High pumping-efficiency and wideband L-band erbium-doped fiber ASE source using two-stage double-pass backward pumping configuration

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ABSTRACT

We present a wideband and high pumping-efficiency L-band erbium-doped fiber (EDF) amplified spontaneous emission (ASE) source using a two-stage double pass backward (DPB) pumping configuration.DPB configuration has been proved to have a high pumping-efficiency. In this paper we use a two-stage DPB pumping configuration to generate a stable L-band ASE source for the first time. The source consists of two sections of EDF, a 1480nm pumping laser diode (LD) which is divided into two portions to pump two sections of EDF separately. By using a power splitter, the pumping power of two stages can be adjusted proportionally. The effects of EDF length and pump power arrangement on the output characteristics of L-band ASE spectrum, output power and mean wavelength are theoretically investigated. The results show that the pumping-conversion efficiency and the linewidth can be improved significantly by optimizing the fiber length ratio and pump ratio of the two-stage DPB configuration. Based on former work, the total fiber length is chosen at 19m in this paper. With the total fiber length fixed, the proposed source has a high pumping efficiency of 53%, an output power of 111mW, and a broadening linewidth of 49nm with the mean wavelength at 1580.18nm under the optimizing fiber ratio of 0.842 and pump power ratio of 0.5.

Keywords: Amplified spontaneous-emission (ASE), erbium-doped fiber (EDF), superfluorescent fiber source (SFS), L-band.

1. INTRODUCTION

The erbium-doped fiber (EDF) based ASE sources have been applied in various areas such as a light source for fiber optic gyroscopes (FOGs), component testing sources and spectrum sliced dense wavelength-division-multiplexing (DWDM) systems [1-3] because they can simultaneously offer broad spectral linewidth, high output power and excellent mean wavelength stability to satisfy application requirements. In the past few years a lot of work have been done on conventional wavelength band (C-band) EDF ASE source and the double-pass backward(DPB) configuration has been proved to offer the highest output power, higher mean wavelength stability and broader linewidth for the C-band ASE sources[4]. Recently, more and more researchers are focused on long wavelength band (L-band, 1560nm-1610nm) erbium-doped ASE source for the expansion of the fiber optical communication window [5-8]. In [6], Tsai et al found that the double-pass forward (DPF) configuration is a better choice to implement a single-laser pumped

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L-band ASE source. It's also proved in that paper that it's hard to realize L-band ASE by using single-laser pumped double-pass backward (DPB) configuration. We proposed a stable L-band ASE source using double-pass bi-directional pumped configuration [9] in 2005, but the linewidth is also limited to 43nm. In [10] we proposed a single pumped L-band ASE source by using an additional un-pumped fiber between the wavelength division multiplexing coupler and the isolator in the single stage DPB configuration. Stable mean wavelength was attained in that simple configuration and the linewidth achieved 49nm, but the conversion efficiency is only about 25%. Therefore, it is still necessary to do researches on high efficiency L-band ASE source with larger linewidth.

In this paper, we propose a wideband and high pumping-efficiency L-band EDF ASE source. The configuration is based on the conventional DPB configuration, containing two sections of EDF and a power splitter to divide the pump power into two portions. The effects of EDF length and pump power arrangement on the output characteristics of L-band ASE spectrum, output power and mean wavelength are theoretically investigated. The results show that the pumping-conversion efficiency and the linewidth can be improved significantly by optimizing the fiber length ratio and pump ratio of the two-stage DPB configuration.

