A dual-wavelength erbium-doped fiber laser with widely tunable wavelength spacing*

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A stable dual-wavelength erbium-doped fiber laser (EDFL) with tunable wavelength spacing and equalized output power is proposed and experimentally demonstrated. The fiber laser uses two fiber Fabry-Perot tunable filters (FFP-TFs) as the wavelength filter. The main cavity is divided into two sub-cavities with imbalance cavity losses through a 30/70 optical coupler. The tunable wavelength spacing can be achieved by changing the center wavelength of the filters and the equalized dual-wavelength output power can be achieved by properly controlling the variable optical attenuator (VOA) inserted in the lower-loss cavity.
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Dual-wavelength erbium-doped fiber lasers (EDFLs) with tunable wavelength spacing have attracted considerable attention owing to their potential applications in optical sensors, optical communication networks, and radio-over-fiber communication systems especially for microwave or millimeter-wave generation and terahertz radiation[1-4]. Many different methods have been demonstrated to eliminate the homogenous gain broadening (HGB) of the erbium-doped fiber so as to achieve stable and tunable dual-wavelength output at room temperature. A tunable dual-wavelength fiber laser with fixed 0.16 nm spacing has been demonstrated by cascading a delay interferometer and a tunable band-pass filter[5]. By introducing the wavelength-dependent loss mechanism induced by two comb filters, a switchable dual-wavelength operation fiber laser has been presented[6]. Dual-wavelength lasing can be achieved by using polarization-maintaining fiber Bragg grating (FBG)[7] or dual-wavelength FBG[8]. An arrayed waveguide grating (AWG) incorporating two fiber optic switches is used to generate dual-wavelength output with tunable wavelength spacing[9]. A stable and switchable dual-wavelength fiber ring laser has been proposed and demonstrated experimentally by using a novel filter formed from dual-pass Mach-Zehnder interferometer incorporating a Sagnac loop[10].

In this paper, we propose and experimentally demonstrate a dual-wavelength EDFL with widely tunable wavelength spacing and equalized output power. Two fiber Fabry-Perot tunable filters are used as wavelength filter and the dual-wavelength spacing can be tuned in a wide range by changing the center wavelength of the filters. Through properly controlling the attenuation value of the variable optical attenuator inserted in the lower-loss cavity, which is initially formed by a 30/70 optical coupler, the stable dual-wavelength lasing with equalized output power level can be achieved.

Fig.1 shows the configuration of the proposed dual-wavelength fiber ring laser. A 5 m EDF pumped by a 980 nm pump laser diode with the maximum output power of 150 mW through a 980/1550 nm wavelength division multiplexer (WDM) is employed as the gain medium. An optical isolator (ISO) is utilized to provide a unidirectional propagation of the laser inside the ring cavity and also to enhance the side mode suppression ratio (SMSR) by compressing the backward amplified spontaneous emission (ASE). A 30/70 optical coupler (C1) incorporating a 3 dB optical coupler (C2) is used to divide the main cavity into cavity A and cavity B which have different cavity losses initially. Two fiber Fabry-Perot tunable filters (FFP-TFA, FFP-TFB) are used as the wavelength filter. A variable optical attenuator (VOA) is located in cavity A to control the intra-cavity loss. The lasing outputs of the fiber laser are measured by an optical spectrum analyzer (OSA, AQ6370B) with a resolution of 0.05 nm through the 50% port of C2.

The individual tuning ranges of the two cavities are investigated firstly because they determine the tuning range of the dual-wavelength spacing. By modifying the attenuation value of the VOA, the lasing could be established individually in cavity A or cavity B. When the attenuation is set at zero, only the wavelength decided by FFP-TFA is lasing in cavity A due to the lower cavity

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loss initially induced by C1. Through changing the applied voltage of FFP-TFA, the lasing wavelength could be tuned from 1523 nm to 1562 nm at the 980 nm pump power of 150 mW, as shown in Fig.2. When the attenuation of VOA is set at a high value which leads to the loss of cavity A is higher than that of B, the lasing would be only established in cavity B. By changing the applied voltage of FFP-TFB, the lasing wavelength could be tuned from 1523 nm to 1561 nm at the 980 nm pump power of 150 mW. Due to the unflattened gain profile of the erbium amplification, the peak power levels of the lasing wavelengths are not consistent within the tuning range. There is a difference between the peak power levels of the two cavities at the same wavelength and under the same pump power owing to the unbalanced cavity loss, which brings the convenience to achieve equalized dual-wavelength output.

