Er-doped superfluorescent fiber source with enhanced mean-wavelength stability incorporating a fiber filter

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Abstract: The mean wavelength dependence on pump power in an Er-doped superfluorescent fiber source of double-pass backward configuration was studied. Data presented shows that mean wavelength variations with pump power can be reduced to -9 ppm/mW for selected pump powers by using an Er-doped fiber filter. And the total mean wavelength instability of the fiber source is less than 33 ppm(peak-to-peak) over the -40 ℃ to 60 ℃. The bandwidth reaches 17 nm. The pump power is 55 mW at 974.2 nm and the output power reaches 5.83 mW with 5-m Er-doped fiber.

Key words: Er-doped fiber filter; fiber optic gyroscopes; superfluorescence fiber source
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采用光纤滤波器的高波长稳定性掺铒光纤光源

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摘 要: 研究了双程后向结构掺铒光纤光源的平均波长对泵浦功率的依赖性。实验结果表明,通过采用掺铒光纤滤波器以及选择合适的泵浦功率, 平均波长随泵浦功率的变化能够降低到-9 ppm/mW。在-40~+60 ℃温度范围内,光纤光源的平均波长不稳定性小于 33 ppm(峰峰值)。采用 5 m 长的掺铒光纤、泵浦功率 55 mW 与泵浦波长 974.2 nm 时,光纤光源输出光波的谱宽达到 17 nm,功率达 5.83 mW。

关键词: 掺铒光纤滤波器; 光纤陀螺; 掺铒光纤光源

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0 Introduction

Erbium (Er)–doped superfluorescent fiber sources (SFSs) are of great interest for use in interferomentric fiber optic gyroscopes (IFOGs), because of their broadband output and good intrinsic wavelength stability[1]. The mean wavelength stability of the source is very important in a FOG to stabilize the scale factor between the rotation rate and the measured Sagnac phase shift. A high-grade IFOG requires that the SFS has a mean wavelength stability in parts per million (ppm)[2], which is primarily affected by the pump power, pump wavelength, the pump state of polarization, the feedback power returning from the IFOG, and the Er–doped fiber (EDF) temperature[3]. The influences of the former four factors can be reduced to ppm level by selecting optimal pump parameters[1–4], stabilizing pump laser and using high-performance fiber optic components [3,5]. The main instability source is from the EDF–temperature. It can modify the emission and absorption cross–sections of erbium ions, inducing a drift in the mean wavelength. Values of the thermal coefficient ranging from –3 to +10 ppm/℃ have been reported in different SFS configurations[1,4,6]. Even though a temperature controller can be applied on EDF, it is quite power consuming, making the system more complicated, especially when the source works in broad temperature range(over 100 degrees).

As for the emission cross-section of erbium ions, the 1 530 nm emission is much more sensitive to pump power perturbations than the 1 560 nm emission of the spectrum[7]. In order to achieve a significant 1 560 nm emission band, several techniques have been adopted. A Bragg fiber grating has been applied as a filter in a double-pass forward configuration with a 980 nm pump[8]. A 1 480 nm pump and a Faraday rotator mirror have been used in a double-pass forward configuration[9–10]. The 1 480 nm pump is more expensive than the 980 nm pump. For the sake of reducing the cost of SFS, several means have been reported in SFS configurations with 980 nm pump, such as an Er–doped fiber has been employed in a single-pass backward configuration[7], and a photonic bandgap fiber has been used in a double-pass backward configuration[11–12]. Although the 1 530 nm emission has been absorbed greatly, there was still a little 1 530 nm band emission remained[7,11–12].

In this paper, we proposed and demonstrated a 980 nm pumped double-pass backward-signal (DPBS) Er –doped SFS with enhanced mean-wavelength stability on pump power using an Er–doped fiber as a filter. The filter absorbs the 1 530 nm emission peak and only the 1 560 nm emission peak is remained. The experiment data presented here show that a near-zero gradient region of mean wavelength against pump power can be achieved, and the pump power at which zero gradient occurs can be tuned continuously over a wide range. With restrictions due to mean wavelength against pump power instability relaxed, the optimum pump power can be chosen according to the SFS output power required for the FOG. The total mean wavelength instability is less than 33 ppm (peak-to-peak) over the –40 ℃ to 60 ℃ range. The bandwidth reaches 17 nm. The pump power is 55 mW at 974.2 nm and the output power reached 5.83 mW with 5–m Er–doped fiber. In this configuration, no any additional temperature compensating device is needed.