2. Proposed two-stage DPB L-band ASE source configuration

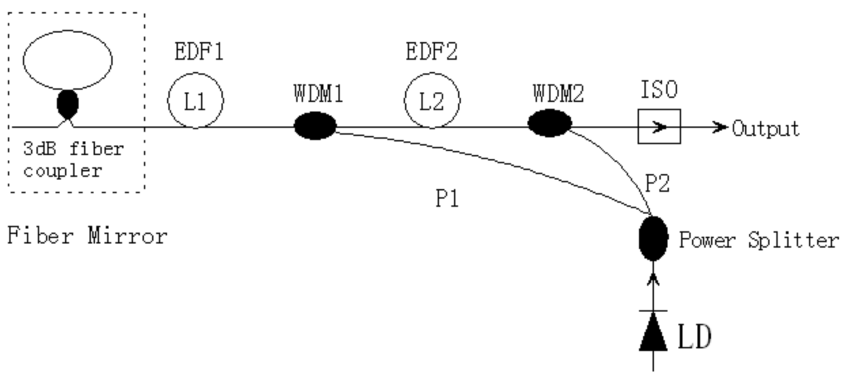

Fig.1. Proposed two-stage DPB L-band ASE source

The proposed configuration is shown in Fig.1. The source consists of two sections of erbium-doped fiber (EDF), two 1480/1590 nm wavelength division multiplexers (WDM), one 1480 nm pump laser diode (LD), a power splitter used to divide the pumper into two portions, one FLM (fiber loop mirror) used to reflect the ASE light to form a double-pass configuration, and an optical isolator (ISO) at the output port. In this configuration, both EDF1 and EDF2 are backward pumped by the LD through the 1480/1590 nm WDM. We defined the total length of EDF as L=L1+L2, where L1 and L2 refer to the first stage (EDF1) and the second stage (EDF2) lengths, respectively. The fiber length ratio of the EDF1 length to the total fiber length is defined as R_L=L1/L. Similarly, the pump ratio is defined as the forward pump power to the total pump power, Rp=P1/P_{total}. The EDF used in the simulation is offered by Lucent which has peak absorption of 27-33 dB/m at 1530 nm, a mode field diameter of 5.2um, a cut-off wavelength of 1100-1400 nm, and a numerical aperture of 0.25.

It has been proved that the L-band ASE is realized through a longer EDF. The principle of L-band ASE source proposed in this paper can be explained as follow: 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 spectrum can be obtained in the end of the second EDF with an appropriate fiber length arrangement. The second portion power P2 together with EDF2 work as an amplifier to amplify the L-band spectrum.

3. RESULTS AND DISCUSSIONS

In order to get the optimal parameters of this configuration and gain the best output properties, the commercial amplifier simulation package OASIX [11] is used to perform the simulations of the proposed configuration in this paper. It is proved that the results obtained by this software are accurate to those obtained from the experiments [9, 12-13].

Previous simulations and experiments have indicated that the output ASE spectrum largely depends on the total fiber length used. Our first task is to find the proper total fiber length to get a flat L-band spectrum output. During simulations, the effective reflectivity of the FLM is selected to be 90% and the total pump power is 100mW. The simulation results show that the optimal total EDF length to generate flat L-band spectrum, which is according to the maximal value of linewidth, is approximately 19m. This result is shown in Fig.2. Therefore, for the following simulations the total EDF length is fixed at 19m for L-band ASE spectrum.

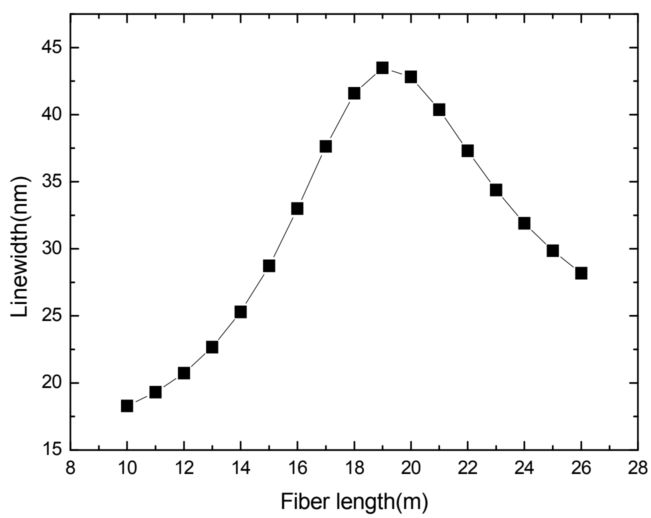

Fig.2. Output linewidth versus total fiber length

Then, the effects of the fiber length ratio R_L on the output spectrum have been investigated. Fig.3 shows the output spectra for the configuration of different R_L with a pump power of 100mW and pumping ratio of 0.5. Curves (a) to (h) correspond to R_L=0.210, 0.316, 0.421, 0.526, 0.632, 0.737, 0.842 and 0.947 respectively. The variation of the output linewidth, the mean wavelength and output power versus R_L are illustrated in Fig.4. As present in Fig.3 and Fig.4, when R_L is lower than 0.6, R_L has little influence on the L-band spectral shape. The mean wavelength and the spectral linewidth remain almost unchanged except a gradually increase of the output power. With R_L further increasing larger than 0.6, the spectral intensity increases significantly in the short-wavelength range and decreases in the long-wavelength range gradually. The mean wavelength shifts toward shorter wavelength and the linewidth increases to the maximum value when R_L is adjusted to around 0.842. If R_L is larger than 0.85, the ASE spectrum is not L-band fiber soured any more, the output spectrum shifts to C-band mostly with a decreasing of the output power and the linewidth.

