A high-stability single pumped L-band superfluorescent fiber source for the fiber optic gyroscope

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ABSTRACT

In this paper, a simple single-backward configuration with a section of un-pump fiber is presented to achieve a stable L-band superfluorescent fiber source (SFS). The effects of the structural parameters on the output characteristics of the L-band SFS in terms of output spectrum, mean wavelength, and linewidth are theoretically examined. By selecting suitable structure parameters, an L-band SFS with mean wavelength insensitive to pump power is achieved under a pump power of 190mW, corresponding to a mean wavelength of 1583.20nm, an output power of 47mW, and a spectral linewidth of 49.6nm. The proposed L-band SFS design shows its tremendous advantages as simple structure and good performances that make it be useful in WDM system, fiber optic gyroscopes and fiber sensor systems applications.

Keywords: Amplified spontaneous emission (ASE), superfluorescent fiber source (SFS), backward pumped configuration, L-band.

1. INTRODUCTION

In the recent decades, superfluorescent fiber sources (SFS) using amplified spontaneous emission (ASE) from an erbium-doped fiber (EDF) have been a topic of continuing research because of their wide range of applications, from fiber optic gyroscopes (FOGs), component testing sources to sliced spectrum sources for low cost access networks and so on [1-3]. The conventional wavelength band (C-band, 1525-1565nm) EDF SFSs have been studied intensively and the double-pass backward (DPB) configuration has been demonstrated to offer the highest output power, better mean wavelength stability, and broader linewidth for the C-band SFSs [4]. Recently, most researches are focused on the long wavelength band (L-band, 1565nm-1605nm) SFS in order to increase its output power, spectral linewidth and wavelength stability to cater for the demand of band expansion of the fiber optic communication window [5-8]. We have proposed a stable L-band SFS using double-pass bi-directional pumped configuration [9, 10]. However, the configuration presented in ref. [9, 10] is quite complicated and had a strict requirement to the structural parameters. The wavelength stable L-band SFS with simpler configuration and larger linewidth is useful to accelerate its further application in all-fiber FOG. It is well known that the single-forward-pumped configuration offers a low efficiency and mean wavelength instability operation [5]. In this paper, we present a single backward pumped L-band SFS. The configuration is based on the conventional double-pass backward configuration, while using an additional un-pumped fiber between the wavelength division multiplexing coupler and the isolator at the end of the output terminal. It is proved that the proposed design can not only have the characteristic of mean wavelength insensitive to pump power operation but also has a large linewidth with the optimized structural parameters.

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2008 International Conference on Optical Instruments and Technology: Advanced Sensor Technologies and Applications, edited by Anbo Wang, YanBiao Liao, AiGuo Song, Yukihiro Ishii, Xudong Fan, Proceedings of SPIE Vol. 7157, 71571C
 · doi: 10.1117/12.811163

2. PROPOSED L-BAND SFS CONFIGURATION

The proposed configuration is shown in Fig.1. The source consists of two sections of erbium-doped fiber (EDF1 and EDF2), a 980nm pump laser diode (LD), a 980/1590nm wavelength division multiplexer (WDM), a fiber mirror made by a 3 dB broadband couple, and an optical isolator (ISO) at the output port. The section of EDF1 is backward pumped by the 980nm LD. The other section of erbium-doped fiber (EDF2) is un-pumped and separated from EDF1 by the WDM, which is arranged between the WDM and the isolator at the end of the output terminal. We define the total length of EDF as $L=L_1+L_2$, where L_1 and L_2 are referred to as the first stage (EDF1) and the second stage (EDF2) lengths, respectively. The fiber length ratio of the EDF1 to the total length is defined as $R_L=L_1/L$. The EDF used in the numerical simulations and experiments is offered by Lucent company which has a peak absorption of 27-33dB/m at 1530nm, mode field radius of 5.2μm, cutoff wavelength of 1100-1400nm, and numerical aperture of 0.25.

The principle of the proposed L-band SFS with backward pumped configuration can be explained as follow. Generally, the L-band ASE is realized through a longer fiber, that is: the C-band ASE generated by the anterior fiber is injected into the later fiber to be a second pump source, then L-band ASE will be attained in the output. For the configuration presented in this paper, the C-band output of EDF1 is transfused into the EDF2 to be a second pump-source, so L-band output can be achieved in the end of the second EDF with an appropriate fiber length arrangement.

