A STABLE TUNABLE AND SWITCHABLE DUAL-WAVELENGTH SINGLE-LONGITUDINAL-MODE ERBIUM-DOPED FIBER LINEAR-CAVITY LASER

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Keywords: Fiber laser, Fiber bragg grating sagnac loop, Linear-cavity.

Abstract: A simple linear cavity erbium-doped linear-cavity laser is proposed and experimentally demonstrated, with tunable and switchable multi-wavelength SLM operation. The main mode-selection components of our system include an FBG Sagnac loop, an umpumped EDF together with a tunable FBG. The unpumped EDF together with the tunable FBG form a super narrow-band self-tracking FBG around the reflection peak of such tunable FBG, which ensures the SLM laser operation. By simple adjustment of two polarization controller, the laser can be designed to operate in a stable single-wavelength or dual-wavelength with a wavelength spacing of 0.05 nm at room temperature.

1 INTRODUCTION

There has been increased research on multi-wavelength fiber lasers because of their potential applications in optical communications, optical instrument testing, and optical fiber sensors (Libatique and Jain, 1999); (Yao et al., 2006). A dual-wavelength single-longitudinal-mode (SLM) fiber laser, for instance, can be used for microwave signal generated source by beating dual-wavelength in the photodiode (Chen et al., 2008); (Yao et al., 2006). However, the erbium-doped fiber (EDF) is a homogeneous broadening gain medium at room temperature, and moreover it inevitably brings a long cavity length for using in the fiber laser. Thus, some issues must be addressed to achieve SLM multi-wavelength operation. A fiber loop mirror with a saturable absorber has been utilized as a passive self-tracking narrow multi-band optical filter, to counter against homogeneous broadening gain and implement a stable SLM multi-wavelength operation (Liu et al., 2004). Unpumped EDF as a saturable absorber (SA) has also been used in a fiber loop mirror (Zhang and Kang, 2008) or a standing-wave arm (Chen et al., 2008); (He et al., 2009) for obtaining a passive self-tracking narrow multi-band optical filter of erbium-doped fiber lasers. Furthermore, an ultra-narrow mode selecting mechanism could also be utilized in erbium-doped fiber lasers to select emitting wavelengths from the long cavity. The ultra-narrow mode selection filter can be obtained by using a phase shifted fiber Bragg grating (FBG) (Yao et al., 2006), the FBG Sagnac loop (Feng et al., 2009), a FBG-based Fabry-Perot (F-P) filter (Zhou et al., 2008); Sun et al., 2006), etc.

In this paper, we propose a novel linear-cavity EDF laser based on an FBG Sagnac loop mirror, which generates a wavelength tunable and switchable SLM multi-wavelength lasing. The operating wavelengths and their spacing can be selected by use of a FBG Sagnac loop mirror with a narrow-band FBG in the laser cavity. An umpumed EDF as an SA, together with the narrow-band FBG, in a standing-wave arm helps in achieving stable single- or dual- wavelength SLM operation.

2 EXPERIMENTAL SETUP AND OPERATION PRINCIPLE

2.1 Experimental Setup

Fig.1 shows the configuration of the proposed tunable and switchable SLM EDF laser. The EDF (Highwave-tech EDF-741) with a length of 12 meters is used as the gain medium, pumped by a 980nm laser diode (LD) via a 980nm/1550nm wavelength division multiplexing (WDM) coupler

He X., Wang D. and Liao C..
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DOI: 10.5220/0003433501230127
In *Proceedings of the International Conference on Data Communication Networking and Optical Communication System* (OPTICS-2011), pages 123-127
ISBN: 978-989-8425-69-0

(50:50). The absorption coefficient of the EDF is ~6-8 dB/m at 1530nm. An FBG Saganc loop (Shu et al., 2000), used as a narrow-band transmission comb filter to select the resonance wavelengths, is connected at the left arm of the linear system. The design parameters of such FBG Sagnac loop are presented in section 2.2. The unpumped EDF (Nufern, EDFC-980-HP) of three meter long in the right arm of linear system is utilized as the SA which, together with a tunable FBG, can enhance the SLM performance and balance the optical powers of the lasing wavelengths. The absorption coefficient of the unpumped EDF at 1530 nm is ~ 5-7 dB/m. The whole cavity length was measured to be approximately 20.5m. The laser output is monitored by an optical spectrum analyzer (OSA) (ANDO AQ6319) with 0.01nm resolution. By adjusting the FBG and two polarization controller, the lasing wavelengths can be tuned and switched.