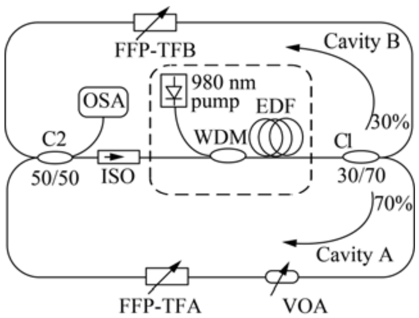

Fig.1 Experimental setup of the proposed dual-wavelength fiber laser

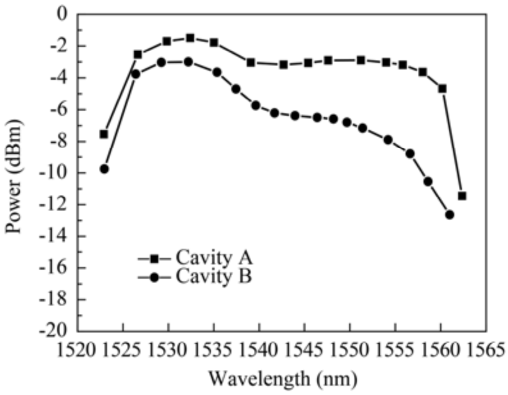

Fig.2 Tuning ranges of the cavities A and B at 150 mW 980 nm pump power

Stable dual-wavelength operation is achieved through properly modifying the attenuation value of the VOA. The zero attenuation value results in the dominant lasing in the cavity A. With the increase of the attenuation value, the peak power of the lasing wavelength in cavity A is reduced and the lasing is established in cavity B. Further increase leads to the peak power growth in the cavity B and the continuous reduction in the cavity A. When the VOA is adjusted to an appropriate value, the output power levels of the dual-wavelength reach the same level and stable dual-wavelength output can be achieved. By changing the center wavelengths of FFP-TFA and FFP-TFB, widely tunable wavelength spacing is achieved. Figs.3 and 4 show the selected dual-wavelength output spectra with different wavelength spacings. In Fig.3, the center wavelength of the FFP-TFA is fixed at 1530 nm, while the center wavelength of the FFP-TFB is changed to 1530.4 nm, 1530.8 nm, 1535.4 nm, 1542 nm, 1549 nm and 1561 nm, respectively. The peak power differences of these six dual-wavelength outputs are 0.38 dB, 0.16 dB, 0.74 dB, 0.8 dB, 0.67 dB and 0.64 dB, respectively. In Fig.4, the center wavelength of the FFP-TFA is fixed at 1550 nm, while the center wavelength of the FFP-TFB is changed to 1530 nm, 1541 nm and 1561 nm, respectively. The peak power differences of these three dual-wavelength outputs are 0.71 dB, 0.37 dB and 0.27 dB, respectively. The difference of the dual-wavelength output power levels can be reduced by more precisely controlling the attenuation value of the VOA. The results show that the fiber laser can provide equalized dual-wavelength output power even as the wavelength spacing is changed. Fig.5 shows the magnified view of the dual-wavelength output with 0.4 nm spacing at the wavelengths of 1530 nm and 1530.4 nm. The side mode suppression ratios (SMSRs) are higher than 60 dB, which indicates that the fiber laser has good optical quality.

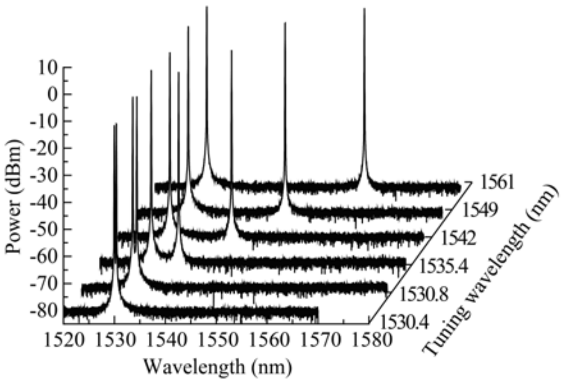

Fig.3 Dual-wavelength output spectra with different wavelength spacings at FFP-TFA of 1530 nm

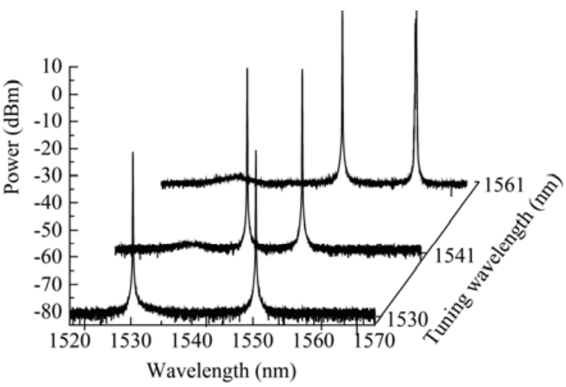

Fig.4 Dual-wavelength output spectra with different wavelength spacings at FFP-TFA of 1550 nm

