and L-bands. The laser has two outputs; the high output power port exhibits better than 35-dB wavelength extinction ratio, and the second output has much lower power but exhibits a large extinction ratio of better than 60 dB.**

***Index Terms*—Continuous-wave laser, fiber ring laser, lanthanum (La)-codoped bismuth-based erbium-doped fiber (Bi-EDF), laser tuning, microelectromechanical system (MEMS) filter.**

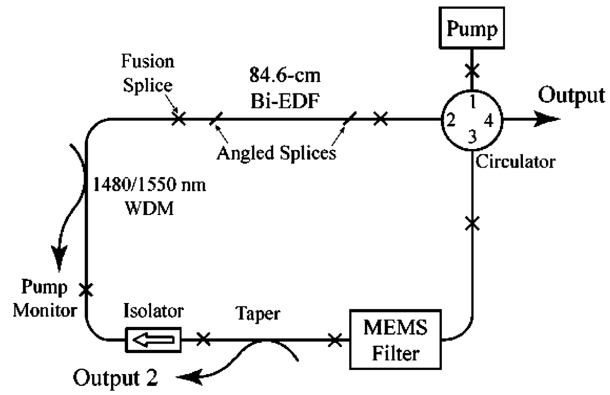

Fig. 1. Configuration of the tunable Bi-EDF ring laser.

I. Introduction

TUNABLE fiber ring lasers have attracted tremendous interest because of their many important applications in fiber-optic test and measurement [1], fiber communications [2], and fiber sensing [3] systems. This is because fiber ring lasers exhibit wide tunable range, narrow linewidth, and could be tuned at high speed allowing fast component characterization. Silica-based erbium-doped fibers (Si-EDFs) are commonly employed as gain medium in the construction of fiber ring lasers. However, pair-induced quenching and clustering effects [4] limit the concentration of erbium ions that can be doped into silicate fiber and, therefore, a long length of Si-EDF is normally needed in the construction of fiber ring lasers. The typical tunable range of Si-EDF fiber ring laser is less than 50 nm and operates around the C-band region. Furthermore, a longer length of Si-EDF is required to extend the tunable range to the L-band region. Bellemare *et al.* reported a very broad tunable fiber ring laser over 110 nm covering both the C- and L-bands using 20-m-long Si-EDF [1], by pumping the EDF to deep saturation regime. Another technique used optical switch to alter the length of Si-EDF in the fiber ring laser cavity to extend its wavelength tuning range to 100 nm was reported [4]. This laser requires an extra switching signal and is not continuously tunable. Fiber ring lasers based on Si-EDF are difficult to tune to wavelengths beyond 1610 nm. Furthermore, the long cavity length makes them more susceptible to environmental influence.

In this letter, we report a wide-band short-cavity length tunable fiber ring laser that can be tuned at high speed from 1520 to 1626 nm using just one tunable optical filter and a short length of lanthanum (La)-codoped Bismuth-based erbium-doped fiber (Bi-EDF). The filter is a microelectromechanical system (MEMS) device that could be tuned over an extremely broad wavelength range from 1510 to 1630 nm. The La-codoped Bi-EDF used in the ring laser is about 84.6 cm long and doped with very high concentration of erbium ions, which is much higher than that in Si-EDF but with negligible ion quenching effect [5]. The La ions extend the distance between Er ions and reduce the concentration quenching significantly. This configuration has two outputs; one is high power but low extinction ratio and the other is high wavelength extinction ratio with low output power. Some applications may prefer higher output laser power, whereas for others such as in the noise figure measurement of optical fiber amplifiers, a high extinction ratio is preferred.

II. Experimental Setup

Fig. 1 shows the configuration of the traveling wave tunable fiber ring laser. The Bi-EDF is pumped by one 1480-nm semiconductor laser diode via Port 1 of a four-port optical circulator, which exhibit fairly flat passband in the wavelength range of 1460–1630 nm. The unabsorbed pump power was measured via the 1480-nm port of a wavelength-division-multiplexer (WDM)

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constructed with thin-film filter and has flat passband in the signal port for wavelength ranges from 1520 to 1630 nm. The length of the Bi-EDF was 84.6 cm long. The refractive index of the core and cladding of the Bi-EDF are 2.03 and 2.02, while the diameter of the core and cladding are 4.0 and 125.6 μm, respectively. The erbium concentration in the Bi-EDF is 6470 wt-ppm and the La concentration is 4.4% wt. The peak absorption of the Bi-EDF at 1480 and 1530 nm are 167 and 267 dB/m, respectively. Both ends of the Bi-EDF was first angle spliced to high numerical aperture fiber (Corning HI980) before splicing to Port 2 [(single-mode fiber (SMF-28)] of the circulator and to the signal port (SMF-28 fiber) of the WDM, providing better mode field diameter matching. The splicing loss attained was less than 0.2 dB for the angled splices. The angled splices reduce the reflection in the laser cavity to less than 60 dB.

