Wavelength-Switchable La-Codoped Bismuth-Based Erbium-Doped Fiber Ring Laser

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***Abstract*—A wavelength-switchable La-codoped bismuth-based erbium-doped fiber ring laser with the capability to switch to one of 35 lasing wavelengths, spaced at 0.8 nm from 1545 to 1575 nm, is reported. Excellent wavelength stability of better than 1 pm and power fluctuation of less than 0.15 dB were observed during a 2-h stability test.**

***Index Terms*—Optical fiber laser, ring laser.**

I. Introduction

WAVELENGTH-SWITCHABLE laser sources are promising candidates for applications in fiber sensing, fiber-optic test and measurement, and fiber communication systems. Most reported wavelength-switchable fiber laser configurations [1]–[4] usually employ additional wavelength-selective elements which match their lasing wavelengths. The configuration of these lasers can be complicated and the numbers of switchable wavelengths are, thus, limited. In addition, a long length of silica-based erbium-doped fiber (Si-EDF) [5] is commonly used as gain medium in wavelength-switchable fiber lasers. Fiber ring lasers with long cavity length, however, are susceptible to environmental disturbance.

In this letter, we present a short-cavity wavelength-switchable fiber ring laser that can be switched between 35 different wavelengths from 1545 to 1573 nm with a wavelength spacing of 0.8 nm. The fiber laser was constructed with a Fabry–Pérot (F-P) etalon filter, a polarizer, a programmable electric-actuated polarization controller, and a 0.85-m-long La-codoped bismuth-based Bi-EDF. La-codoped bismuth oxide glass is much more soluble to Er^{3+} ions than silicate glass and, thus, high concentration of Er^{3+} ions up to 13 000 ppm can be doped in Bismuth-based glass without significant ion quenching effect [6], [7]. Consequently, short-cavity fiber ring lasers can be constructed with La-doped Bi-based EDF. Wavelength switching of the proposed fiber ring laser is achieved by suitably adjusting the polarization state inside the cavity. Since no additional component was used, high switching speed can be achieved. In addition, excellent wavelength stability and output power stability were also demonstrated.

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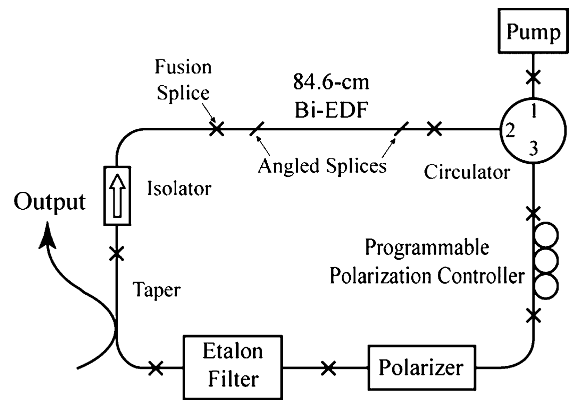

Fig. 1. Configuration of the short-cavity wavelength-switchable la-codoped bismuth-based EDF ring laser.

II. Experiment Setup

Fig. 1 shows the configuration of the wavelength-switchable La-codoped bismuth-based EDF ring laser. The Bi-EDF is pumped by one 1480-nm semiconductor laser diode via Port 1 of the circulator, which exhibit fairly flat passband in the wavelength range from 1460 to 1630 nm. 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 $\cdot$ 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 were 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 isolator, 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. The F-P etalon filter used in the configuration has a free spectral range of 100 GHz. The insertion loss and bandwidth of the wavelength peaks of the etalon filter are less than 1 dB and about 0.1 nm, respectively. The linear polarizer and the programmable polarization controller are employed to switch the lasing wavelengths. The polarization controller contains three actuators that can be programmed separately to alter the birefringence of the fiber and subsequently changes

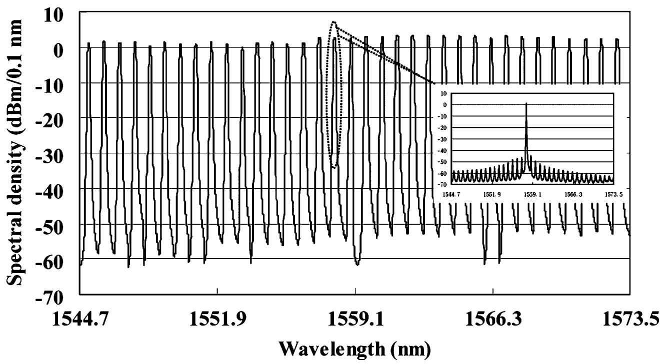

Fig. 2. Superimposed output laser spectra (35 lasing wavelengths) measured with an OSA with 0.1-nm resolution (Inset: Spectrum of fiber laser output at one lasing wavelength measured with an OSA at 0.1-nm resolution).

the polarization states of the light passing through the fiber. The extinction ratio of the linear polarizer is larger than 30 dB and its insertion loss is less than 1 dB. The circulator (from Ports 3 to 2) and the optical isolator were used to ensure unidirectional operation of the fiber ring laser. A 20% fused fiber taper was added to the laser cavity to provide the laser output.

