C-band single-longitudinal mode lanthanum co-doped bismuth based erbium doped fiber ring laser

Khurram Karim Qureshi[1*], X. H. Feng[2], L. M. Zhao[3], H. Y. Tam[1], C. Lu[4] and P. K. A. Wai[4]

[1] *Photonics Research Centre, Department of Electrical Engineering*
The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
[*] *khurram@alumni.polyu.edu.hk*
[2] *Institute of Photonics Technology, Jinan University, Guangzhou, China*
[3] *School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798*
[4] *Photonics Research Centre, Department of Electronic and Information Engineering*
The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

Abstract: We propose and demonstrate a stable, tunable and narrow linewidth C-band lanthanum co-doped bismuth based erbium doped fiber (EDF) ring laser with single longitudinal mode (SLM) operation. A free space thin film filter acts as a wavelength discriminative component selecting a few oscillating modes while a Lyot filter formed by a polarization maintaining (PM) fiber and a linear polarizer further discriminates and selects SLM efficiently. A power stability of ≤ 0.05 dB, central wavelength variation of ≤ 0.02 nm, a side-mode suppression ratio (SMSR) of at least > 43 dB, and a linewidth of about 1.3 kHz have been experimentally demonstrated.

OCIS codes: (060.2330) Fiber optics communications; (140.3410) Laser resonators; (140.3570) Lasers, single-mode; (140.3600) Lasers, tunable; (060.2410) Fibers, erbium.

References and links

1. C. S. Kim, F. N. Farokhrooz, and J. U. Kang, "Electro-optic wavelength-tunable fiber ring laser based on cascaded composite Sagnac loop filters," Opt. Lett. **29**, 1677-1679, (2004).
2. J. Q. Sun, X. Yuan, X. Zhang, and D. Huang, "Single longitudinal mode fiber ring laser using fiber grating-based Fabry-Perot filters and variable saturable absorbers," Opt. Commun. **267**, 177-181 (2006).
3. C. H. Yeh, T. T. Huang, H. C. Chien, C. H. Ko, and S. Chi, "Tunable S-band erbium-doped triple-ring laser with single longitudinal-mode operation," Opt Express **15**, 382-386 (2007).
4. C. C. Lee, Y. K. Chen, and S. K. Liaw, "Single-longitudinal-mode fiber laser with passive multiple-ring cavity and its application for video transmission," Opt. Lett. **23**, 358-360 (1998).
5. J. Zhang, C. Y. Yue, G. W. Schinn, W. R. L. Clements, and J. W. Y. Lit, "Stable single-mode compound-ring erbium-doped fiber laser," IEEE J. Lightwave Technol. **14**, 104-109 (1996).
6. X. P. Cheng, P. Shum, C. H. Tse, J. L. Zhou, M. Tang, W. C. Tan, R. F. Wu, and J. Zhang "Single-longitudinal-mode erbium-doped fiber ring laser based on High finesse fiber Bragg grating Fabry–Perot etalon," IEEE Photon Technol. Lett. **20**, 976-978 (2008).
7. Y. W. Song, S. A. Havstad, D. Starodubov, Y. Xie, A. E. Willner, and J. Feinberg, , "40-nm-wide tunable fiber ring laser with single-mode operation using a highly stretchable FBG**,"** IEEE Photon Technol. Lett. **3**, 1167-1169 (2001).
8. C. O' Riordan, M. J. Connelly, P. M. Anandarajah, R. Maher, and L. P. Berry, "Lyot filter based multiwavelength fiber ring laser actively mode-locked at 10 GHz using an electroabsorption modulator," Opt. Commun. **281**, 3538-3541 (2008).
9. Sugimoto, "Ultrafast optical switches and wavelength division multiplexing (WDM) amplifiers based on Bismuth oxide glasses," JACS. **85**, 1083-1088 (2002).
10. H. L. Liu, H. Y. Tam, W. H. Chung, P. K. A. Wai, and N. Sugimoto, "Wavelength switchable La-codoped bismuth based erbium-doped fiber ring laser," IEEE Photon. Technol. Lett. **17**, 986-988 (2005).