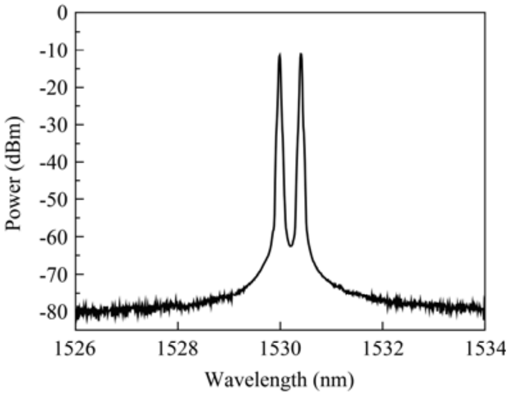

Fig.5 The magnified view of the dual-wavelength output with 0.4 nm spacing

Fig.6 shows the dual-wavelength output power versus pump power. The dual-wavelength is fixed at 1541 nm and 1553 nm. The threshold power is around 60 mW and the lasing power increases with the pump power. When the 980 nm pump power reaches 150 mW, the peak power levels are -14.86 dBm and -14.66 dBm. The stability of the dual-wavelength output is also investigated. The output of the fiber laser is scanned with 5 min interval during 1 h. The proposed fiber laser has a stable output with the maximum power fluctuations of 0.94 dB and 0.95 dB during the observation period, as shown in Fig.7.

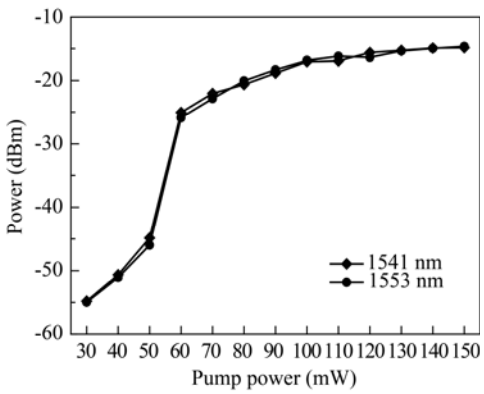

Fig.6 Output power at 1541 nm and 1553 nm versus the 980 nm pump power

We propose and experimentally demonstrate a stable dual-wavelength erbium-doped fiber ring laser with widely tunable wavelength spacing and equalized output power. The fiber laser introduces two cavities with

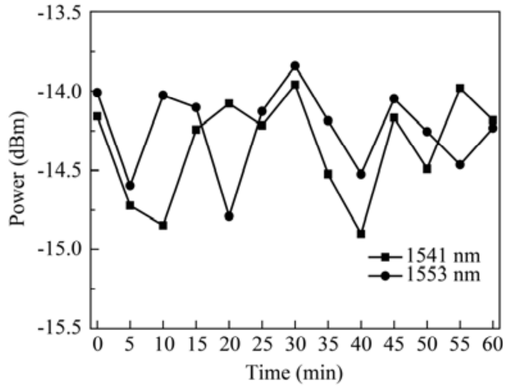

Fig.7 Stability of the dual-wavelength output

different losses through a 30/70 optical coupler. By using two fiber Fabry-Perot tunable filters, the wavelength spacing of the dual-wavelength output can be tuned in a wide range which has potential application in millimeter-wave generation and terahertz radiation. The peak power levels of dual-wavelength output are equalized by modifying the attenuation value of the VOA. The fiber laser shows good optical quality.

References

[1] H. Ahmad, A. A. Latif, M. Z. Zulkifli, N. A. Awang and S. W. Harun, IEEE Sensors J. **12**, 2496 (2012).

[2] B. Q. Wu, Y. Lu, L. Jing, X. H. Huang and J. Q. Yao, Laser Phys. **23**, 115103 (2013).

[3] S. C. Feng, S. H. Lu, W. J. Peng, Q. Li, C. H. Qi, T. Feng and S. S. Jian, Opt. Laser Technol. **45**, 32 (2013).

[4] M. Y. Jeon, N. Kim, J. Shin, J. S. Jeong, S-P Han, C. W. Lee, Y. A. Leem, D-S Yee, H. S. Chun and K. H. Park, Opt. Express **18**, 12291 (2010).

[5] G. Chen, D. Huang, X. Zhang and H. Cao, Opt. Lett. **33**, 554 (2008).

[6] X. H. Feng, P. K. A. Wai, H. Y. Tam, C. Lu and B. O. Guan, Opt. Fiber Technol. **17**, 138 (2011).

[7] S. Feng, O. Xu, S. Lu, X. Mao, T. Ning and S. Jiang, Opt. Laser Technol. **41**, 264 (2009).

[8] D. S. Moon, G. Sun, A. Lin, X. Liu and Y. Chung, Opt. Commun. **281**, 2513 (2008).

[9] J. F. Zhao, T. Q. Liao, C. Zhang, R. X. Zhang, C. Y. Miao, H. Q. Li and Z. R. Tong, Optik **124**, 1092 (2013).

[10] H. Zou, S. Q. Lou, G. L. Yin and W. Su, IEEE Photon. Technol. Lett. **25**, 1003 (2013).