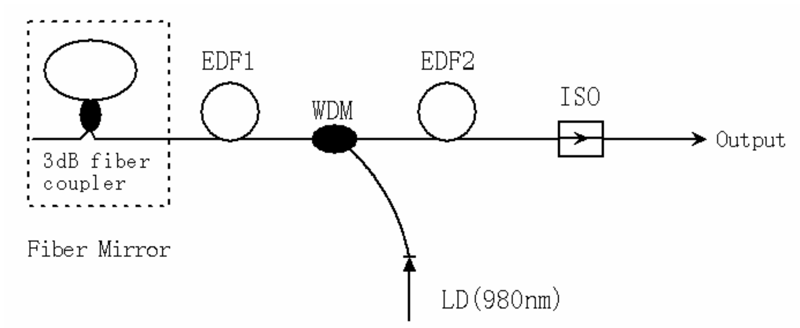

Fig.1. Proposed L-band SFS using single backward pumped technique

3. RESULTS AND DISCUSSIONS

Previous simulations and experiments have indicated that the simulation results obtained by the commercial amplifier simulation package OASIX are quite accurate [9, 12-13]. Therefore, the OASIX is used to perform the simulations of the proposed configuration as shown in Fig.1 in order to gain insight into and to optimize its output properties. It is noted that that the mean wavelength of the amplified spontaneous emissions (ASE) is computed by

$$\bar{\lambda} = \frac{\sum_{i=1}^{n} p(\lambda_i)\cdot\lambda_i}{\sum_{i=1}^{n} p(\lambda_i)} \tag{1}$$

and the spectral linewidth is defined as

$$\Delta\lambda = \frac{\left[\sum_{i=1}^{n} \Delta\lambda_i \cdot P_i\right]^2}{\sum_{i=1}^{n} \Delta\lambda_i \cdot P_i^2} \tag{2}$$

Where $P(\lambda_i)$ is the emission spectrum of the light source.

There is no doubt that the output ASE spectrum is largely depended on the total fiber length used. Therefore, the total fiber length is firstly optimized obtain a flat L-band spectrum output. The effective reflectivity of the fiber mirror is selected to be 90% and the total pump power is set to 100mW. For different fiber length ratios, R_L, the output spectra of the L-band SFS at various EDF lengths are simulated. The result indicates that for different R_L, the optimal EDF length for the flat L-band spectrum, i.e. for the maximal value of linewidth, is approximately19m. Hence, the total EDF length is fixed at 19m of the L-band SFS in the following simulations.

Then, the effects of the fiber length ratio R_L on the output spectrum have been addressed. Fig.2 shows the output spectra for the configuration of different R_L with a pump power of 100mW. Curves (a) to (g) correspond to R_L=0.42, 0.63, 0.68, 0.79, 0.84, 0.89 and 0.95, respectively. The variation of the output linewidth and the mean wavelength versus R_L are shown in Fig.3. As apparent from Fig.2 and Fig.3, when the R_L is lower than 0.7, R_L has little influence on the L-band spectral shape. However, when R_L changes from 0.7 to 0.85, the spectral intensity increases significantly in the short-wavelength range and decreases in the long-wavelength range gradually. The mean wavelength shifts toward shorter wavelengths and the linewidth increases to the maximum value when R_L is adjusted to around 0.84. If R_L is larger than 0.85, the SFS is no longer an L-band fiber source, the output spectrum shifts to C-band mostly with a decreasing of the mean wavelength and the linewidth.

