Single-longitudinal-mode Dual-Wavelength Fiber Ring Laser by Cascading Two Filters and Using a Saturable Absorber*

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Abstract: A fiber ring laser was proposed and demonstrated. By cascading a bandpass filter with a bandstop filter and employing a polarization-maintaining erbium-doped fiber as a saturable absorber, a single-longitudinal-mode dual-wavelength fiber ring laser was achieved. The results show that the wavelength spacing is 0.40 nm and the side-mode suppression ratio is greater than 49 dB. The proposed laser has potential to generate microwave signal of 49.85 GHz by heterodyning the two wavelengths.

Key words: Fiber ring laser; Dual-wavelength; Single-longitudinal-mode; Filter cascade; Saturable absorber

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0 Introduction

Multi-wavelength single-longitudinal-mode erbium-doped fiber lasers (EDFLs) have attracted great interest[1-4] for many applications such as wavelength division multiplexing (DWM) fiber communications, high-resolution spectroscopy, fiber sensors. Especially, high-frequency-microwave ROF technologies are of increasing interest owing to the large bandwidth and excellent frequency reusability between adjacent picocell coverage ranges with severe atmospheric attenuation[5]. Photonic generation of high-frenquency microwave signals by optical heterodyning of two single-longitudinal-mode wavelengths[6-7] has been considered to be an effective and promising alternative. Unfortunately, because of the homogeneous line broadening of the erbium-doped fiber (EDF) and the narrow longitudinal mode spacing originated from the long lasing cavity, EDFLs usually operate unstably in multimode oscillation with mode competition and hopping[8]. These behaviors limit their practical applications. Therefore, to achieve stable single-longitudinal-mode EDFLs, a filters to serve as wavelength selection components in the laser cavity should be constructed, and the homogeneous line broadening of EDF should be suppressed. Recently, several approaches have been proposed and experimentally demonstrated. Using a fiber loop mirror with a saturable absorber, Liu et al[1]. have implemented a single-longitudinal-mode multiwavelength fiber ring laser, and a beating signal at 25 GHz is observed. Chen et al[9]. have demonstrated dual-wavelength single-longitudinal-mode SOA-based fiber ring lasers by using a ultra-narrow dual-transmission-peak bandpass filter. Unfortunately, the ultra-narrow bandpass filters must be especially designed with the equivalent phase shift technique. Moreover, the ultra-narrow bandpass filters with the wavelength spacing of higher than 0.35 nm are difficult to be fabricated[9]. Sun et al[10]. have proposed a single-longitudinal-mode dual-wavelength fiber ring laser by introducing two cascaded fiber Bragg gratings, feedback fiber loops and a variable saturable absorber in a fiber ring cavity. However, the dual-reflectivity-peak spectrum for the combined filter by cascading two fiber Bragg gratings has asymmetric reflectivity, and the feedback fiber loops are more complicated configurations.

In this paper, a single-longitudinal-mode dual-wavelength fiber ring laser was presented and demonstrated. In the cavity, a tunable bandpass filter was cascaded with a bandstop filter to serve as a coarse dual-wavelength selector, which greatly simplifies the fabrication of the narrow dual-transmission-peak filters. A segment of unpumped polarization maintaining (PM)-EDF is used as a saturable absorber, ensuring the single-longitudinal-mode operation of the laser and improves its stability. The wavelength spacing of

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two lasing wavelengths was measured to be 0.40 nm at room temperature. The proposed laser offers the possibility of generating microwave signal of 49.85 GHz by heterodyning the two wavelengths at a high-speed photodetector, which has attracted great interest in radio-over-fiber (ROF) networks.

1 Experimental setup and principle

Fig. 1 shows the experimental setup for the proposed fiber ring laser. A tunable bandpass filter (Santec OTF-300) is cascaded with a bandstop filter (FBG) to serve as a coarse dual-wavelength selector. A 3-m unpumped PM-EDF, replacing a conventional unpumped-EDF, is used as a saturable absorber, acting as a narrow multiband filter[11]. An Au-film is coated directly on the end of the EDF to form a reflector. An optical circulator is used to ensure the unidirectional propagation of the light, and form a standing wave pattern in the unpumped PM-EDF. Since the stability of the multiband filter is related to the polarization state of the light in the saturable absorber, the saturable absorber of the PM-EDF can improve the stability of the single-longitudinal-mode operation of the laser. The combined interaction of the filters and the saturable absorber can ensure the laser operation in single-longitudinal-mode. Two polarization controllers PC_1 and PC_2 are employed to control the polarization state of the light. A 12-m EDF pumped by 980 nm DFB laser with tunable injected current is employed as the gain medium. The laser output through an 80:20 optical coupler is monitored by an optical spectrum analyzer with 0.05 nm resolution.