1 Design

The configuration of the DPBS Er–doped SFS configuration is a modification of the conventional double-pass backward configuration shown in Fig.1. The pump source is a fiber-pigtailed 980 nm laser diode (LD) with peak wavelength at 974.2 nm, which utilizes a double fiber Bragg grating (FBG) design for enhanced wavelength and power stability performance. A high-stability, low-noise current source with an integrated temperature controller ensures that the output of the LD has superior wavelength and power stability over environment temperature change. Hence, the effects of the pump power and the pump wavelength on the mean-wavelength stability of the SFS can be minimized. The pump light is coupled through a 980/1 550 nm wavelength division multiplexer (WDM) coupler to 5 m of single mode Er-doped fiber (EDF). The active EDF is highly Er-doped with an absorption coefficient around 17.1 dB at 1 532 nm. Amplified spontaneous emission(ASE) which travels in the direction along the pump is directed towards the Faraday rotator mirror (FRM). It is then reflected so that it makes a second pass through the EDF. The ASE passes back through the WDM coupler, and then is propagated through a non-optically pumped 2.5 m of Er-doped fiber, which acts as a filter to absorb 1 530 nm emission peak. The length of the EDF filter has been optimized by simulation. Finally, the ASE passes through a 49 dB optical isolator, which is associated at the output of the SFS to eliminate the effect of the feedback power.

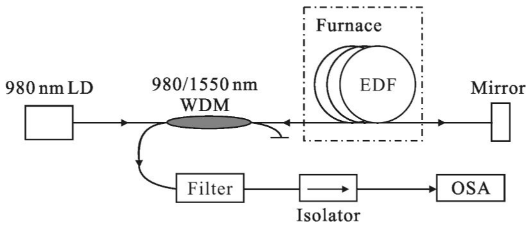

Fig.1 Configuration of DPBS Er-doped SFS with an EDF filter

In Fig.1, if there is any 980 nm light reflected back to the pump, the pump light will be affected and an undesired light signal will be emitted by the SFS ultimately. In order to prevent any 980 nm light being reflected back to the pump via EDF and the WDM coupler, the range of reflected wavelength of the FRM is from 1 400 nm to 1 600 nm. On the other hand, the FRM is used to reduce the polarization dependent gain (PDG), which gives rise to long-term drifts of the source output mean wavelength through changes in the fiber birefringence[10].

2 Experiment and discussion

The output of spectrum was measured using an Agilent optical spectrum analyzer(OSA). Figure 2 shows the spectra of the DPBS Er-doped SFSs with and without an EDF filter. In the DPBS SFS without EDF filter, the emission peaks near 1 530 nm and 1 558 nm are existent distinctly. And the power spectral density near 1 530 nm is -36.9 dB. When adopting an EDF filter in the DPBS SFS, the peak emission near 1 530 nm is absorbed greatly and declines to -62.7 dB.

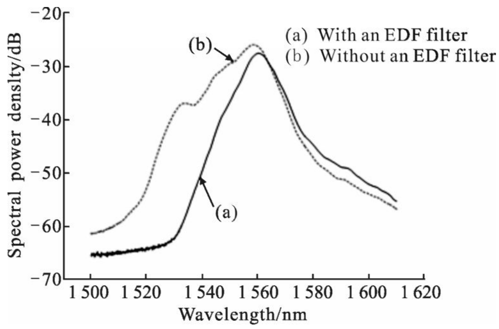

Fig.2 Spectra of the DPBS SFSs

The mean wavelength and full width at half maximum (FWHM) of the DPBS SFS with an EDF filter are 1 561.687 nm and 17.1 nm, respectively. The pump power is 55 mW at 974.2 nm and the output power of the SFS is 5.82 mW, measured by an ILXlightwave Fiber Optic Power Meter.

To analyze the mean-wavelength dependence on the pump power, the spectrum of the DPBS Er-doped SFS was measured using the OSA. The variations of mean wavelength and FWHM of SFS against pump power are shown in Fig.3. Fig.3(a) shows that mean wavelength drops from 1 602.3 nm to 1 571.7 nm sharply when the pump power is less than 14 mW. With the increasing of pump power, the higher the pump power, the more stable the mean wavelength is. The experiment data presented here show that a near-zero gradient region of mean wavelength against pump power can be achieved when the pump power is larger than 54 mW, and the pump level at which zero gradient occurs can be tuned continuously over a wide range. The change of FWHM with pump power is approximate to that of the mean wavelength. Fig.3(b) shows that a less than 0.02 nm/mW gradient region of

FWHM against pump power is achieved with the pump power larger than 54 mW.