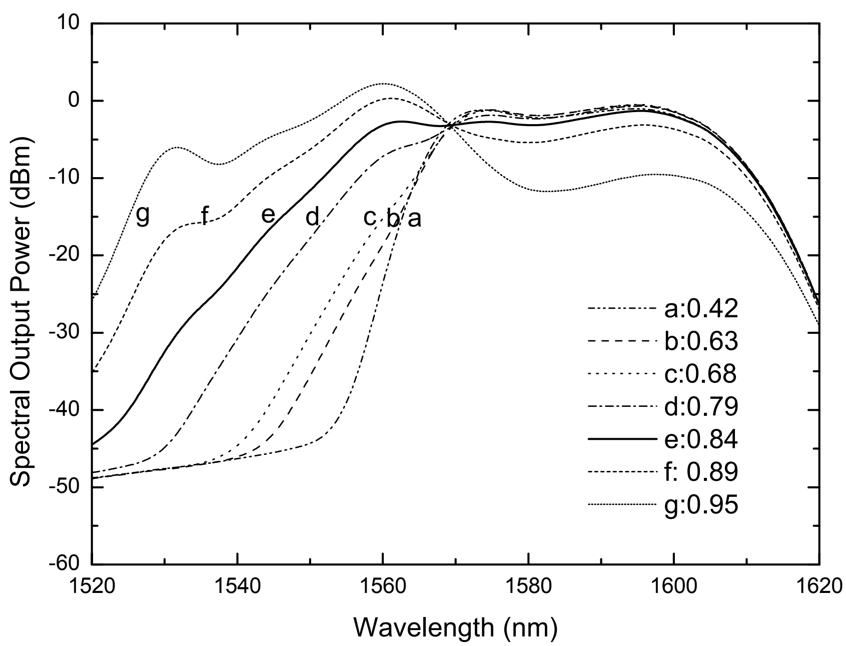

Fig.2. Simulated output spectra in different R_L cases

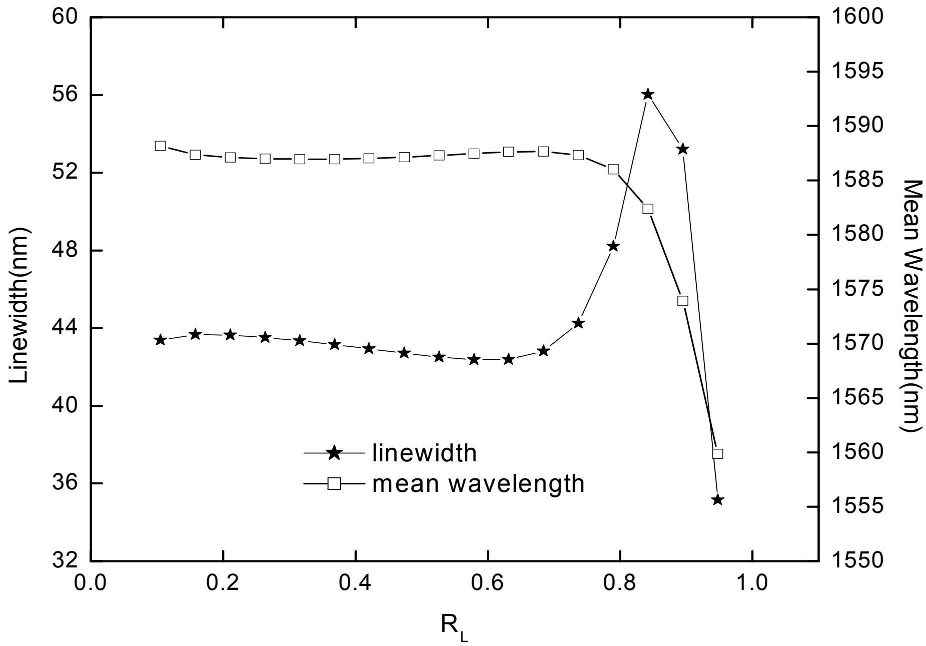

Fig.3. Linewidth and mean wavelength versus R_L

The variation of the mean wavelength versus pump power is also investigated. Fig.4 compares the mean wavelength profiles against pump power, and shows the high tunability of the mean wavelength against pump power characteristic by adjusting the fiber length ratio R_L. The total fiber length is fixed of 19m as optimizing above. It is shown clearly in Fig.4 that when R_L is lower, for the cases of R_L=0.42 (L_1=8, L_2=11m), and 0.63 (L_1=12, L_2=7m), the mean wavelength keeps decreasing with the increase of pump power. However, with a suitable R_L as 0.68 (L_1=13, L_2=6m), 0.79 (L_1=15, L_2=4m)、0.84 (L_1=16, L_2=3m), the characteristic of mean wavelength performs a different way. It increases first and then begins to decline after reaching a maximum with the increase of the pump power. With further increase the R_L to a high value as 0.89 (L_1=17, L_2=2m), the pump power independent mean wavelength operation disappeared. The mean wavelength keeps increasing with the pump power within the set largest pump power of 225mW. The results of Fig.4 show high tunability of the mean wavelength against pump power characteristic by adjusting the fiber length ratio R_L. The pump power independent mean wavelength operation with $\partial\overline{\lambda}/\partial P = 0$ is able to exist for the suggested SFS source by selecting a suitable R_L within a certain range. Too lower or higher fiber length ratio are not satisfied for a stability SFS. The results show that a fiber length ratio between 0.6 to 0.9 is suitable to achieve a stability L-band SFS using this design. Further more, the results of Fig.4 also indicates that the larger the value of R_L is, the higher pump power need to get the stable mean wavelength operation. For example, when the parameters of the fiber length ratio, R_L, is selected of 0.84, i.e. L_1=16, L_2=3m, for achieving a mean wavelength stability L-band SFS with a moderate pump power. In this case, the stable mean wavelength operation was experimentally observed when the pump power adjusts to 190mW, corresponding to a mean wavelength of 1583.20nm, an output power of 47mW, and a spectral linewidth of 49.6nm. The experimental results show good agreement with the simulations, with quantitative discrepancies attributable primarily to splice loss, and insertion loss in WDM coupler etc. We also notice that the pumping efficiency is not high with the proposed single-pumped L-band SFS. To improve the pumping efficiency, the pump power can be divided into another portion to pump the output stage backwardly. Therefore, the mean wavelength stability is primarily concerned in this case. Fig.5

illustrates the mean wavelength versus total pump power in several different pump power ratio R_p with fiber length ratio of 0.84, i.e. L_1=16, L_2=3m. The results of mean wavelength stability are similar to that of single pumped case. That is to say, the pump power independent mean wavelength operation with $\partial\bar{\lambda}/\partial P = 0$ is able to exist for the improved SFS design by dividing the pump into another portion to pump the output stage backwardly. However, it has the advantage of higher pumping efficiency. The more detailed characteristics of the improved SFS design are being research.