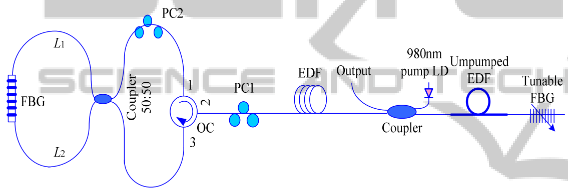

Figure 1: Schematic diagram of the proposed tunable and switchable Erbium-doped fiber laser with a simple linear cavity.

2.2 Operation Principle

As shown in Fig.1, the incident light derived from the pumped EDF has been split into two identical waves by the 50:50 coupler in the Sagnac loop, which forms a comb filter together with the FBG. In the Sagnac loop, a 2.8mm-long FBG is written in H_2-free SMF-28 by use of femto-second laser pulse irradiation and the phase mask. The grating has a peak reflectivity of ~70% and a 3-dB bandwidth of ~1.2 nm. When the grating is asymmetrically located in the Sagnac loop, a sinusoidal response occurs within the envelope of the reflection spectrum of the grating (Shu et al., 2000), which forms a comb filter. The channel spacing of such Sagnac loop is approximately expressed as (Shu et al., 2000):

$$\Delta\lambda = \frac{\lambda^2}{2n_{eff}\Delta L} \tag{1}$$

where n_{eff} is the effective refractive index of SMF-28 fiber, λ is the center wavelength of the FBG. By controlling the fiber length difference, ΔL, we can construct the FBG Sagnac loop with different wavelength spacings. Here, the fiber length difference used is ΔL=0.32cm.

The FBG Sagnac loop has been carefully packaged in a box, which helps in keeping a constant temperature and stable operation situation in our system. When the pump power of the EDF is ~105 mW, the transmission spectrum of the FBG Sagnac loop measured at point A is given in Fig. 2.

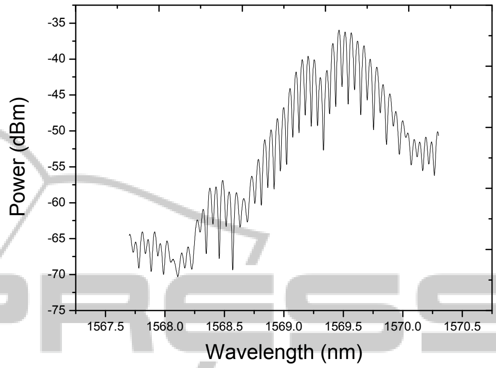

Figure 2: Transmission spectrum of the FBG Sagnac loop.

The tunable FBG at the right arm of the fiber laser system has a reflection peak at 1569.81 nm, with peak reflectivity of over 90% and 3-dB bandwidth of 0.71 nm. Such an FBG is also typed-II grating written in H_2-free SMF-28 fiber by use of 800nm/120fs femto-second laser pulses and a phase mask (Ibsen Photonics). The laser pulse energy is 400-480 µJ, with 1/e Gaussian beam radius of 3 mm, and exposure time of ~45 min. This type of FBG exhibits high temperature stability and good spectral quality.

