Simulation analysis of one-stage C+L-band erbium-doped fiber ASE source with double-pass bi-directional pumping configuration

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Received September 28, 2003

A new technique to generate a C+L-band flat amplified spontaneous emission (ASE) source in one-stage erbium-doped fiber (EDF) using bi-directional pumping configuration is analyzed. The simulation results show that the key point of obtaining flat C+L-band ASE spectrum in one-stage EDF is using a laser diode operated at 980 nm as backward pump source. ASE source with nearly 80-nm bandwidth can be obtained by means of selecting suitable fiber length and properly adjusting the ratio of forward to backward pump power.

OCIS codes: 060.2380, 060.2410, 060.2390.

Incoherent broadband optical source with low spectral ripples and high spectral intensity based on the amplified spontaneous emission (ASE) from an erbium-doped fiber (EDF) invited much attention for its various applications such as optical sensor systems, fiber optic gyroscopes and spectrum-sliced sources in wavelength division multiplexing (WDM) system[1,2]. Recently, much attention has focused on development of efficient-pumping high power broad band sources operating at both conventional and long wavelength range for the recent demand for immediate expansion of the fiber-optic communication window. Although the bandwidth of several C+L-band erbium-doped ASE sources could be up to 80 nm[3,4], however, the sources are complexity since they are both based on two stages, which generated C-band and L-band ASE independently. To increase the compact of the source, one could introduce a mechanism to generate the C-band and L-band ASE in one-stage EDF simultaneously. We have realized this idea in a one-stage EDF by using bi-direction pumping configuration, and the experimental results show that a nearly 80-nm bandwidth ASE source is easy obtained by adjusting the pumping power of the forward and backward laser diode (LD) properly[5]. The one-stage C+L-band ASE source shows better qualities compared to the double-stage configuration.

In this paper, the principle and characteristics of the one-stage ASE source are analyzed in details by simulation. The characteristics including spectrum shape, mean wavelength, and output power of a single-pass backward and double-pass forward EDF ASE sources against fiber length and pump power are investigated and compared for 980- and 1480-nm pumping, respectively. The results show that the key point of designing a one-stage C+L-band ASE source is selecting 980-nm LD as backward pump source and ASE source with nearly 80-nm bandwidth can be obtained by means of selecting suitable fiber length and properly adjusting the ratio of forward to backward pump power.

The schematic diagram of the one-stage ASE source is shown in Fig. 1. The erbium-doped fiber is pumped with a 1480- or 980-nm LD and a 980-nm LD as forward and backward pump, respectively. A broadband reflector (BBR) is used to reflect most of the backward propagating ASE into the stage. An isolator with ~ 60-dB isolation is used at the output port to avoid lasing. An ANDO6317 optical spectrum analyzer (OSA) is used to measure the output spectra.

To expatiate the principle of the one-stage C+L-band ASE configuration, we have investigated the characteristics of backward ASE and forward ASE spectra with 980- and 1480-nm LDs pump, respectively. First, we perform simulation of the single-pass backward ASE spectra with 980- or 1480-nm LD as pump source in order to insight into the distinction between them when using commercial EDF optical amplifier simulation software[6]. A piece of lucent technologies-type LRL EDF is used in the simulation. Figure 2 shows the simulation results of the single-pass backward ASE spectra against fiber length for 80-mW pump power at 980 and 1480 nm. It can be seen from Fig. 2 that for both pump wavelengths, their spectra are similar when fiber length is short. With fiber length increase, their spectra will move slightly at first and keep unchanged when the fiber length longer than a certain value. For 980-nm pump, the ASE spectrum keeps unchanged when fiber length beyond 15 m, and for 1480-nm pump, the length is about 20 m. However, their spectra shape has important distinction in long EDF length case. Though both of them have two humps, while for 980-nm pumping, the 1530-nm hump and the 1560-nm hump are nearly the same level and their spectra are similar to the forward ASE spectra in strongly pump case, which cover mostly C-band, but for 1480-nm pumping, the 1560-nm hump is much higher than the 1530-nm hump, thus the mean wavelength of its ASE

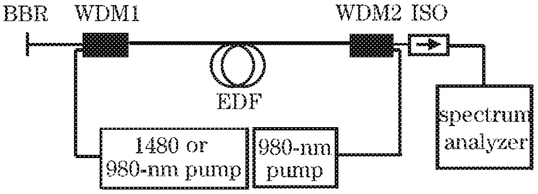

Fig. 1. Configuration of the one-stage ASE source.

