A pump power insensitive high stability L-band erbium-doped superfluorescent fibre source

This content has been downloaded from IOPscience. Please scroll down to see the full text.
(http://iopscience.iop.org/1464-4258/7/4/005)

View the table of contents for this issue, or go to the journal homepage for more

Download details:

IP Address: 59.77.43.191
This content was downloaded on 12/07/2015 at 12:45

Please note that terms and conditions apply.
A pump power insensitive high stability L-band erbium-doped superfluorescent fibre source

Wencai Huang¹, Xiulin Wang², Zhiping Cai¹, Huiying Xu¹ and Chenchun Ye¹

1 Department of Electronics Engineering, Xiamen University, Xiamen, 361005, People’s Republic of China
2 Department of Computational Science and Applied Physics, Jimei University, Xiamen, 361021, People’s Republic of China

Received 7 November 2004, accepted for publication 25 January 2005
Published 18 February 2005
Online at stacks.iop.org/JOptA/7/179

Abstract

A simple one-stage configuration for a high stability L-band (1565–1605 nm) erbium-doped superfluorescent fibre source (SFS) is designed and investigated for the first time. The SFS is realized in a section of erbium-doped fibre (EDF) with a double-pass bi-directional pump configuration. With an appropriate pump ratio of forward to total pump power and fibre length, pump power insensitive mean wavelength L-band SFS operation can be obtained. Theoretical simulations indicate that the proportion of the forward pump power to the total pump power should be 0.2, in order to obtain high mean wavelength stability and high output power simultaneously. For a 19 m long EDF with a peak absorption of 27–33 dB m⁻¹ at 1530 nm, a SFS with a linewidth of 42.6 nm, an output power of 34 mW, and a high mean wavelength stability insensitive to pump power is obtained with a pump ratio of 0.2 and 82 mW total pump power. Pump power insensitive mean wavelength characteristics are attributable to the bi-directional pumping configuration and the use of a power splitter which ensures simultaneous variations of forward and backward pump power.

Keywords: superfluorescent fibre source, amplified spontaneous emission, erbium-doped fibre, double-pass bi-directional pumping

1. Introduction

Broadband optical sources with short coherence length, low spectral ripples, and high spectral intensity have been a topic of continuing research because of their wide range of applications, from gyroscopic sensors and component testing sources to sliced spectrum sources for lower cost access networks [1, 2]. In particular, fluorescent sources using amplified spontaneous emission (ASE) from an erbium-doped fibre (EDF) have been considered to be one of the optimum candidates of choice, owing to their broad spectral range, high output power, and low splicing loss [3]. In fibre optic gyroscope (FOG) applications, it is known that the accuracy of rotation detection of the FOG is determined by the stability of the scale factor, which depends on the mean wavelength stability of its light source [1]. The mean wavelength \( \lambda \) is defined as

\[
\lambda = \frac{\sum_{i=1}^{n} p(\lambda_i) + \lambda_i}{\sum_{i=1}^{n} p(\lambda_i)} \tag{1}
\]

where \( p(\lambda_i) \) is the emission spectrum of the light source. In addition, broad bandwidth and high output power are the other two desirable characteristics of the light source since a broad bandwidth in a superfluorescent fibre source (SFS) implies that a higher value of SNR would be obtained for the FOG. Previous researchers note that the double-pass backward (DPB) SFS can have pump power insensitive mean wavelength operations with broader linewidth and better pump efficiencies than those in the commonly adopted single-pass backward (SPB) configuration [4]. Bao et al used a bi-directional pump configuration to adjust the population distribution along the
1530 nm, a mode field radius of 5 µm, a cut-off wavelength 21 m, a mode field radius of 5 µm, a cut-off wavelength 19 m, a mode field radius of 5 µm, a cut-off wavelength 17 m, a mode field radius of 5 µm, a cut-off wavelength 15 m, a mode field radius of 5 µm, a cut-off wavelength

 fibre length; then a flattening broadband spectrum with high stability was obtained [5]. In 2002, Zatta et al reported another ultrastable two-stage SFS for FOG [6]; not only can the linewidth and output power be optimized, but also the remaining intrinsic instability of the EDF with temperature can be minimized by adjusting both the length and pump ratio to achieve an ultrastable SFS. However, all of the high stability SFSs reported so far were restricted to the C band. Although they have the potential for a flatter spectrum, there are no reports on a high stability L-band SFS because both theoretical and experimental results show that it cannot have pump power insensitive mean wavelength operation with a single laser pump [1, 7].