#113546 - $15.00 USD Received 30 Jun 2009; revised 5 Aug 2009; accepted 5 Aug 2009; published 28 Aug 2009

1. Introduction

Single-frequency, single longitudinal mode (SLM) erbium-doped fiber lasers working at room temperature are attractive for potential applications in optical communications, high-resolution spectroscopy and sensing [1,2]. Single frequency oscillators operating in the C-band are crucial due to their compatibility with the optical fiber and a variety of existing photonics components. A long cavity fiber laser typically suffers from multimode operation with mode hopping and leads to very narrow longitudinal mode spacing. A fiber Fabry Pérot (FFP) filter can be employed for wavelength tuning in a fiber laser. However, the FFP alone is not adequate to stabilize lasing wavelength and power of the laser. Many other techniques have been researched to demonstrate SLM behavior [3-7]. These techniques include, the introduction of a bandpass filter in a multi-ring cavity [3], a compound ring resonator consisting of a dual coupler fiber ring [4,5], by means of a tunable fiber Bragg grating (FBG) Fabry Pérot etalon [6], and by inserting a saturable absorber with a tunable FBG in the cavity [7]. Unfortunately, the mode competition and mode hopping instabilities could not be avoided in an FBG based scheme because of their broad bandwidth.

In this study, we present a stable, narrow linewidth and tunable SLM fiber ring laser. Single frequency oscillation is achieved by utilizing a combination of free space thin film bandpass filter and a Lyot filter [8]. The performance of the proposed laser in terms of output power, wavelength stability, tuning range, side mode suppression ratio (SMSR), narrow linewidth and SLM operation has been investigated.

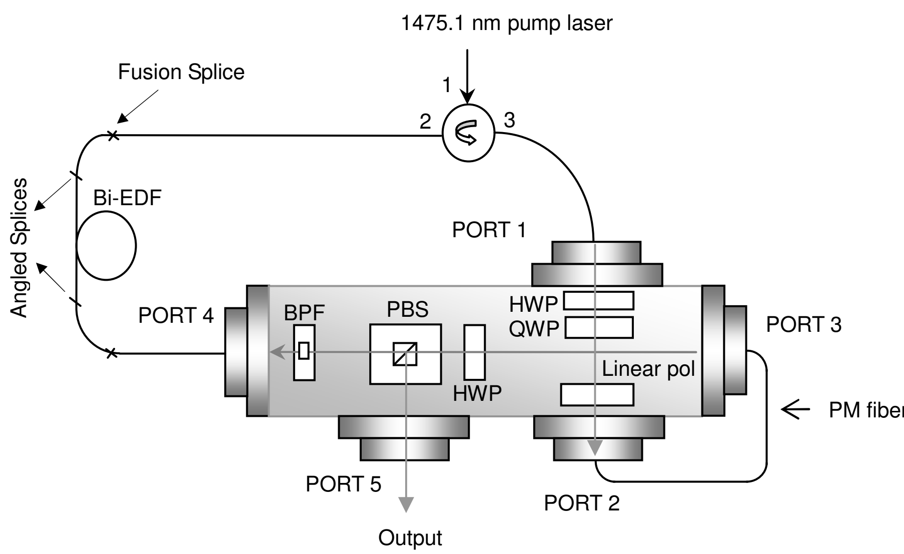

Fig. 1. Proposed experimental setup of C-band lanthanum-co-doped bismuth based erbium doped fiber laser. Note: PBS—polarization beam splitter; HWP—half wave plate; QWP—quarter wave plate; BPF—bandpass filter.

2. Experiment

The experimental setup of the proposed C-band ring laser with SLM output is shown in Fig. 1. The laser is constructed from a 0.85-m long lanthanum-co-doped bismuth-based erbium doped fiber (Bi-EDF), a three port circulator, a fiber bench with a rotatable thin film bandpass filter, a linear polarizer, a polarization beam splitter (PBS), a quarter wave plate (QWP), two half wave plates (HWPs) and a short section of PM fiber. Since, La-codoped bismuth oxide glass is much more soluble to Er^{3+} ions than silicate glass, high concentration of Er^{3+} ions up to 13000 ppm can be doped in bismuth-based glass without significant ion quenching effect

#113546 - $15.00 USD Received 30 Jun 2009; revised 5 Aug 2009; accepted 5 Aug 2009; published 28 Aug 2009