When several wavelengths of the incident light pass though the FBG Sagnac loop and return, in the unpumped EDF, if the frequency and intensity of the incident light (forward wave) are identical to that of the light (backward wave) reflected by the tunable FBG at the right arm, a standing wave can be formed. That is to say, the unpumped EDF together with the tunable FBG forms a super narrow-band self-tracking FBG around the reflection peak of the tunable FBG. The total ring cavity was measured to be approximately 19.5m, which corresponds to a longitudinal mode spacing of 10 MHz. The unpumped EDF length is $L_e \approx$ 3m, and its effective refraction index $n_{eff} \approx$ 1.45, the free spectral range (FRS) of the narrow-band self-tracking FBG should be less than 5.6 MHz. Moreover, when the dual-wavelength optical signal propagates in the unpumped EDF, the interaction between the two wavelengths becomes negligible as the wavelength spacing is much greater than the cutoff frequency (<

1GHz) and their output powers can be balanced. Therefore, simultaneous SLM lasing at dual-wavelength is ensured.

3 EXPERIMENTAL RESULTS AND DISCUSSIONS

The reflection peak of the FBG in Fig.1 can be tuned by strain using a translation stage. The dual-wavelength emitting spectra of the proposed fiber laser are shown in Fig.3, where eleven pairs of dual-wavelength lasing are tuned from 1568.334nm to 1569.654nm. The wavelength spacing is about 0.05nm. The side mode suppression ratios (SMSR) of the fiber laser keeps ~50dB in the tuning range.

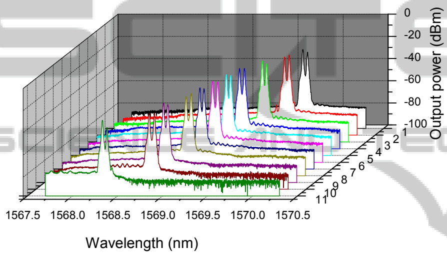

Figure 3: Experimental emitting spectra of the Erbium-doped fiber laser by tuning the reflection peak of the FBG.

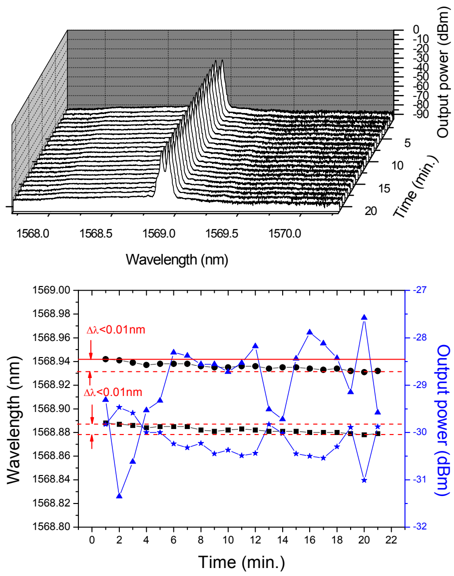

Figure 4: Measured output spectrum at fixed wavelengths of 1568.889 and 1568.944nm at 21-time repeated scanning spectra with a time interval of 1 minute, pump power of 134mW.

In order to investigate the laser output stability and amplitude-equilibrium, the output power of the dual-wavelength at 1568.89 and 1568.94 nm have been measured for 21 minutes under the pump power of 134 mW. In Fig. 4(a), the output power of dual-wavelength is ~-29.5 dBm and the SMSR is ~50dB. The linewidth of the laser at wavelengths of 1568.89 and 1568.94 nm are less than 0.01nm. The wavelength fluctuations of dual-wavelength are both less than 0.01nm as shown in Fig. 4(b), which is due to thermal drift, and their outputs are stable with power fluctuation of ~3dBm and ~1dBm. With the increase of sweeping time, the fluctuation of output power is decreased, as the lasing would tend to a stable operation status with the increase of sweeping time. If the stability of the pump LD and operation surroundings are improved, a more stable dual-wavelength lasing can be achieved.