In this paper, a high stability and high power L-band erbium-doped SFS using double-pass bi-directional pump configuration is proposed. It is the first time, to the best of our knowledge, that it has been shown theoretically and experimentally that a pump power insensitive mean wavelength L-band SFS can be obtained by means of appropriately adjusting the pump ratio of forward to total pump power and fibre length. The effects of the EDF length and pump power arrangement on the characteristics of the L-band ASE spectrum, output power, and mean wavelength are investigated.

2. L-band SFS configuration

The suggested configuration of the L-band erbium-doped SFS is shown in figure 1; it consists of a section of EDF, two 1480/1590 nm wavelength division multiplexers (WDM), a 1480 nm pump laser diode (LD), a power splitter used to divide the pump power into two portions, a fibre mirror with nearly 100% reflectivity which is composed of a 3 dB broadband coupler, and an optical isolator (ISO) at the output port. Consequently, the L-band SFS is a double-pass bi-directional pump configuration. The EDF used in the numerical simulations and experiments was Lucent Technologies heavily doped LRL fibre with a peak absorption of 27–33 dB m⁻¹ at 1530 nm, a mode field radius of 5.2 µm, a cut-off wavelength of 1100–1400 nm, and a numerical aperture of 0.25.

3. Simulations and experiments

The following results and analysis are based on the commercial EDF optical amplifier simulation software [8]. The simulation software is sufficiently accurate for presenting the same results as those obtained by experiments [6, 9, 10]. According to our previous work on one-stage C + L-band ASE sources [9], when the EDF is bi-directionally pumped by two laser diodes, the longer wavelength ASE generated by the forward pump is substantially amplified by the ASE generated by the backward pump. Therefore, to obtain the L-band output, the EDF length should be selected appropriately in order to make the forward ASE move to the L band. As indicated by previous work on one-stage double-pass forward (DPF) L-band SFSs implemented with a single laser, an optimum EDF length exists for obtaining the flattest L-band SFS spectrum. Therefore, we used the commercial simulation software to depict the output spectra of the DPF L-band SFS against the EDF length with 100 mW pump power. The effective fibre mirror reflectance was selected to be 90% after correction for the insertion losses. The results are shown in figure 2. We note that for 100 mW pump power, 19 m LRL EDF is the optimal length for obtaining flat L-band SFS. Therefore, the EDF length was selected to be 19 m for simulations of the double-pass bi-directional pump L-band SFS as shown in figure 1, to optimize its output properties.

Then, the effect of the pump ratio $R_p = P_{forward}/P_{total}$ on the output spectra of the proposed L-band SFS was simulated, and the results for four representative pump ratio values ($R_p = 1.0, 0.5, 0.2$, and $0$) are shown in figure 3 for comparison. From figure 1 we can see that when $R_p = 1.0$, the SFS became a DPF configuration. Similarly, when $R_p = 0$, the SFS became a double-pass backward (DPB) configuration. The results of figure 3 show that the output spectrum of the L-band SFS is effectively improved with $R_p = 0.5$ and 0.2 as compared to $R_p = 1.0$, which shows that the double-pass bi-directional pump configuration is more effective than the DPF configuration for generating high power L-band ASE [11].

