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A New Three-stage Structure for a High-performance L-band Erbium-doped Superfluorescent Fiber Source

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Abstract A new three-stage L-band erbium-doped superfluorescent fiber source (Er-SFS) is introduced. The structure utilizes the first-stage none-pumping, the second-stage forward-pumping and the third-stage backward-pumping. The influence of the pump wavelength, the length of erbium doped fiber (EDF) and the pumping ratio to the Er-SFS characteristics are studied numerically. Finally, a set of optimal parameters to simultaneously achieve a higher output power, lower ripple and lower cost as compared to the conventional L-band Er-SFS is given.

Keywords Erbium doped fiber (EDF); Three-stage; Superfluroscent Fiber Source (SFS); L-band

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0 Introduction

Erbium-doped superfluorescent fiber sources (Er-SFSs) have been widely used in the area of optical fiber communications[1,2] and fiber sensors[3,4] due to their potential advantages of high output power, relatively broad emission spectrum and low splicing loss, etc. With the rapid growth of dense-wavelength division multiplexing (DWDM) systems, the conventional C-band Er-SFSs (1525 nm ~ 1565 nm) can not satisfy the demand of L-band optical testing components, which in turn requires the development of L-band Er-SFSs. However, L-band Er-SFSs are relatively inefficient since they operate at the tail of the erbium gain band[5]. In order to improve the output power in the L-band, several schemes using various techniques such as C-band wasted backward amplified spontaneous emission (ASE)[6] and double-pass technique[7,8] have been reported recently. The double-pass technique can improve the output power and pumping efficiency. However, two pumping wavelengths and a special broadband reflector are needed for double-pass technique and thus the cost increases. Comparing to the double-pass configuration, the former configuration is much simpler and lower-cost, but it has limited output power and relatively large spectrum ripple.

In this paper, a new three-stage L-band Er-SFS structure is introduced to simultaneously achieve a high output power, low ripple and low cost. The first EDF is none-pumping, the second EDF is forward-pumping and the third EDF is backward-pumping. Only one pump is used and the pump is split into two parts in this work. The effects of the pump wavelength, the length of each EDF section and the pumping ratio on the performance of this new L-band Er-SFS are investigated comprehensively. Finally, the optimal L-band Er-SFS parameters, which can provide high output power, low spectrum ripple and low cost simultaneously, are proposed through a numerical simulation.

1 L-band Er-SFS design

In general, there are four basic kinds of Er-SFS′s configurations: single-pass forward (SPF), single-pass backward (SPB), double-pass forward (DPF) and double-pass backward (DPB). Among them, SPF Er-SFS has insufficient ASE power, SPB Er-SFS has the advantages of easy designing and less susceptibility to lasing. Double-pass Er-SFS has broader spectrum bandwidth, higher output power and more susceptibility to lasing as compared to the former two configurations. As mentioned above, ASE pumping serving as the secondary pump is the most effective scheme to improve the L-band Er-SFS performance. The structure introduced by Lee J. H. et al[6] as shown in Fig. 1(a) is simple and interesting. However, it can only provide limited output power and 3 dB spectrum bandwidth. Furthermore, the forward ASE of the unpumped EDF is not large enough to serve as a secondary pump. Therefore it is very necessary to modify the refered structure to improve the performance of L-band Er-SFS. We proposed a new three-stage L-band Er-SFS structure combining the advantages of both double-pass pumping and single-pass backward pumping

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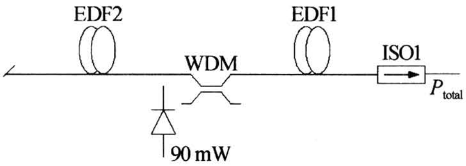
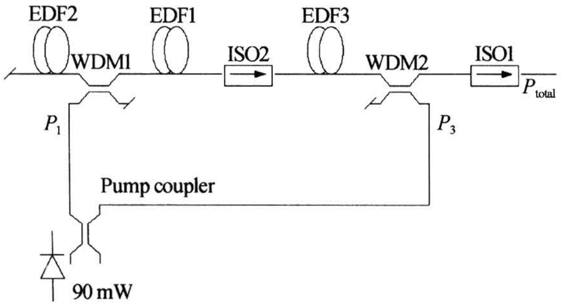
as shown in Fig. 1(b), where the pump used in Fig. 1(a) is split into two parts and a third EDF was added. Note that EDF2 in Fig. 1 is designed to reuse the backward ASE from EDF1 and ISO2 (mid-way isolator) in Fig. 1(b) is prefered to choose broadband (1525～1610 nm).