[9]. Therefore, comparatively short-cavity fiber ring lasers can be constructed with lanthanum-co-doped Bi-EDF. During the experiment, Bi-EDF is pumped using a semiconductor laser diode working at 1475.1 nm with 200 mW of optical power via Port 1 of the circulator. The index of refraction of the core and cladding of the Bi-EDF are 2.03 and 2.02, while their diameters are 4.0 and 125.6 µm, respectively. The erbium and lanthanum concentration in the Bi-EDF is respectively 6470 wt-ppm and 4.4% by weight. The peak absorption of the Bi-EDF at 1480 and 1530 nm are respectively 167 and 267 dB/m [10]. The two ends of Bi-EDF were first angle spliced to a high numerical aperture fiber (Corning HI980) before splicing to single-mode fiber (SMF-28). This technique provides a better mode field diameter matching. The total splicing loss achieved for these angled splices was less than 0.2 dB. The reflection in the laser cavity is decreased to less than 60 dB due to the angled splices. A circulator working in C-band is engaged to couple the light from the diode pump and also to ensure the unidirectional operation of the laser cavity. The backward propagating amplified spontaneous emission (ASE) generated by the 1475.1 nm diode pump enters Port 1 of the fiber bench. The HWP and QWP along with a linear polarizer resting on the fiber bench are employed to input linearly polarized light into the panda type PM fiber at Port 2 of the fiber bench. This linearly polarized light after traveling through a short section of PM fiber re-enters into the fiber bench through Port 3. Now the light beam first passes through a HWP, a polarization beam splitter and finally a bandpass filter. The entire length of the ring cavity is around 2.5 m, producing a mode spacing of about 60 MHz. The thin film bandpass filter with an anti-reflection coating has 0.05 nm of 3-dB bandwidth with an insertion loss of less than 1 dB. The function of the PBS in the cavity is two fold. First it acts as a coupler to provide the laser output and second it couples light back into the ring cavity. The measured free space loss from Port 1 to Port 2 and from Port 3 to Port 4 is around 2.9 dB. In the laser setup, the Lyot filter is created by using a short section (around 1 meter) of PM fiber together with a linear polarizer. This configuration helps to alleviate the multi-mode operation and selects only a SLM efficiently. By manually adjusting the HWP located just before the PBS on the fiber bench, stable SLM output is achieved.

3. Results and discussions

The laser can be tuned over the entire C-band by rotating the free space bandpass filter placed just after the PBS on the fiber bench. Figure 2 shows the output spectra of the laser, measured at Port 5 of the fiber bench with a resolution of 0.01 nm. The amplified spontaneous emission (ASE) increases when the lasing wavelength is tuned away from wavelength range where Bi-EDF provides higher optical gain. Figure 3 shows the output power and SMSR of the proposed laser over the operating range from 1530 to 1560 nm. A maximum peak power of -7 dBm is achieved at 1559.5 nm while it drops to around -10 dBm at 1531 nm, respectively. The SMSR reaches up to 62 dB/0.01 nm at around 1559.5 nm while it drops to 43.1 dB/0.01 nm at around 1531 nm. In the whole C-band, output powers of around -10 dBm and the SMSR of larger than 43 dB can be maintained.

In order to further probe the power and spectral variation of the proposed laser, a long term stability test was performed. The lasing wavelength under test was at 1559.5 nm and the observation duration was 1 hour. Figure 4 shows the output power variation and the wavelength shift over 1 hour duration. The output power variation is $\leq$ 0.05 dB and the peak wavelength shift is $\leq$ 0.02 nm. These results prove that the proposed laser has remarkable stability under laboratory conditions. These results can be further improved by packaging the whole experimental setup in a vibration free compartment

#113546 - $15.00 USD Received 30 Jun 2009; revised 5 Aug 2009; accepted 5 Aug 2009; published 28 Aug 2009

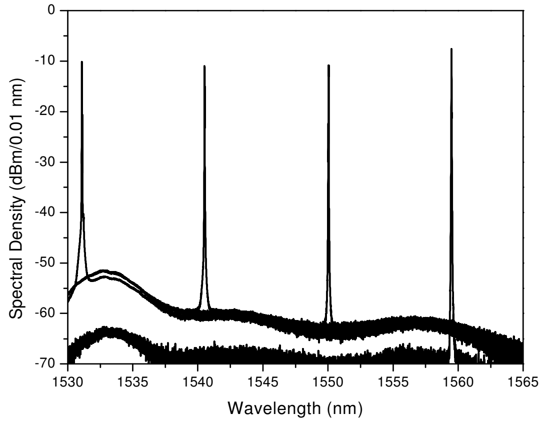

Fig. 2. Optical spectra of the proposed C-band fiber ring laser in the tuning range of 1531 to 1560 nm.