Figure 4 illustrates the calculated output power and mean wavelength as a function of the total pump power with pump ratios of 0.2, 0.5, and 1.0. Figure 4(a) shows that for different pump ratios, the output power increases almost linearly with the pump power. The pump conversion efficiency of about 50–60% with pump ratios of 0.2 and 0.5 is much higher than that with the pump ratio of 1.0. In fact, the pump conversion efficiency of 50–60% is close to the limit of quantum conversion efficiency when the total component loss is negligible. For the pump ratio of 0.2, the pump conversion efficiency is slightly higher than that for the pump ratio of 0.5.
These two pump ratios correspond to the small variations in the power splitting ratio of the power two pump ratios where the mean wavelength is independent of and the result is shown in figure 5. It is found that there exist for the total pump power fixed at 100 mW is characterized, the inset of figure 4(b).

The variation of the mean wavelength with the pump ratio for the total pump power fixed at 100 mW is characterized, and the result is shown in figure 5. It is found that there exist two pump ratios where the mean wavelength is independent of the small variations in the power splitting ratio of the power splitter. These two pump ratios correspond to $R_p = 0.2$ and 0.5; these values are consistent with the previous choice of the pump ratio. Figure 5 also implies that, between $R_p = 0.2$ and 0.7, the mean wavelength is insensitive to the small variations in the power splitting ratio. This virtue is significant because the splitting ratio may have small variations with the ambient temperature and total pump power etc. The mean wavelength is more stable with $R_p$ around 0.5 than that around 0.2. For a pump ratio of 0.5, the tolerance of the splitting ratio variations is larger. However, the pump ratio should be selected at 0.2 to have pump power independent mean wavelength operation at high pump power level as indicated in figure 4. Although two pump LDs can be used to substitute for the power splitter and the single LD, the pump power independent mean wavelength operation with $\partial \Sigma / \partial P_{\text{backward}} = 0$ does not occur for this fibre source [11]. Therefore, the proposed high stability L-band SFS with the bi-directional pump configuration should use a power splitter to divide the pump power into two portions to avoid the backward only or forward only pump power variation. Certainly, the most ideal case is that where pump power independent mean wavelength operation can be caused to exist around $R_p = 0.5$ by appropriately adjusting the EDF length and reflectivity of the fibre mirror; thus the tolerance of the splitting ratio variations is larger, which is being researched.

On the basis of the above simulations, we measured the mean wavelength and output power against the pump power with $R_p = 0.2$ and $L_{\text{EDF}} = 19 \text{ m}$. The variation of the mean wavelength with the pump ratio for the total pump power fixed at 100 mW is characterized, and the result is shown in figure 5. It is found that there exist two pump ratios where the mean wavelength is independent of the small variations in the power splitting ratio of the power splitter. These two pump ratios correspond to $R_p = 0.2$ and 0.5; these values are consistent with the previous choice of the pump ratio. Figure 5 also implies that, between $R_p = 0.2$ and 0.7, the mean wavelength is insensitive to the small variations in the power splitting ratio. This virtue is significant because the splitting ratio may have small variations with the ambient temperature and total pump power etc. The mean wavelength is more stable with $R_p$ around 0.5 than that around 0.2. For a pump ratio of 0.5, the tolerance of the splitting ratio variations is larger. However, the pump ratio should be selected at 0.2 to have pump power independent mean wavelength operation at high pump power level as indicated in figure 4. Although two pump LDs can be used to substitute for the power splitter and the single LD, the pump power independent mean wavelength operation with $\partial \Sigma / \partial P_{\text{backward}} = 0$ does not occur for this fibre source [11]. Therefore, the proposed high stability L-band SFS with the bi-directional pump configuration should use a power splitter to divide the pump power into two portions to avoid the backward only or forward only pump power variation. Certainly, the most ideal case is that where pump power independent mean wavelength operation can be caused to exist around $R_p = 0.5$ by appropriately adjusting the EDF length and reflectivity of the fibre mirror; thus the tolerance of the splitting ratio variations is larger, which is being researched.