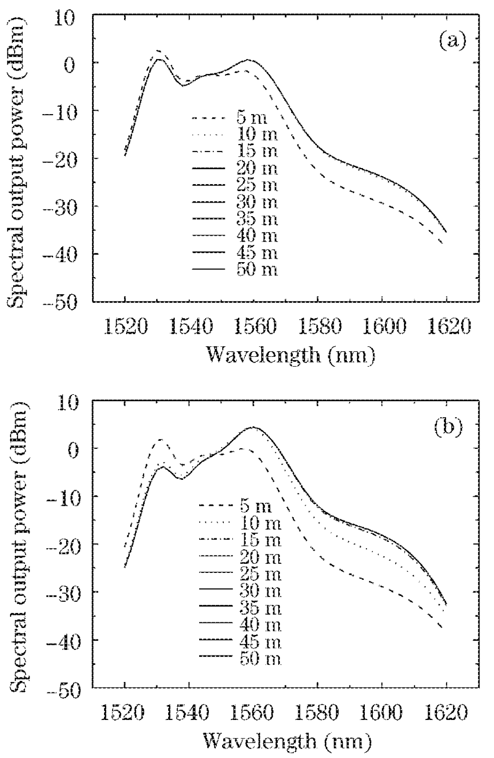

Fig. 2. Backward ASE spectra against EDF length. (a) Pumped by 980-nm LD; (b) pumped by 1480-nm LD.

spectrum is longer than in 980-nm pump. The reason for this is pump reemission that limits the inversion of the medium to a maximum of 80% for 1480-nm pumping. With less inversion, signal absorption becomes important and shifts the emission towards longer wavelengths.

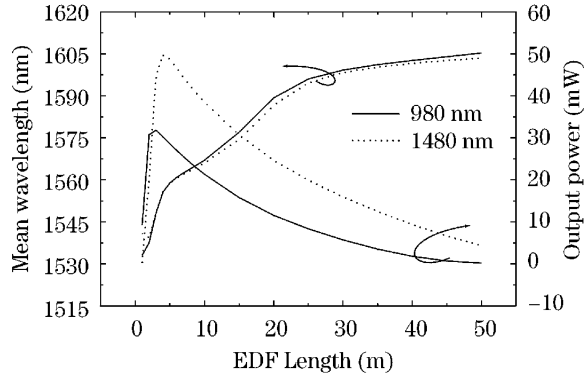

Fig. 3. Mean wavelength and output power versus fiber length for 80 mW of pump power at 980 or 1480 nm for double-pass, forward signal.

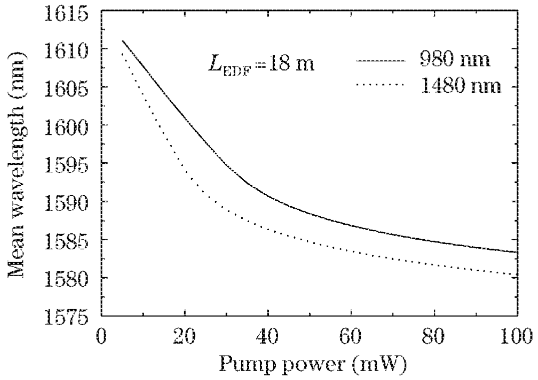

Fig. 4. Mean wavelength of double-pass forward ASE versus pump power.

As for the forward signals, a single-pass forward amplified spontaneous emission is of less interest because of its poor quantum conversion efficiency. Here, we simulate the double-pass forward configuration. The dependence of mean wavelength and total ASE power upon fiber length is shown in Fig. 3. For both pump wavelengths, the effective fiber mirror reflectance is ~ 50% after correction for the insertion losses. Figure 3 notes that, for both pump wavelengths, mean wavelength moves to long wavelength gradually with fiber length. The reason for this is as the fiber length increases, signal saturation and pump depletion produce regions of the fiber with little inversion. Such conditions favor emission at longer wavelength where the gain coefficient exceeds the absorption coefficient. Furthermore, from Fig. 3 it is note that for short fibers, the output power increases rapidly with length to maximum quantum conversion efficiency. Beyond this optimal length, the output power decreasesm gradually. The 1480-nm pump is able to produce greater power than the 980-nm pump. This advantage is mostly due to the similarity of pump and signal photon energies in the 1480-nm pump case. Figure 4 shows the dependence of the mean wavelength on pump power with the EDF length of 18 m. Such length is chosen due to the reason that for 18-m-long EDF, the mean wavelength of the double-pass forward signal has moved to long wavelength around 1580 nm. For both pump wavelength, the mean wavelength decreases with pump power. In the lower pump power region, the mean wavelength decreases more quickly than that of in the higher pump power region.