A narrow-band tunable MEMS filter was employed to tune the laser wavelength. The optical bandwidth of the MEMS is about 20 pm (~2.5 GHz) and can be tuned over 120 nm, from 1630 to 1510 nm by varying the input voltage from 10 to 32 V, respectively. The MEMS filter also exhibits very high scanning speed (greater than 100 000 nm/s). The insertion loss of the MEMS filter at the peak of the passband is less than 1.5 dB. The out-of-band reflection from both ends of the MEMS filter is very high (>95%). The circulator (from Ports 3 to 2) and the optical isolator were used to reduce the reflection from the MEMS back to the Bi-EDF as well as to ensure unidirectional operation of the ring laser. Reflection from the input end of the MEMS filter was employed for the laser output and exit from Port 4 of the circulator. A 20% fused fiber taper was included in the laser cavity to provide a second laser output.

III. Performance and Discussions

Fig. 2(a) and (b) shows the output spectra of the fiber ring laser obtained from Port 4 of the circulator and taper, respectively, which is measured with an optical spectrum analyzer (OSA) with 0.1-nm resolution. The fiber ring laser was pumped with 120 mW of optical power. By varying the passband of the MEMS filter, the laser wavelength was tuned from 1520 to 1626 nm, exhibiting a large tuning range of 106 nm. From Output 1 fiber ring laser, over the C-band region (from 1530 to 1570 nm), the extinction ratio is over 45 dB and the output power is greater than +7 dBm. Outside the C-band, both the output power and the extinction ratio reduce. The amplified spontaneous emission (ASE) in both outputs increase when the lasing wavelength is tuned away from the wavelength range where the Bi-EDFA provide higher optical gain. It is more pronounced for Output 1 because of the extremely high out-of-band reflection of the MEMS filter which reflects virtually all the ASE to Output 1, whereas in Output 2, the ASE is filtered by the MEMS filter. The measured 3-dB linewidth of this multilongitudinal mode laser using the OSA with 0.01-nm resolution is ~0.02 nm; this moderate coherence laser is suitable for test and measurement applications [1]. Note that the 106-nm tuning range was achieved without the 20% taper inside the laser cavity. With the inclusion of the 20% taper, the cavity loss was slightly increased and both

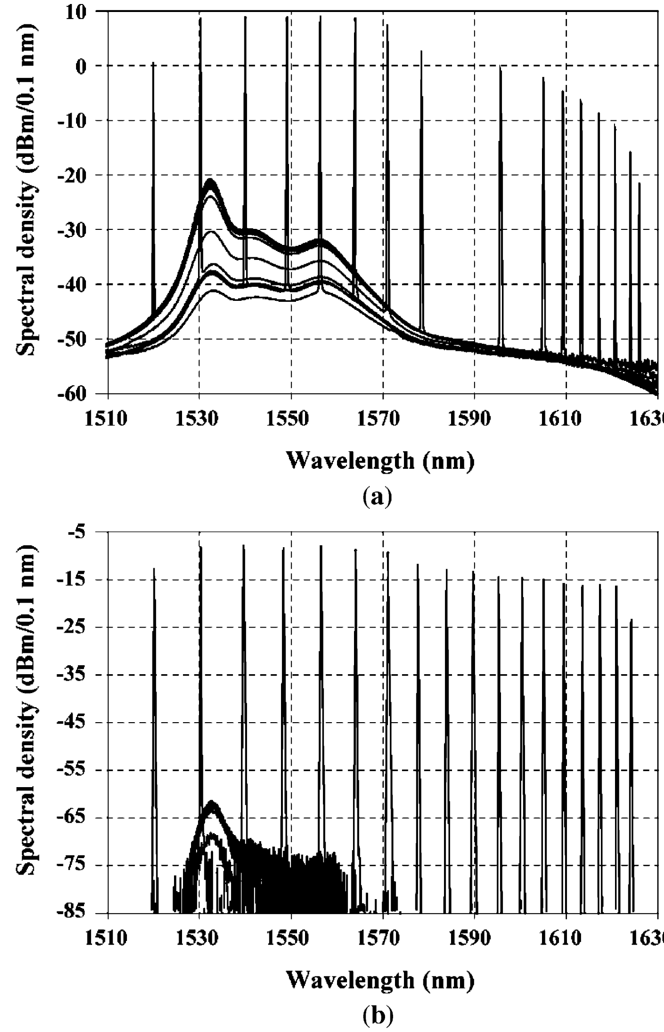

Fig. 2. Laser output spectra measured with an OSA with 0.1-nm resolution. (a) From Port 4 of the circulator of the tunable fiber ring laser; (b) from the 20% taper of the tunable fiber ring laser.