(a)The structure introduced by Lee et al.(1999)



(b)Our three-stage L-band Er-SFS structure

Fig. 1 The configurations of two different L-band Er-SFS

2 Simulation results and discussion

It is well known that EDF pumped by 980 nm or 1480 nm laser can be modeled as the two-level model of Giles and Desurvire[9]. The mathematical modeling of the Er-SFS is to solve a dual boundary value problem of a set of nonlinear differential equations. These equations can be solved by Runge-Kutta algorithm, together with the relaxation method[10]. For the purpose of objective analysis, a comparison between the former structure and ours is done here. In all the simulations, we keep the total pump power at 90 mW. Both configurations are constructed with identical EDF's. The EDF used in the numerical simulation is a commercially available MP980 erbium doped fiber. Its absorption and emission spectra are shown in Fig. 2. The other parameters for the EDFs are set as follows: cutoff wavelength $\lambda_c = 842$ nm, absorption coefficient $\alpha(980\text{ nm}) = 4.57$ dB/m, emission coefficient $g^*(980\text{ nm}) = 0$ dB/m, $\alpha(1530\text{ nm}) = 5.86$ dB/m, backgroundloss $l = 0.91$ dB/km, and bandwidth $\Delta\nu = 125$ GHz.

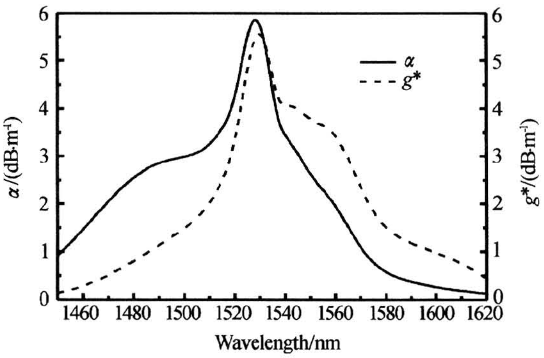


Fig. 2 Spectra of α and g^*

Fig. 3 shows the spectra of two different L-band Er-SFSs when the pump wavelengths, λ_p, are 980 nm and 1480 nm respectively. The length of EDF and the corresponding pump power for these structures are listed in Table 1. From Fig. 3 one sees clearly that our structure can provide higher ASE as compared to the structure introduced by Lee for both the pump wavelength is 980 nm and 1480 nm. Note that 1480 nm pump is the best choice to obtain large output power. As can be seen from Table 1, it is obvious that our structure can reduce the total length of EDF, L_{total}, together with the increase of the total output power of the ASE source, P_{total}, the pumping-conversion effiency, η ($P_{total}/P_p \times 100\%$) and improve the flatness of the spectrum, ΔP. In addition, the mean wavelengths, $\bar{\lambda}$, of these two Er-SFSs both lie in the long-wavelength band. The simulation

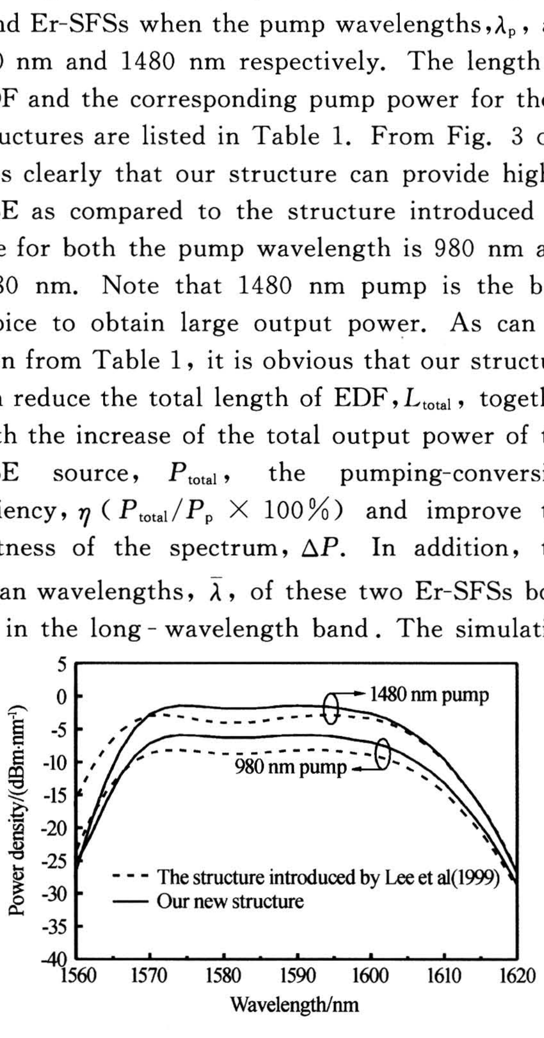


Fig. 3 Spectra of two different L-band Er-SFSs for various pumping wavelength

Table. 1 Lengths of EDF sections and the corresponding pump powers for various structures shown in Fig. 1