According to the above results, the principle of the one-stage C+L-band ASE configuration can be explained as follow. In the case of backward pumping (forward pump source is blocked), the ASE spectrum is composed mostly of C-band wavelength and keeps unchanged with fiber length when a 980-nm LD is used for the pump source (shown in Fig. 2(a)), while for forward pumping with 980- or 1480-nm LD (backward pump source is blocked), the ASE spectrum will move to long-wavelength when prolong the fiber length and its spectrum composed of only long wavelength components because of low average inversion level of erbium ions. When with backward and forward pumping simultaneously, the long wavelength ASE is substantially amplified while the conventional wavelength ASE is slightly reduced. Therefore, by selecting suitable fiber length and properly adjusting the ratio of forward to backward pump power, a broadband ASE source with equal power in both the conventional and long wavelength ASE could be obtained in the one-stage configuration.

Figure 5 shows the simulate C+L-band ASE output spectra using the configuration in Fig. 1. The simulation parameters are that EDF length is 18 m, backward pump power of 980-nm LD is 80 mW, forward pump power of

980-nm LD is 13 mW, or forward pump power of 1480-nm LD is 9 mW and the effective fiber mirror reflectance is 50%. As can be seen from the figure, bandwidths of the ASE spectra for both conditions are nearly 80 nm. The pump power required for the forward pump source is a little higher for 980 nm than 1480 nm due to the higher pump efficiency of the 1480-nm LD for generating the long wavelength ASE[7], as shown in Fig. 3.

It is necessary to emphasize that the requirement of EDF length is not rigorous in such a one-stage configuration. In generally, flat C+L-band ASE can be obtained within a certain fiber length range. It can be seen from Fig. 3 that the long wavelength ASE power generated by the forward pump laser decreases gradually with fiber length, but its mean wavelength increases with fiber length. Therefore, if the fiber length is slightly longer, the forward pomp power can be properly increased then the long wavelength ASE power will increase slightly and the mean wavelength will decrease in the same time (shown in Fig. 4). As a result, the long wavelength ASE will re-match the conventional ASE and a flat C+L-band ASE will be obtained again. When the fiber length is slightly shorter, we can properly decrease the forward pump power to obtain the flat C+L-band ASE. As for the forward pump laser, though the pump efficiency of 980-nm LD is relative lower than 1480-nm LD, the 980- and 1480-nm LDs are both suitable for such a configuration because it needs only very small long-wavelength ASE power to match the conventional ASE.

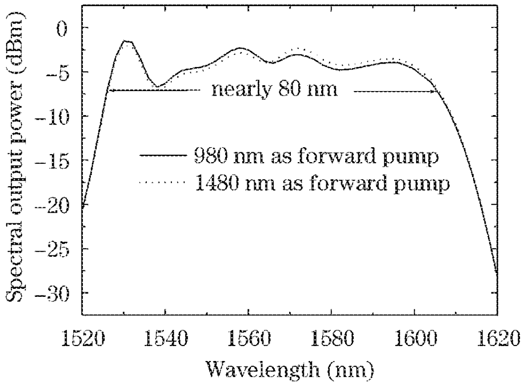

Fig. 5. Simulated ASE spectrum with flat bandwidth of nearly 80 nm.

In conclusion, we have demonstrated that, with selecting a 980-nm LD as backward pump source and another 980- or 1480-nm LD as forward pump source, flat C+L-band ASE spectrum with nearly 80-nm bandwidth could be obtained in one-stage EDF by means of selecting suitable fiber length and properly adjusting the ratio of forward to backward pump power. The flat C+L-band ASE source will play an important role in optical sensor systems and WDM system.

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