On the basis of the above simulations, we measured the mean wavelength and output power against the pump power with $R_p = 0.2$ and $L_{\text{EDF}} = 19 \text{ m}$. The variation of the mean wavelength with the pump ratio for the total pump power fixed at 100 mW is characterized, and the result is shown in figure 5. It is found that there exist two pump ratios where the mean wavelength is independent of the small variations in the power splitting ratio of the power splitter. These two pump ratios correspond to $R_p = 0.2$ and 0.5; these values are consistent with the previous choice of the pump ratio. Figure 5 also implies that, between $R_p = 0.2$ and 0.7, the mean wavelength is insensitive to the small variations in the power splitting ratio. This virtue is significant because the splitting ratio may have small variations with the ambient temperature and total pump power etc. The mean wavelength is more stable with $R_p$ around 0.5 than that around 0.2. For a pump ratio of 0.5, the tolerance of the splitting ratio variations is larger. However, the pump ratio should be selected at 0.2 to have pump power independent mean wavelength operation at high pump power level as indicated in figure 4. Although two pump LDs can be used to substitute for the power splitter and the single LD, the pump power independent mean wavelength operation with $\partial \Sigma / \partial P_{\text{backward}} = 0$ does not occur for this fibre source [11]. Therefore, the proposed high stability L-band SFS with the bi-directional pump configuration should use a power splitter to divide the pump power into two portions to avoid the backward only or forward only pump power variation. Certainly, the most ideal case is that where pump power independent mean wavelength operation can be caused to exist around $R_p = 0.5$ by appropriately adjusting the EDF length and reflectivity of the fibre mirror; thus the tolerance of the splitting ratio variations is larger, which is being researched.

On the basis of the above simulations, we measured the mean wavelength and output power against the pump power with $R_p = 0.2$ and $L_{\text{EDF}} = 19 \text{ m}$. The variation of the mean wavelength with the pump ratio for the total pump power fixed at 100 mW is characterized, and the result is shown in figure 5. It is found that there exist two pump ratios where the mean wavelength is independent of the small variations in the power splitting ratio of the power splitter. These two pump ratios correspond to $R_p = 0.2$ and 0.5; these values are consistent with the previous choice of the pump ratio. Figure 5 also implies that, between $R_p = 0.2$ and 0.7, the mean wavelength is insensitive to the small variations in the power splitting ratio. This virtue is significant because the splitting ratio may have small variations with the ambient temperature and total pump power etc. The mean wavelength is more stable with $R_p$ around 0.5 than that around 0.2. For a pump ratio of 0.5, the tolerance of the splitting ratio variations is larger. However, the pump ratio should be selected at 0.2 to have pump power independent mean wavelength operation at high pump power level as indicated in figure 4. Although two pump LDs can be used to substitute for the power splitter and the single LD, the pump power independent mean wavelength operation with $\partial \Sigma / \partial P_{\text{backward}} = 0$ does not occur for this fibre source [11]. Therefore, the proposed high stability L-band SFS with the bi-directional pump configuration should use a power splitter to divide the pump power into two portions to avoid the backward only or forward only pump power variation. Certainly, the most ideal case is that where pump power independent mean wavelength operation can be caused to exist around $R_p = 0.5$ by appropriately adjusting the EDF length and reflectivity of the fibre mirror; thus the tolerance of the splitting ratio variations is larger, which is being researched.