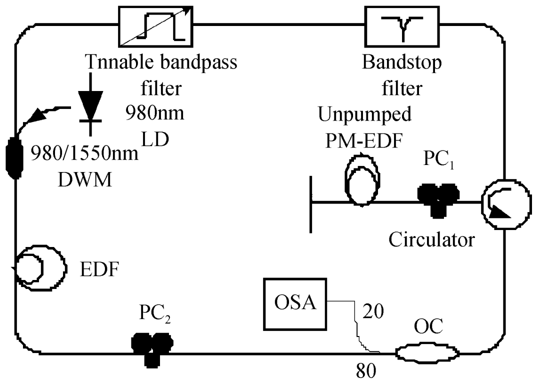


Fig. 1 Proposed dual-wavelength fiber ring laser

2 Experimental results and discussions

Using the EDFA spontaneous emission spectrum, the measured transmission spectra of the bandstop filter and the bandpass filter are shown in Fig. 2(a) and (b), respectively. The results show that the bandstop filter has the 3 dB stopband width of 0.1 nm with the notch wavelength of 1 551.39 nm, and the bandpass filter is 3 dB passband width of 0.36 nm. By tuning carefully the central wavelength of the bandpass filter near the central wavelength of the bandstop filter, and adjusting the two PCs to an appropriate state, the stable dual-wavelength lasing is established at the pump power of 80 mW for EDF, as shown in Fig. 3. At this time, the combined spectrum of the bandpass filter and the bandstop filter is measured as shown in Fig. 2(c). The peak-wavelength spacing of the two transmission peaks is 0.40 nm and the side-mode suppression ratio is 32 dB. The two lasing wavelengths in Fig. 3(a) are measured at 1 551.25 nm and 1 551.65 nm, respectively. The wavelength spacing between them is 0.40 nm, corresponding to the frequency spacing of 49.85 GHz, which matches the two peaks of the combined spectrum in Fig. 2(c). The side-mode suppression ratio of each wavelength is greater than 49 dB.

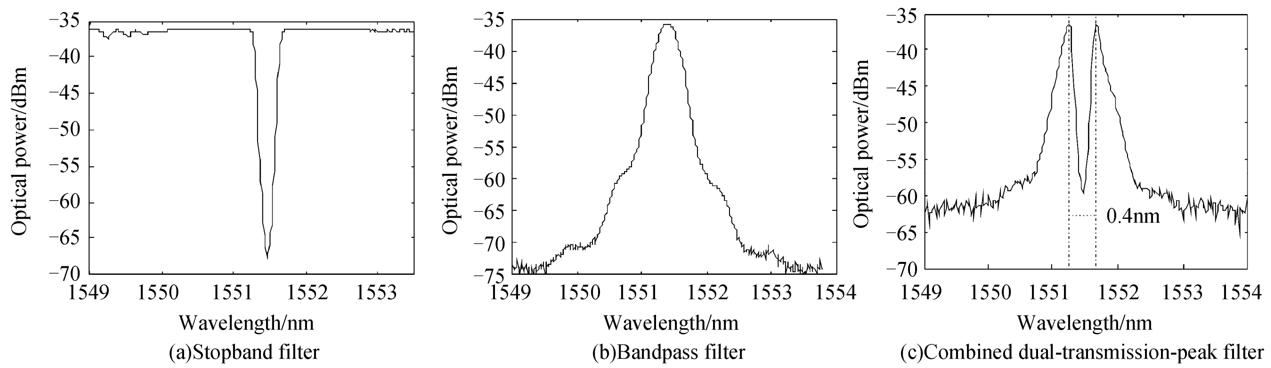
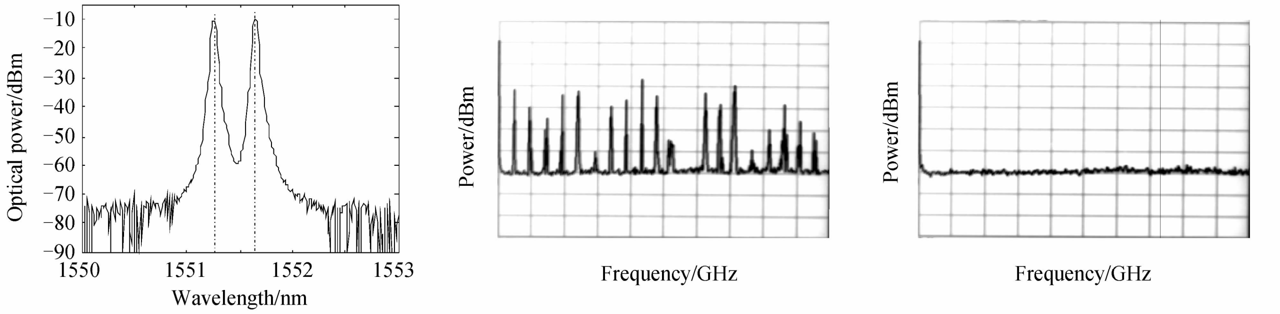