.

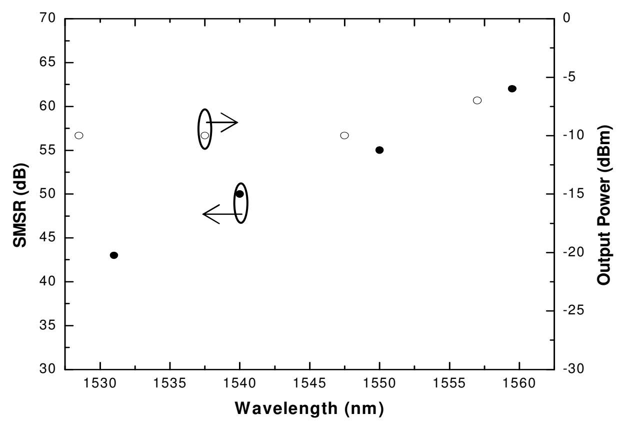

Fig. 3. The SMSR and the output power of the proposed ring laser versus tuning wavelengths in the operation range from 1530 to 1560 nm.

When the bandpass filter is removed from the cavity a comb type spectrum is observed at port 5 of the fiber bench as shown in Fig. 5. The spectrum exhibits minima at around 1531, 1540, 1550 and 1560 nm, respectively. The spectrum can be shifted by rotating the HWP located just before the PBS. The spectral minima in the Fig. 5 can be regarded as narrow bandpass filter with a very sharp edge. The combination of free space bandpass filter and the spectral minima of the Lyot filter act as very narrow bandpass filter, which helps to achieve SLM operation of the laser. Although the laser can be continuously tuned over the entire C-band, the SLM operation is only possible at wavelengths where the Lyot filter exhibits the spectral minima.

#113546 - $15.00 USD Received 30 Jun 2009; revised 5 Aug 2009; accepted 5 Aug 2009; published 28 Aug 2009

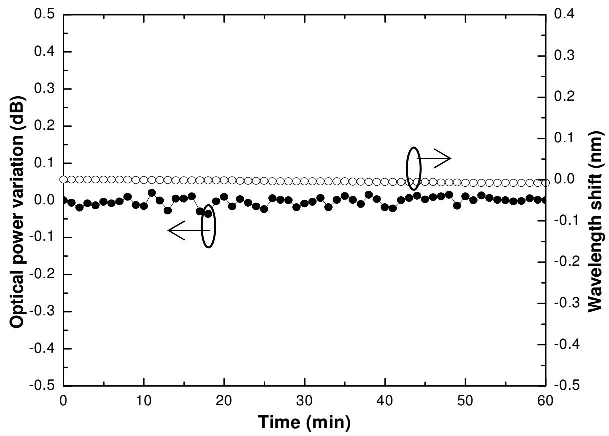

Fig. 4. The output power fluctuation and the wavelength variation of the single-frequency fiber ring laser at a wavelength of 1559.5 nm.

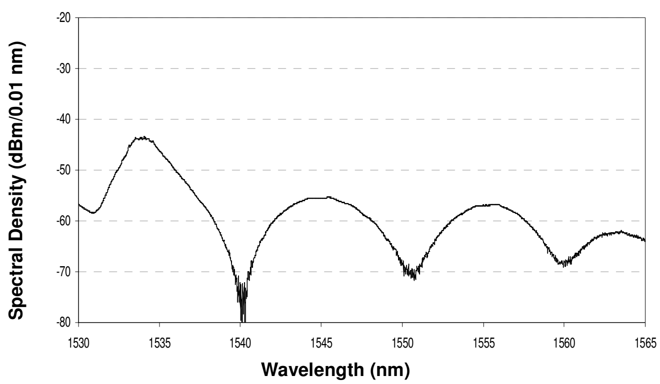

Fig. 5. Optical spectrum observed at port 5 without bandpass filter in the cavity.