On the basis of the above simulations, we measured the mean wavelength and output power against the pump power with $R_p = 0.2$ and $L_{\text{EDF}} = 19 \text{ m}$. The variation of the mean wavelength with the pump ratio for the total pump power fixed at 100 mW is characterized, and the result is shown in figure 5. It is found that there exist two pump ratios where the mean wavelength is independent of the small variations in the power splitting ratio of the power splitter. These two pump ratios correspond to $R_p = 0.2$ and 0.5; these values are consistent with the previous choice of the pump ratio. Figure 5 also implies that, between $R_p = 0.2$ and 0.7, the mean wavelength is insensitive to the small variations in the power splitting ratio. This virtue is significant because the splitting ratio may have small variations with the ambient temperature and total pump power etc. The mean wavelength is more stable with $R_p$ around 0.5 than that around 0.2. For a pump ratio of 0.5, the tolerance of the splitting ratio variations is larger. However, the pump ratio should be selected at 0.2 to have pump power independent mean wavelength operation at high pump power level as indicated in figure 4. Although two pump LDs can be used to substitute for the power splitter and the single LD, the pump power independent mean wavelength operation with $\partial \Sigma / \partial P_{\text{backward}} = 0$ does not occur for this fibre source [11]. Therefore, the proposed high stability L-band SFS with the bi-directional pump configuration should use a power splitter to divide the pump power into two portions to avoid the backward only or forward only pump power variation. Certainly, the most ideal case is that where pump power independent mean wavelength operation can be caused to exist around $R_p = 0.5$ by appropriately adjusting the EDF length and reflectivity of the fibre mirror; thus the tolerance of the splitting ratio variations is larger, which is being researched.

On the basis of the above simulations, we measured the mean wavelength and output power against the pump power with $R_p = 0.2$ and $L_{\text{EDF}} = 19 \text{ m}$. The variation of the mean wavelength with the pump ratio for the total pump power fixed at 100 mW is characterized, and the result is shown in figure 5. It is found that there exist two pump ratios where the mean wavelength is independent of the small variations in the power splitting ratio of the power splitter. These two pump ratios correspond to $R_p = 0.2$ and 0.5; these values are consistent with the previous choice of the pump ratio. Figure 5 also implies that, between $R_p = 0.2$ and 0.7, the mean wavelength is insensitive to the small variations in the power splitting ratio. This virtue is significant because the splitting ratio may have small variations with the ambient temperature and total pump power etc. The mean wavelength is more stable with $R_p$ around 0.5 than that around 0.2. For a pump ratio of 0.5, the tolerance of the splitting ratio variations is larger. However, the pump ratio should be selected at 0.2 to have pump power independent mean wavelength operation at high pump power level as indicated in figure 4. Although two pump LDs can be used to substitute for the power splitter and the single LD, the pump power independent mean wavelength operation with $\partial \Sigma / \partial P_{\text{backward}} = 0$ does not occur for this fibre source [11]. Therefore, the proposed high stability L-band SFS with the bi-directional pump configuration should use a power splitter to divide the pump power into two portions to avoid the backward only or forward only pump power variation. Certainly, the most ideal case is that where pump power independent mean wavelength operation can be caused to exist around $R_p = 0.5$ by appropriately adjusting the EDF length and reflectivity of the fibre mirror; thus the tolerance of the splitting ratio variations is larger, which is being researched.
wavelength of the spectrum is computed from equation (1). The experimental results are in good agreement with the simulation. The pump power independent mean wavelength operation, i.e. ∂λ/∂P_{total} = 0, was observed when the pump power was 82 mW. In this case, the output power and linewidth were measured as 34 mW and 42.6 nm respectively. Mean wavelength and output power discrepancies between the experiment and simulation can be attributed primarily to about 1 dB total component loss.

4. Conclusion

In conclusion, we have characterized, for the first time to our knowledge, an L-band SFS with high mean wavelength stability and high output power. The simulation results indicate that its mean wavelength can be independent of the pump power and pump ratio when the length of the EDF and pump ratio are appropriately chosen. The L-band SFS with pump power insensitive mean wavelength was achieved with a linewidth of 42.6 nm and output power of 34 mW. Pump power insensitive mean wavelength characteristics are attributable to the bi-directional pumping. Simultaneous variations of the forward and backward pump power were obtained by using a single laser diode and a power splitter. The advantages of the proposed L-band SFS are high mean wavelength stability, broad linewidth, and high output power, which means that it could play an important role in a navigation-grade FOG.

Acknowledgments

This work was supported by the Fujian Provincial Key Laboratory of Photonic Technology under Grant No FP0408 and the National Science Foundation of Fujian Province under Grant No A0440009.

References

[8] OASIX v3.0: Lucent Technologies erbium doped fiber devices simulation software