Fig. 2 Measured spectrum

The laser single-longitudinal-mode operation is verified by monitoring the beating signals of the longitudinal modes through applying the two lasing wavelengths to a 40 GHz photodetector cascaded with a 6.75 GHz electrical spectral analyzer. When the saturable absorber is not incorporated in the laser cavity, the electrical frequency spectrum of the beating signal from 0 to 1 GHz is shown in Fig. 3(b). It is found that a number of beating signals of the laser longitudinal modes are observed, which can be ascribed to the laser longitudinal mode beating, and indicate that the fiber laser operates in multimode oscillation. Fig. 3(c) shows the electrical spectrum of the dual-wavelength fiber laser with the saturable absorber. As seen from Fig. 3(c), no beating signal at frequencies equal to the round-trip frequency of the fiber ring laser and its multiples are monitored, indicating that the two lasing wavelengths operate in single-longitudinal-mode. Because we have no electrical spectrum analyzer with more than 50 GHz and the wavelength spacing (>49 GHz) of the two lasing wavelengths exceeds the frequency response of the electrical spectrum analyzer, the beating signal of the two lasing wavelengths can not be observed.



(a)Measured dual-wavelength output spectra of the laser
(b)Electrical spectrum of the beating signal without the saturable-absorber
(c)Electrical spectrum of the beating signal with the saturable-absorber

Fig. 3 Spectrum

To verify the stability of the laser, the optical spectrum and the beating signal of the two lasing wavelengths are the monitored about 60 min with measurement time interval of 6 min at room temperature, respectively. No wavelength spacing drift and no mode hopping are observed, and the fluctuation of the peak power is measured within 0.1 dB. This indicates that the two lasing wavelengths can operate stably in single-longitudinal-mode. This can be explained by the suppression of the homogeneous line broadening of EDF using a gain equalization technique[12]. Because the two transmission peaks of the combined filter in the laser has nicer symmetry by carefully adjusting PCs, and the saturable absorber serve as a narrow multiband filter to select lasing mode, when the cavity-loss is small enough for the population inversion density in the erbium-doped fiber to support the two wavelengths to reach saturation power, the stable lasing operation is maintained.

3 Conclusion

A narrow dual-transmission-peak filter is proposed and realized by cascading a tunable bandpass filter with a bandstop filter. By using these filters and a saturable absorber of the PM-EDF, a single-longitudinal-mode dual-wavelength laser is demonstrated with the wavelength spacing of 0.40 nm and the side-mode suppression ratio more than 49 dB. The proposed laser has potential to generate microwave signal of 49.85 GHz by heterodyning the two wavelengths at a high-speed photodetector, which has attracted great interest in ROF networks.

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基于两滤波器级联和饱和吸收体的单纵模双波长光纤激光器

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摘 要:提出和证实了一种光纤环形激光器. 将一个带通滤波器与一个带阻滤波器级联,用一段保偏掺铒光纤作为饱和吸收体,得到了一种单纵模双波长光纤激光器. 结果表明,该激光器波长间隔为 0.4 nm,边模抑制比大于 49 dB. 如果将两个波长进行差拍,该激光器有潜力得到 49.85 GHz 的微波信号.
关键词:光纤激光器;双波长;单纵模;滤波器级联;饱和吸收体

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