λ_p /nm	Configuration in Fig. 1	L_1/P_1(EDF1) /m · mW^{-1}	L_2/P_2(EDF2) /m · mW^{-1}	L_3/P_3(EDF3) /m · mW^{-1}	P_{total} /dBm	ΔP /dB	$\bar{\lambda}$ /nm	η /(%)
980	(a)	96/90	125/0	0	7.66	0.6	1583.82	6.48
	(b)	30/70	80/0	104/20	9.68	0.4	1587.24	10.32
1480	(a)	96/90	186/0	0	12.92	1.17	1585.60	21.76
	(b)	30/70	80/0	120.7/20	14	0.46	1584.15	27.91

result shows that a high performance L-band Er-SFS (with simultaneously high output power, low ripple) could be realized by our novel structure and 1480 nm pump is the best one, which is thus accepted in the following discussion.

The P_{total} and L_{total} of our Er-SFS, as the length of EDF1, L_1, increases for various lengths of EDF2, L_2, are shown in Fig. 4, where the pumping ratio, $P_1 : P_3$ is fixed at 7 : 2. It should be noted that all the set of parameters shown in the Fig. 4 could provide less than 1 dB ΔP. Therefore, we don't show the effect on the spectrum ripple and transmission bandwidth similar to the results shown in Fig. 3 and this decision of scanning parameters will be used in the following. From Fig. 4(a), it is obvious that there is a peak P_{total} for each curve and this peak P_{total} increases with the increase of L_2. In addition, the peak point moves slowly toward the increase of L_1, especially for the case ranging from 96 m to 110 m, where L_1 is around 35 m. It can be seen from Fig. 4 (b) that L_{total} of each curve decreases drastically with the increase of L_1 when L_1 is less than 50 m. Furthermore, all L_{total} of the same L_1 increase with the increase of L_2. As discussed above, the case of 110 m L_2 and 35 m L_1 can give relatively large P_{total} and save the corresponding L_{total}. Therefore, 110 m L_2 is investigated in the following discussion.

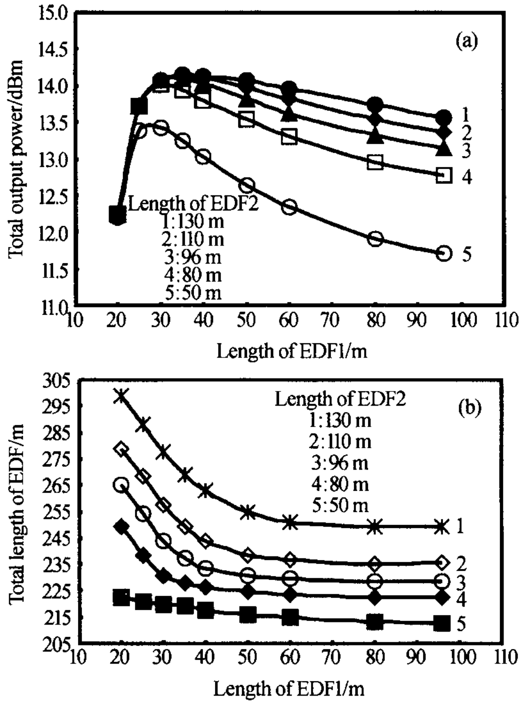


Fig. 4 Total output power of Er-SFS and total length of EDF, as the length of EDF1 increases for various lengths of EDF2 when the pumping ratio ($P_1 : P_3$) is fixed at 7 : 2

Fig. 5 shows the total output power of our Er-SFS and the total length of EDF, as the length of EDF1 increases for various pumping ratio, $P_1 : P_3$, where the length of EDF2 is fixed at 110 m. The results are similar to the ones shown in Fig. 4. As shown in Fig. 5 (a), it is obvious that the peak P_{total} increases with the decrease of the pumping ratio. In addition, the peak point is almost same around 35 m L_1. From Fig. 5 (b), one can see that L_{total} of each curve decreases drastically with the increase of L_1 when L_1 is less than 50 m. Furthermore, all L_{total} of the same L_1 increase with the decrease of the pumping ratio. Note that 1 : 1 pump coupler is easier to achieve than the others. Therefore, 110 m L_2 and 1 : 1-pump coupler are considered in our final design to give relatively large P_{total}. In order to save the total cost of our Er-SFS, the L_{total} should be shorten at least 20 m, as compared to the total cost of the structure introduced by Lee.