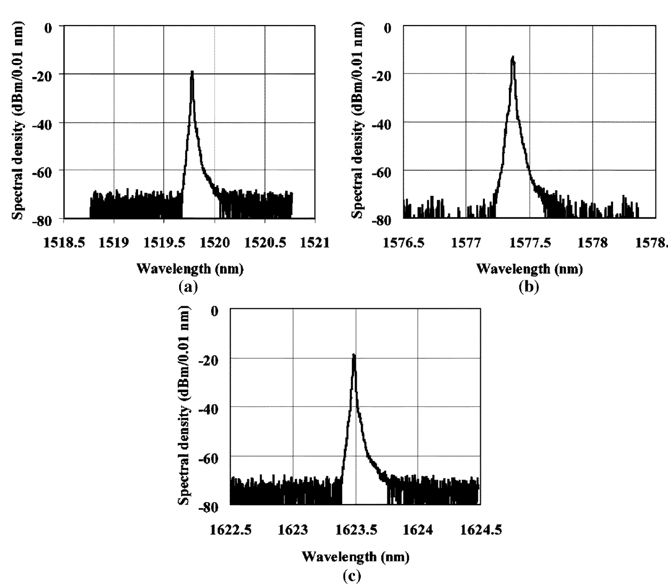

Fig. 3. Output spectra of the fiber ring laser tuned at (a) 1519.78, (b) 1577.37, and (c) 1623.48 nm, measured with an OSA with 0.01-nm resolution.

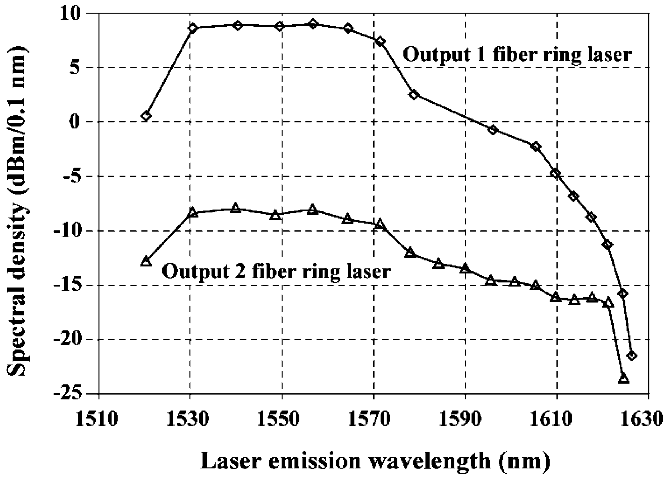

Fig. 4. Output powers versus lasing wavelength measured from the two outputs of the fiber ring laser.

the output power and wavelength tuning range from Output 1 were reduced slightly.

The laser output from the taper exhibits very high extinction ratio of better than 60 dB throughout the entire 104-nm wavelength tuning of the fiber ring laser. However, the output power of the laser in this port is much lower. The improvement in the extinction ratio is because the laser output was taken from the output of the MEMS filter which filters the out-of-band ASE. Whereas in the former case, the output was taken from the reflection at the input of the MEMS filter, which reflects both the lasing wavelength as well as the out-out-band ASE. The latter effect plus the fact that the MEMS filter has a very narrow bandpass of about 20 pm contributes to the large different in optical power between the two outputs. The lasing spectrum at 1519.78, 1577.37, and 1623.48 nm measured by an OSA using 0.01-nm resolution are shown in Fig. 3(a), (b), and (c). The asymmetric shape of the laser is mainly caused by the OSA response. Fig. 4 shows the output power versus lasing wavelength of the two output fiber ring lasers. Output 1 was obtained from Port 4 of the circulator without the 20% taper in the laser cavity.

IV. Conclusion

We have demonstrated a short-cavity fiber ring laser configuration that exhibits ultrawide wavelength tuning range by employing only 84.6-cm-long Bi-EDF and a tunable MEMS-based filter. The laser configuration permits continuous wavelength tuning over 106 nm and relatively large output power. A second laser output extracted from a 20% taper in the laser cavity exhibits very high extinction ratio of better than 60 dB but with much lower output power and slightly reduced tuning range of 104 nm.

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