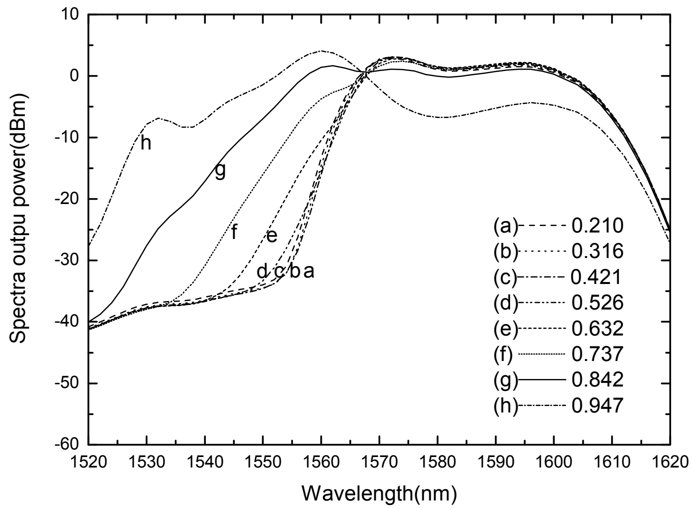

Fig.3. Simulated output ASE spectra with different R_L when Pp=100mW, Rp=0.5

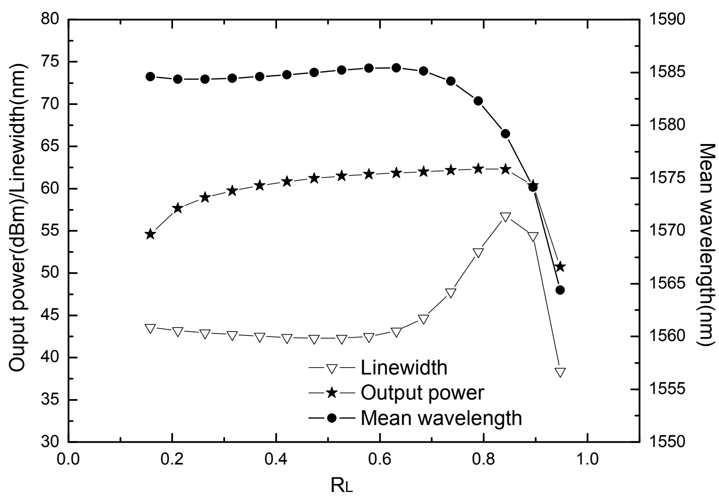

Fig.4. Linewidth, output power and mean wavelength versus R_L when Pp=100mW, Rp=0.5

The reason for the spectral characteristics on R_L shown in Fig.3 can be illustrated as the following. For the two-stage double-pass backward configuration present in this paper, it can be considered as an L-band ASE seed source amplified by a backward pumping erbium doped amplifier. Therefore, the output of the ASE source includes two components: the amplified L-band seed light and the residual forward ASE of EDF2 in the output port. The wavelength ranges and the proportion of these two components determine the spectral shape and wavelength range of the ASE source. When R_L is very low, EDF2 is long enough to absorb most of the pumping power in the second stage. So few residual ASE of EDF2 are left, and the output spectra is a conventional L-band ASE spectrum. With the increase of R_L, the residual forward ASE of EDF2 has gradually became considerable to compete with the amplified L-band seed light. Because the wavelength range of the ASE of EDF2 is always in C-band, the combination of the amplified L-band seed light and the residual ASE of EDF2 results in the L-band output broadening to the edge of C-band, thus a broader linewidth is obtained. The results show that R_L=0.842 is the optimal fiber length ratio to achieve a flat L-band spectrum with maximal linewidth, under the pump power of 100mW. When R_L is very high, the length of EDF2 is very small. Under this situation there is much more residual forward ASE of EDF2, thus the combination of these two parts leads to curve (h) in Fig.3.