III. Performance and Discussions

The fiber ring laser was pumped with 67 mW of optical power from a 1480-nm semiconductor pump laser. By manually adjusting the three voltages applied to the polarization controller, the laser wavelength was switched from about 1545 to 1573 nm, exhibiting 35 different wavelengths. In order to characterize the wavelength-switchable laser, the polarization controller and the optical spectrum analyzer (OSA) were programmed such that the each voltage applied to the actuators is increased at a step of 1 V, and the OSA performed a single measurement swept. Fig. 2 shows the superimposed output spectra of fiber ring laser measured by the OSA with 0.1-nm resolution in maximum hold mode. The output power of the laser is quite uniform across the entire switched wavelength range (variation less than 3 dB) and has an average value of about 0 dBm. The sidemode suppression ratio (SMSR) of the laser is greater than 45 dB. The measured spectrum correspond to one applied voltage setting is shown in the inset of Fig. 2.

The combination of the linear polarizer and polarization controller in the fiber ring laser functions as a wavelength selective element. The lasing wavelength is determined by the peak wavelengths of the F-P etalon filter as well as by the gain bandwidth of the Bi-EDF. The round-trip loss of the cavity experience by different wavelength mainly depends on the loss of the linear polarizer which is proportional to the scalar product between the polarization of the incoming wavelength beam and the polarization of the polarizer. Therefore, by adjusting the polarization controller, only light having its wavelength matches one of the peaks of the etalon filter and its polarization state most closely aligned to the linear polarizer will lase.

The wavelength switching speed of the laser was evaluated by applying a 500-Hz square wave with voltage levels at (28, 0, 0) and (61.4, 0, 0) V to drive the polarization controller. The corresponding lasing wavelengths generated at these two voltages are 1555.175 and 1555.985 nm. The laser output was monitored

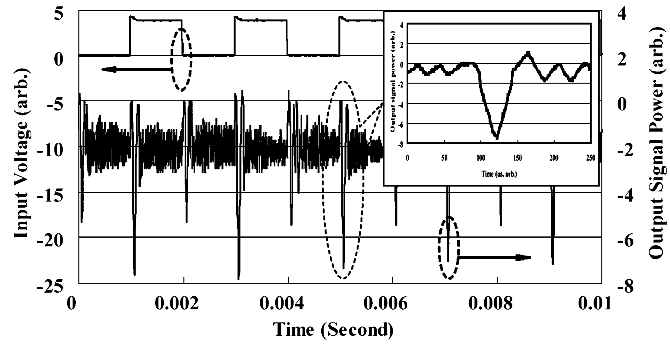

Fig. 3. Output power variation during wavelength switching (i.e., polarization switching).

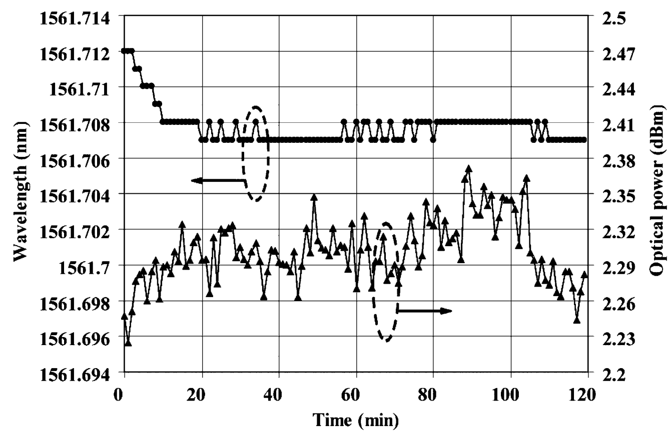

Fig. 4. Wavelength and peak power variations of the fiber ring laser versus time over a 2-h period.

by a 1-GHz photodetector which was connected to a 200-MHz sampling oscilloscope. Fig. 3 shows the voltage generated by the photodetector under this switching condition; the laser becomes stable after a short period of relaxation oscillation. The inset of Fig. 3 shows that the relaxation oscillation time is less than 100 μs, this implied that the maximum switching frequency of the laser is $\sim$10 kHz. The wavelength stability and output power stability of the wavelength-switchable fiber ring laser were also evaluated. Fig. 4 shows the measured wavelength and power fluctuation of the laser operating at 1561.708 nm for 2 h. The measured wavelength stability is better than 1 pm which was limited by the wavelength resolution of the OSA. The initial wavelength decrease in the first 10 min was due to the warm-up time of the OSA. The power stability was measured to be better than 0.15 dB. It is worth noting that the experiment was conducted under laboratory environment and no precautions were taken to isolate the setup from thermal and vibration perturbations, therefore better stability is expected if the short-cavity fiber ring laser is properly packaged.

IV. Conclusion

We have successfully demonstrated a short-cavity wavelength-switchable fiber ring laser using La-codoped bismuth-based EDF. The lasing wavelength can be switched to one of 35 wavelengths in the range of 1545–1573 nm with a wavelength separation of 0.8 nm. The laser exhibits high output power of about 0 dBm, high SMSR better than 45 dB, and output power flatness of 3 dB. The laser is capable of switching at 10 kHz. Excellent wavelength and power stability of 1 pm and less than 0.15 dB, respectively, were observed during a 2-h stability test.

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