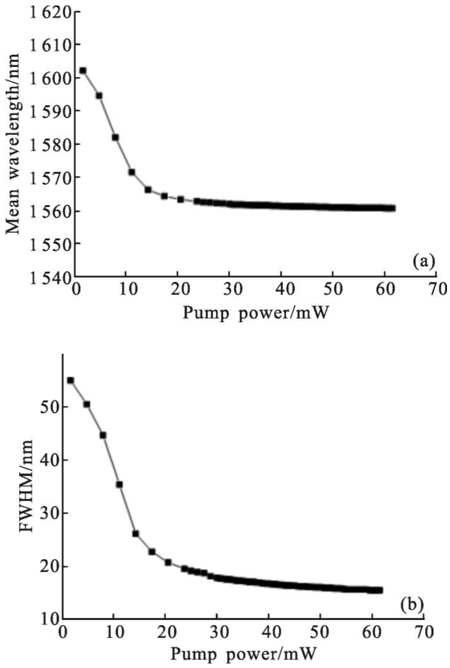

Fig.3 Mean wavelength and FWHM of DPBS Er-doped SFS incorporating FRM and EDFF versus pump power

The variations of the mean wavelength and FWHM of the DPBS SFS against pump power are shown in Tab.1. When the pump power changes from 14 mW to 23 mW, the mean wavelength variation with pump power is −236.71 ppm/mW, and when the pump power drops from 54 mW to 60 mW, the mean wavelength variation with pump power is −9.24 ppm/mW. The FWHM variation with pump power is −0.70 nm/mW when the pump power changes from 14 mW to 23 mW, and it drops to −0.03 nm/mW when the pump power is greater than 54 mW.

Tab.1 Variations of mean wavelength and FWHM of the DPBS SFS against pump power

RPP/mW	VMWL/ppm·mW^{-1}	VFWHM/nm·mW^{-1}
≤14	−2 040.39	−2.07
14−23	−236.71	−0.70
23−30	−79.02	0.25
30−54	−28.24	−0.08
54−60	−9.24	−0.03

Note: RPP = range of pump power, VMWL = variation of mean wavelength, VFWHM = variation of FWHM.

To study the mean wavelength thermal stabilities of these DPBS SFSs, the optically pumped EDF was placed in a temperature-controllable furnace (Votsch industrietechnik, VT4002) covering the range from −40 ℃ to 60 ℃. Figure 4 shows the temperature effect to variation of the mean wavelength of these DPBS SFSs. It is found that the DPBS SFS incorporating an EDF filter has the best mean-wavelength stability less than 33 ppm (peak-to-peak) over the −40 ℃ to 60 ℃ range, with the minimal variation of mean-wavelength 0 nm at 20 ℃ and maximal variation 0.05 nm at 30 ℃. When the EDF filter is removed, the mean-wavelength stability of the DPBS SFS is 122 ppm, with the minimal variation of mean-wavelength −0.17 nm at 60 ℃ and maximal variation 0.02 nm at 0 ℃.

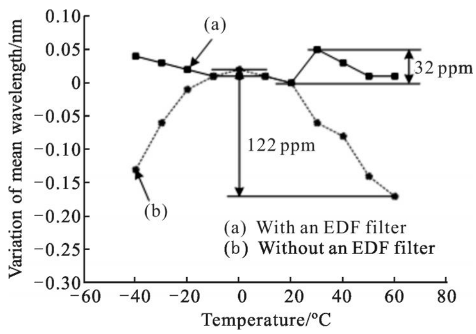

Fig.4 Tested mean wavelengthes of the DPBS SFSs versus temperature

3 Conclusion

In conclusion, a DPBS Er-doped SFS by using a 2.5-m EDF has been proposed in our work. The 2.5-m EDF was used as a filter to improve the SFS′s intrinsic thermal stability. The 1 530 nm peak is absorbed greatly and only a 1 560 nm band is remained in the SFS. Through simulation and experimentation, a near-zero gradient region of mean wavelength against pump power can be achieved, and the pump level at which zero gradient occurs can be tuned continuously over a wide range. When the pump power was 55 mW at 974.2 nm, the final output power reached 5.83 mW with 5-m Er-doped fiber. The total mean wavelength variation can be limited less than 33 ppm (peak-to-peak) from −40 ℃ to 60 ℃. In this configuration, no any additional temperature compensating devices are included, and this SFS is suitable for use in navigation-grade FOG.

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