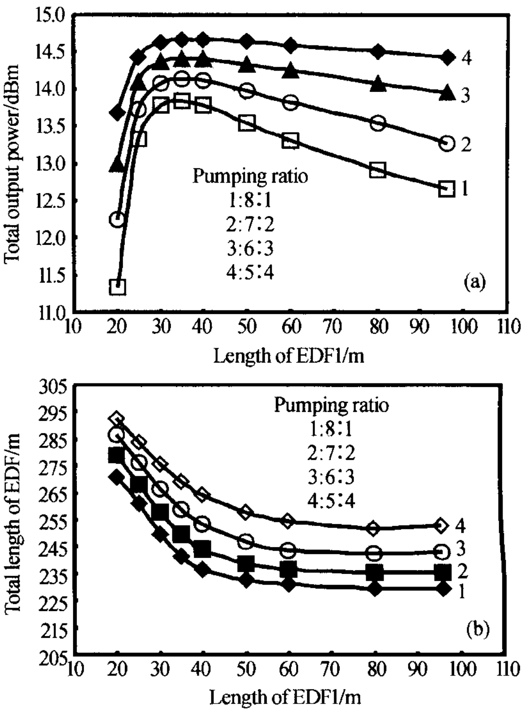


Fig. 5 Total output power of Er-SFS and total length of EDF, as length of EDF1 increases for various pumping ratio when the length of EDF2 is fixed at 110 m

Fig. 6 shows the spectrum of our Er-SFS with a good set of optimal parameters to provide high output power, low spectrum ripple and low cost simultaneously as compared to the former structure where $P_1 : P_2$ is 1 : 1, L_1 is 80 m, L_2 is 110 m, L_3 is 68.7 m, P_{total} is 14.68 dBm, η is 32.64%, $\bar{\lambda}$ is 1583.32 nm, the power density ranging from 1570 nm to 1598 nm is larger than −1.52 dBm/nm and ΔP is 0.6 dB.

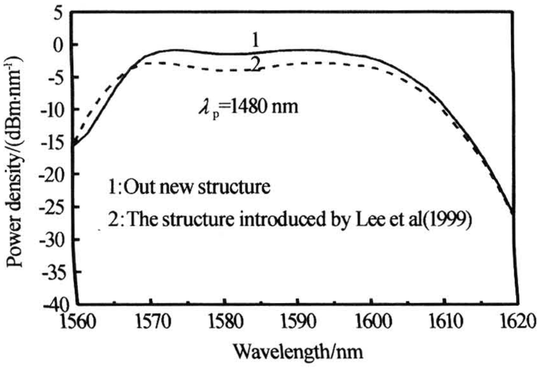


Fig. 6 Spectra of two different L-band Er-SFSs

3 Conclusion

In summary, a new three-stage L-band Er-SFS is proposed, which combines the advantages of both double-pass pumping and single-pass backward pumping. The characteristics of the present L-band Er-SFS influenced by the optical parameters including the length of each EDF section, the pump wavelength and the pumping ratio is numerically studied based on the Giles model. Finally, a set of optimal parameters which can save 23. 3 m EDF, improve 0. 57 dB ΔP and enhance 1. 76 dB P_{total} is obtained, where the pumping ratio is 1 ∶ 1 and the pump wavelength is 1480 nm. Note that the present structure of L-band Er-SFS could be optimized further by using e. g. a genetic algorithm to achieve a better performance.

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新型三段高性能的长波段掺铒光纤超荧光光源的研究

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摘 要 提出了一种第一段无泵浦、第二段前向泵浦和第三段后向泵浦的三段级联掺铒光纤超荧光光纤光源的新结构.数值分析了泵浦光波长、铒光纤长度以及泵浦比例对新结构性能的影响.结果表明可以找到一组适合制作成本低廉、输出功率高、谱平坦的长波段掺铒光纤超荧光光源.

关键词 掺铒光纤;三段;超荧光光纤光源;长波段

Qiang Zexuan was born in March, 1975. He received his Ph. D. degree in Optical Engineering from Zhejiang University. He now works at the Institute of Optical Communication Engineering, Nanjing University. His research interests are in the area of optical fiber amplifiers and fiber sensors.