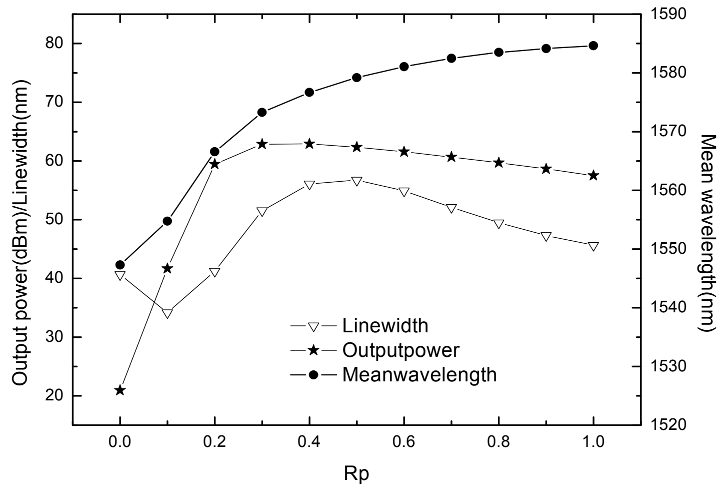

Fig.5. Linewidth, output power and mean wavelength versus R_p when Pp=100mW, R_L=0.842

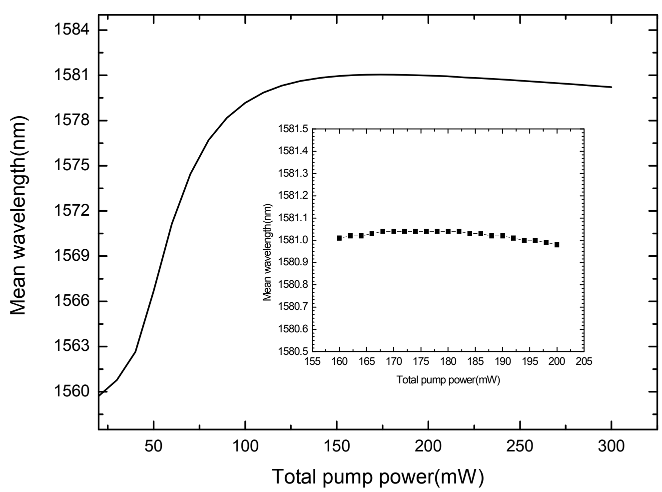

Fig.6. Mean wavelength versus total pump power with R_L=0.842, Rp=0.5

The effects of pump ratio Rp on the output characteristics for the suggested L-band ASE source are also investigated. Fig.5 illustrates the linewidth, output power and the mean wavelength against Rp with the total pump power of 100mW and fiber length ratio of 0.842. When Rp=0, the ASE source becomes a single pumping backward configuration, which generates a C-band spectrum. When Rp=1, it becomes the configuration we discussed in ref. [10], which generates an L-band spectrum with total pump power of 100mW and fiber length ratio of 0.842. Output of ASE spectra simply includes two components when two-stage double backward pumping is using synchronously: the amplified L-band seed light coming into WDM2 and the residual ASE of EDF2 in the output port. The L-band ASE coming into WDM2 is amplified by the C-band ASE generated by the second backward pump. Therefore, the output spectrum shifts gradually from C-band to L-band with the increase of the first pumping power. It has been found that there is an optimal Rp to obtain a broadest linewidth of L-bans ASE source. The largest linewidth of 57nm is obtained when Rp=0.5.

From the above results we learn that R_L=0.842 and Rp=0.5 are the optimal parameters for this two-stage double backward pumping configuration. Then the effect of the total pump power on the mean wavelength is investigated. Fig.6 shows the calculated mean wavelength as a function of the total pump power with fiber length ratio R_L of 0.842 and pump ratio Rp of 0.5. The inset of Fig.6 shows the effect of total pump power in the range of 160-200mW to the mean wavelength in detail. It shows clearly that the mean wavelength increases with the increase of total pump power first, after reaches a maximum value it begins to decrease with the increase of the total pump power. Therefore, the mean wavelength insensitive to the pump power operation is able to exist for this configuration within a large pump power range from 168-182mW.