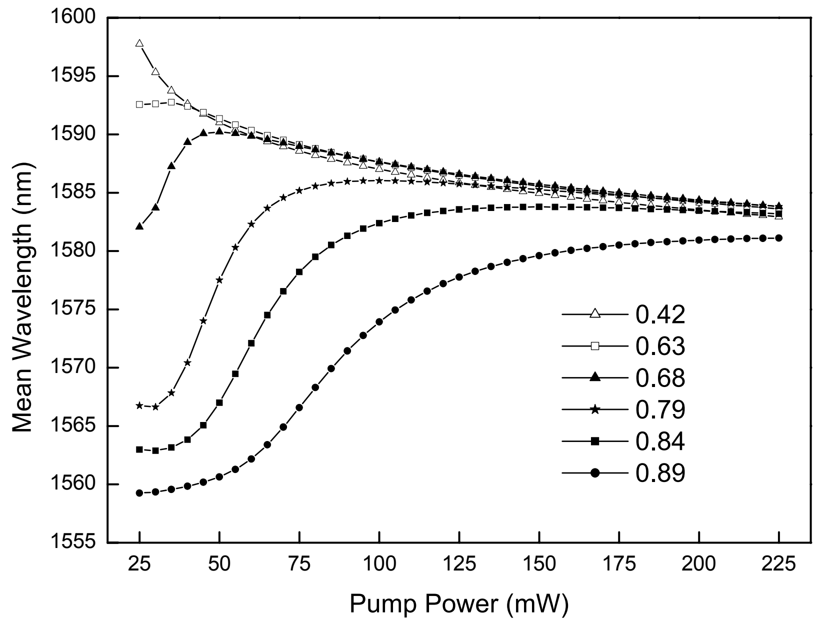

Fig.4. Calculated mean wavelengths versus pump power

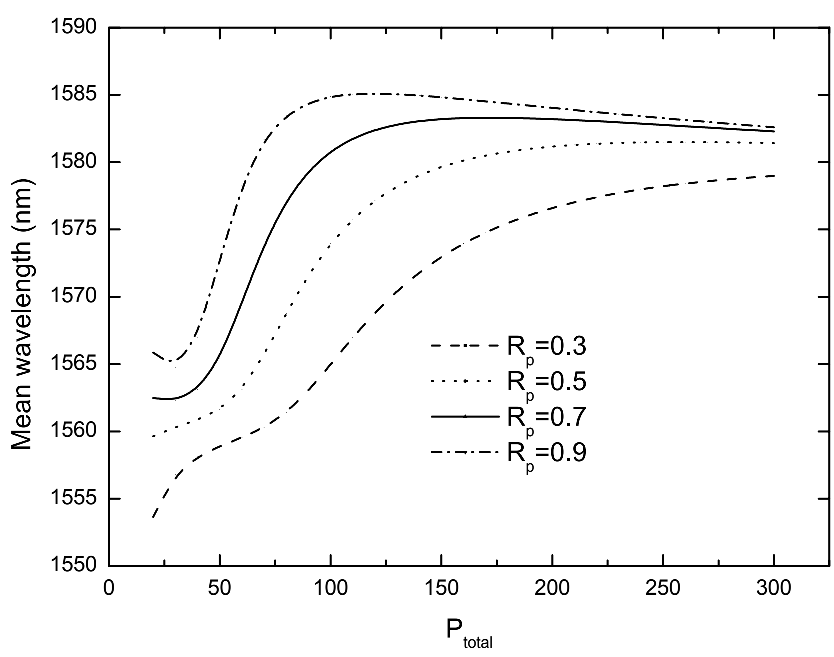

Fig.5 The mean wavelength versus P_{total} in different R_p

4. CONCLUSION

In conclusion, we have presented a single-pumped erbium-doped L-band SFS and demonstrated its tremendous advantages. It is proved that the proposed design can not only have the characteristic of mean wavelength insensitive to pump power operation but also has a large linewidth with the optimized structural parameters. By choosing the appropriate structural parameters, a mean wavelength stable SFS of an output power of 47mW, and a spectral linewidth of 49.6nm is achieved, which is useful to many applications, including WDM system, FOG and fiber sensor systems.

ACKNOWLEDGMENTS

This work was supported by the Program for New Century Excellent Talents in Fujian Province University under Grant No.X07204, the Scientific and Technical Project of Fujian Provincial Department of Education under Grant No.JA08138, and the Key Scientific and Technical Innovation Project of Xiamen University under Grant No.K70007.

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