By carefully adjusting the state of the PC1, single-wavelength, dual-wavelength or three-wavelength operations can be obtained, under the pump power of 134mW, as shown in Fig.5. Because of birefringence chromatic dispersion of the fiber, different wavelengths would emerge with different polarization states in the fiber laser cavity. Moreover, the cavity loss mainly depends on the polarization state of the incident wave and that of the polarizer. Hence, only the wavelengths in which loss is low enough to match their gain produced by pumped EDF would be lasing. In our fiber laser, PC1 is used to change the cavity loss of each resonance wavelength by adjusting the polarization states of the incident wave, and then to realize wavelength-switching. The function of the PC2 is mainly used to adjust the polarization states of resonance lights in the FBG Sagnac loop. Therefore, the FBG Sagnac loop with PC2 can be utilized to select the resonance wavelengths as well as their polarization states and hence each transmission wavelength has its own polarization state, which leads to the enhancement of the polarization hole buring (PHB). Such PHB greatly decreases the homogeneous gain broadening of EDF, and thus reducing the wavelength competition. It is then possible to obtain stable and uniform amplitude dual-wavelength lasing at room temperature. Fig. 6 shows that a uniform amplitude dual-wavelength laser operation is achieved by carefully adjusting PC2, with the same pump power of 134mW.

By simple adjustment of the PC1, a three-wavelength lasing has been presented however, it is unstable. As shown in Fig. 7, through 3-minute repeated scanning, the laser system has automatically switched from three-wavelength lasing to dual-wavelength lasing. This is due to the fact that, when the fiber laser operates in three-wavelength lasing, the PHB in the laser is not high enough to reduce the mode competition caused by the homogeneous gain broadening of EDF, and accordingly the whole system quickly switches to the stable dual-wavelength lasing.

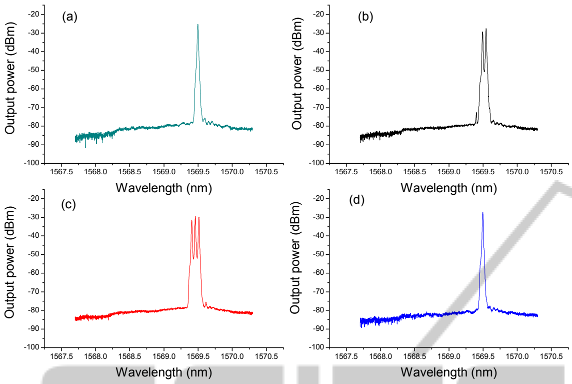

Figure 5: Wavelength switching of the fiber laser by adjusting the PC1, pump power of 134mW.

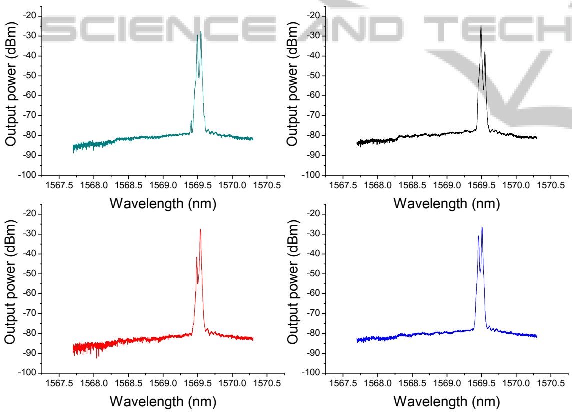

Figure 6: Dual-wavelength emission of the fiber laser by adjusting the PC2, pump power of 134 mW.

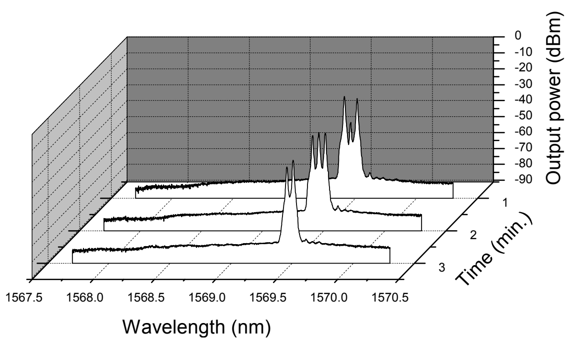

Figure 7: Measured output spectrum at three-wavelength lasing of 1569.408, 1568.460nm and 1569.512nm every 1minute for 3 minutes, pump power of 134mW.