In order to verify the SLM operation of the proposed laser, we measured the RF spectrum of the laser output with a high speed photo-detector connected to an RF spectrum analyzer with 1 MHz resolution. Fig. 6 shows the RF spectrum of the proposed laser when lasing at 1559.5 nm. The spectrum confirms that only SLM exists in the ring laser. A typical linewidth measurement of our SLM fiber ring laser obtained by using the self-heterodyne method is depicted in the inset of Fig. 6. Assuming the laser spectrum to be Lorentzian-shaped, the 3-dB linewidth of the laser is estimated to be around 1.3 kHz, which is calculated from the full-width at -10 dB. When the linear polarizer is removed from the setup, SLM operation is not achieved as shown in Fig. 7(a). This confirms that it is indeed the Lyot filter which is responsible for the SLM operation of the proposed laser. In order to confirm the significance of PM fiber in the setup we replaced the PM fiber with a section of standard SMF-28 between Port 2 and Port 3 of the fiber bench. In this case as well the SLM status is not established and consequently strong beating frequency components are observed in the spectrum as shown in Fig. 7 (b).

#113546 - $15.00 USD Received 30 Jun 2009; revised 5 Aug 2009; accepted 5 Aug 2009; published 28 Aug 2009

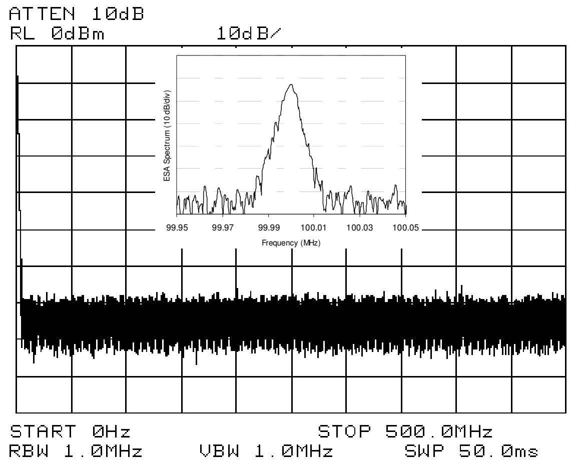

Fig. 6. Noise spectrum of the laser output with PM fiber between port 2 and 3 of fiber bench (inset) shows the linewidth of the fiber ring laser.

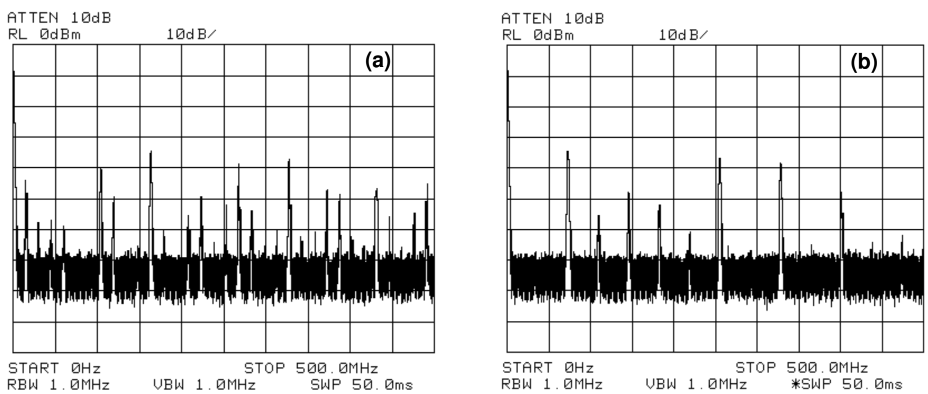

Fig. 7. (a) Noise spectrum of the laser output without linear polarizer in the cavity (b) with SMF-28 between port 2 and 3 of fiber bench.

4. Conclusion

In conclusion, we have proposed and experimentally demonstrated a stable, tunable, narrow linewidth Bi-EDF ring laser with SLM oscillation covering the whole C-band. The laser is constructed by incorporating an intra-cavity thin film bandpass filter and a section of PM fiber. The combination of PM fiber and a linear polarizer serves as a mode-restricting filter and guarantees SLM operation. Finally, a narrow linewidth of 1.3 kHz is achieved.

Acknowledgments

This project was partially supported by grants from Hong Kong Polytechnic University of Hong Kong Special Administrative Region, China (Project No. 1-BBZ8 and G-YF65).

#113546 - $15.00 USD Received 30 Jun 2009; revised 5 Aug 2009; accepted 5 Aug 2009; published 28 Aug 2009