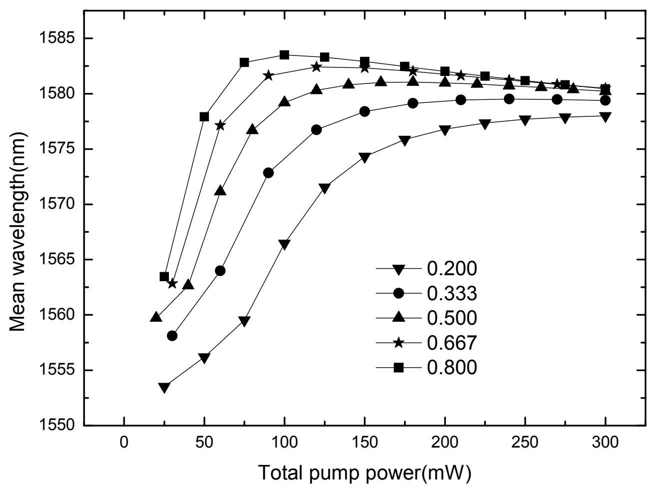

Fig.7. Calculated mean wavelength versus pump power when R_L=0.842

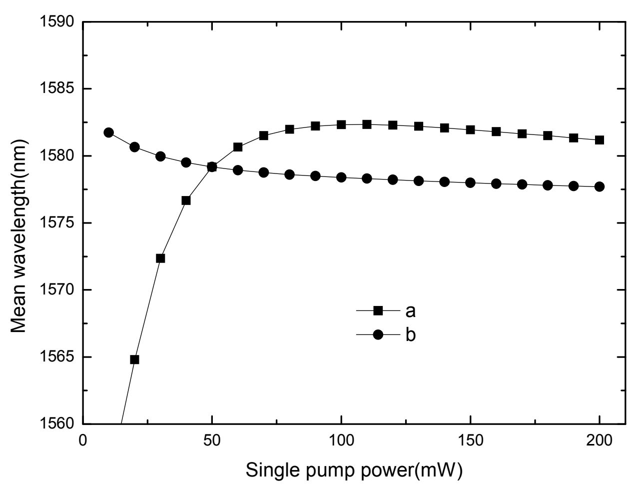

Fig.8. Mean wavelength versus single pump power: (a) mean wavelength versus P1 with P2=50mW, (b) mean wavelength versus P2 with P1=50mW

Further researches prove that mean wavelength insensitive to pump power operation can also be obtained for other pump ratios. Fig.7 shows the effect of total pump power to the mean wavelength with pump ratios of 0.200, 0.333, 0.500, 0.667, and 0.800 respectively. It's shown clearly in Fig.7 that the mean wavelength insensitive to pump operation can be obtained when the power ratio is larger than 0.200. With a larger pump ratio, the mean wavelength insensitive operation appears with a small total pump power; while it needs a very large total pump to reach this operation when the pump ratio is small. Therefore, the mean wavelength insensitive to the pump power operation is tunable by choosing different pump ratios. This characteristic will decrease the requirement to the power splitter.

The reason why this configuration allows mean wavelength insensitive to total pump power is also investigated. We investigate the effects to the mean wavelength brought by the change of P1 and P2 separately. First P2 is fixed at 50mW, and the variation of mean wavelength with the increase of P1 is shown in curve (a), Fig.8. With the increase of P1, the mean wavelength increases first and begins to decrease after reach a maximum value. When P1 is fixed at 50mW, the variation of mean wavelength with the increase of P2 is shown in curve (b), Fig.8. It's obvious that the mean wavelength keeps decreasing with the increase of P2. When we choose a proper pump ratio and let P1 and P2 increase at the same time, the effect to the mean wavelength brought by the increase of P1 could offset the effect brought by the increase of P2. Therefore, with a proper pump ratio the mean wavelength will not change with pump power within a certain pump power range. So, the mean wavelength insensitive to the total pump power operation $\partial\bar{\lambda}_m / \partial P = 0$ can be achieved in a large range pump ratio. In the experiment the proposed configuration has an output power of 111mW and a broadening linewidth of 49nm with the mean wavelength at 1580.18nm under the optimizing fiber ratio of 0.842 and pump power ratio of 0.5. The experimental results show good agreement with the simulations, with quantitative discrepancies attributable primarily to splice loss and insertion loss in WDM coupler etc.

4. CONCLUSIONS

We have presented a high pumping efficiency and wideband L-band ASE source by using a two-stage double backward pumping configuration the first time. The results show that such configuration has a high pumping efficiency as well as a broader linewidth with the optimized structural parameters. By choosing the total fiber length of 19m, the fiber length ratio of 0.842 and the pump ratio of 0.5, an output power of 111mW and a linewidth of 49nm are obtained with a total pump power of 210mW. The proposed ASE source configuration has wide applications, such as DWDM system, FOG and fiber sensor systems and so on.

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