4 CONCLUSIONS

A novel EDF linear-cavity laser is proposed and experimentally demonstrated, with tunable and switchable multi-wavelength SLM operation. The main mode-selection components of our system include an FBG Sagnac loop, an umpumped EDF together with a tunable FBG. The unpumped EDF, together with the tunable FBG, form a super narrow-band self-tracking FBG, which ensures the proposed SLM fiber laser system. By simple adjustment of two polarization controller, the laser can be operated in a stable single-wavelength or dual-wavelength scheme at room temperature. The SMSR is over 50 dB, and the wavelength fluctuation is as low as 0.01nm, and the output power variation are less than 3dB within 21 minutes. Eleven pairs of dual-wavelength lasing could be obtained in a tunable wavelength range from 1568.334nm to 1569.654nm.

ACKNOWLEDGEMENTS

This work is supported by Hong Kong SAR government through a GRF grant PolyU 5298/10E, the Hong Kong Polytechnic University research grants G-YX2N and A-PJ22.

REFERENCES

N. J. C. Libatique and R. K. Jain, 1999, Precisely and rapidly wavelength-switchable narrow-linewidth 1.5µm laser source for wavelength division multiplexing applications, *IEEE Photonics Technol. Lett. 11*, 1584-1586.

L. Talaverano, S. Abad, S. Jarabo, and M. Lopez-Amo, 2001, Multiwavelength fiber laser sources with Bragg-grating sensor multiplexing capability, *IEEE J. Lightwave Technol.*, 19, 553-558 .

P.-C. Peng, H.-Y. Tseng, and S. Chi, 2003, A tunable dual-wavelength erbium-doped fiber ring laser using a self-seeded fabrycprot laser diode, *IEEE Photonics Technol. Lett. 15*, 661-663.

G. Chen, D. Huang, X. Zhang, and H. Cao, 2008, Photonic generation of a microwave signal by incorporating a delay interferometer and a saturable absorber, *Opt. Lett. 33*, 554-556.

S. Pan, J. P. Yao, 2009, A wavelength-switchable single-longitudinal-mode dual-wavelength erbium-doped fiber laser for switchable microwave generation, *Opt. Express 17*, 5414-5419.

Y. Yao, X. Chen, S. Xie, 2006, Dual-wavelength erbium-doped fiber laser with a simple linear cavity and its application in microwave generation, *IEEE Photonics Technology Letters*, 18, 187-189.

J. Liu, J. Yao, J. Yao, and T. H. Yeap, 2004, Single-longitudinal-mode multiwavelength fiber ring laser, *IEEE Photonics Technol. Lett.*, *16*, 1020-1022.

K. Zhang and J. U. Kang, 2008, C-band wavelength-swept single-longitudinal-mode erbium-doped fiber ring laser, *Opt. Express*, *16*, 14173-14179.

X. He, X. Fang, C. Liao, D. N. Wang, and J. Sun, 2009, A tunable and switchable single-longitudinal-mode dual-wavelength fiber laser with a simple linear cavity, *Optic. Express*, *17*, 21773–21781.

S. Feng, O. Xu, S. Lu, X. Mao, T. Ning, S. Jiang, 2009 Switchable dual-wavelength erbium-doped fiber-ring laser based on one polarization maintaining fiber Bragg grating in a Sagnac loop interferometer, *Optics & laser Technology, 41,* 264-267.

J. L. Zhou, L. Xia, X. P. Cheng, X. P. Dong, P. Shum, 2008, Photonic generation of tunable microwave signals by beating a dual-wavelength single longitudinal mode fiber ring laser, *Appli. Physic. B*, *91*, 99–103.

J. Sun, X. Yuan, X. Zhang, and D. Huang, 2006, Single-longitudinal-mode fiber ring laser using fiber grating-based Fabry-Perot filters and variable saturable absorbers, *Opt. Commun., 267(1),* 177–181.

X. Shu, J Shan, D. Huang, 2000, Fiber grating saganc loop and its multiwavelength-laser application, *IEEE Photonics Technol. Lett.*, *12*, 980-982.