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TEMPERATURE INSENSITIVE BROAD AND FLAT GAIN C-BAND EDFA BASED ON MACRO-BENDING

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Abstract—In this paper, a new method is proposed to achieve a temperature insensitive, broad and flat gain C-band erbium-doped fiber amplifier (EDFA) with aid of macro-bending. This gain flattened C-band EDFA is demonstrated by utilizing 2.5 m macro-bent Erbium-doped fiber (EDF) at room temperature of 25°C. Further to this, it is

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shown that gain fluctuation at different temperatures is compensated in the proposed design. The EDFA performance at different temperatures is investigated for various macro-bending diameter and EDF length. The gain saturation and energy transfer from shorter wavelengths to longer wavelengths can be controlled by varying the bending radius and the length of the doped fiber, consequently, a flattened and broadened gain profile in the C-band region can be achieved. The amplifier uses a 2.5 m long EDF with 2000 ppm concentration and bending radius of 6.5 mm as a gain medium. The gain variation of the EDFA is obtained within ±0.5 dB over 35 nm bandwidth of C-band region.

1. INTRODUCTION

The tremendous growth of the Internet and data traffic has created an enormous demand for transmission bandwidth of dense wavelength-division-multiplexed (DWDM) optical communication systems [1–7]. Erbium-doped fiber amplifier (EDFA) is applied in the DWDM because of its broad-band gain region ranging from conventional band (1525 nm–1565 nm) to long-wavelength band (1565 nm–1615 nm, L-band) region [8–10]. However, output power spectral density of the C-band EDFA varies considerably with a marked peak near 1530 nm, which is not suitable for some amplitude modulation (AM) sensing applications and wavelength-division multiplexed (WDM) communication systems when the number of channels increases. The use of gain-flattened C-band EDFA is required to increase the number of channels in the DWDM systems [10–12]. Various methods were suggested in recent years, such as the use of fiber gratings [13], acousto-optic tunable filters (AOTFs) [14], tapered fiber filters [15] in the set-up as well as the use of hybrid fiber configurations [1] to achieve gain-flattened C-band EDFA. However, these methods have a trade-off between achievable bandwidth and loss. Furthermore, these methods also suffer from high cost and complexity.

Recently, macro-bent EDF is used to achieve amplification in S-band region [16]. In this paper, a gain-flattened C-band EDFA is proposed using a macro-bent EDF. This technique is able to compensate the EDFA gain spectrum to achieve a flat and broad gain characteristic based on distributed filtering using a simple and low cost method. This technique is also capable to compensate the fluctuation in operating temperatures due to proportional temperature sensitivity of absorption cross section and bending loss of the aluminosilicate EDF [17]. This new approach can be used to design a temperature insensitive EDFA for application in a real optical communication system which operates at different environments but still maintaining the gain characteristic regardless of temperature variations.

2. CONFIGURATION

The configuration of the proposed gain-flattened C-band EDFA is shown in Fig. 1, which consists of a piece of EDF, a wavelength division multiplexing (WDM) coupler, and a pump laser. An alumino-silicate host EDF with 2000 ppm erbium ion concentration is used in the setup. Alumina in this fiber is used to overcome the quenching effect for high ion concentration. A WDM coupler is used to combine the pump and input signal. Optical isolators are used to ensure unidirectional operation of the optical amplifier. Pump laser at 980 nm is used for providing sufficient pumping power The EDF is bent on an aluminum rod of 6.5 mm radius to achieve consistent macro-bending and uniform heat distribution. This bending radius values are chosen because of suitable loss profile for suppressing the L-band region [12, 18]. The rod has equally spaced threads (8 threads per cm) where each thread houses one turn of EDF to achieve consistency in the desired bending radius. Tunable laser source (TLS) is used to characterize the amplifier in conjunction with the optical spectrum analyzer (OSA).

3. RESULT AND DISCUSSION

The bending loss profile of the erbium-doped fiber (EDF) for various bending radius is firstly investigated by conducting a simple loss-test measurement. In order to isolate the bending loss, the profile is obtained by taking the difference between the loss profile of the same EDF with and without macro-bending across the desired wavelength range. A one meter EDF is used in conjunction with a tunable laser source (TLS) and optical power meter to characterize the bending loss for bending radius of 6.5 mm at wavelength region between 1530 nm and 1570 nm. The bending loss profile indicates the total distributed

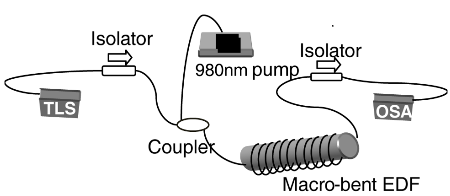

Figure 1. Configuration of the proposed gain-flattened C-band EDFA.

loss for different bending radius associated with macro-bending at different EDF lengths. This information is important when choosing the optimized bending radius to achieve sufficient suppression of the gain. Fig. 2 illustrates the bending loss profile at bending radius of 6.5 mm at different temperatures, which clearly show an exponential relationship between the bending loss and wavelength. It is also shown that the bending loss in L-band is reduced by increasing the temperature. Bending the EDF causes the guided modes to partially couple into the cladding layer, which in turn results in losses as earlier reported [9]. The bending loss has a strong spectral variation because of the proportional changes of the mode field diameter with signal wavelength. As shown in Fig. 2, the bending loss dramatically increases at wavelengths above 1550 nm. This result shows that the distributed ASE filtering can be achieved by macro bending the EDF at an optimally chosen radius.

Initially, the gain of the single pass EDFA is characterized without any macro-bending at different EDF lengths as shown in Fig. 3. The input signal power is fixed at −30 dBm and the 980 nm pump power is fixed at 200 mW. The wavelength range is chosen between 1520 nm and 1570 nm which cover the entire C-band region. To achieve a flattened gain spectrum, the unbent EDFA must operate with insufficient 980 nm pump, where the shorter wavelength ASE is absorbed by the unpumped EDF to emit at the longer wavelength. This will shift the peak gain wavelength from 1530 nm to around 1560 nm. Therefore The EDF length used must be slightly longer than the conventional C-band EDFA to allow an energy transfer from C-band to L-band taking place. This will reduce the gain peak at 1530 nm and increases the gain at longer wavelengths. As shown in Fig. 3, the optimum C-band

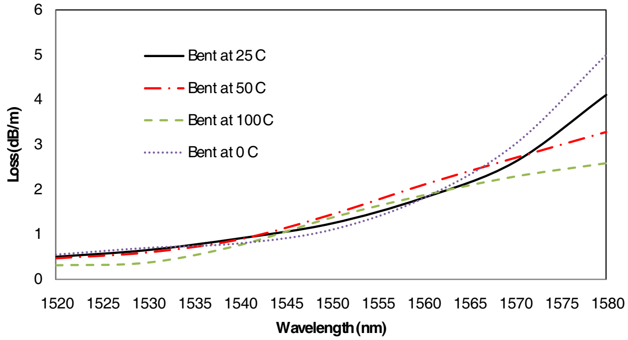

Figure 2. Loss spectrum of the bent EDF with 6.5 mm bending radius at different temperatures.

operation is successfully achieved using only one meter of this high erbium ion concentration EDF. It is also shown that for the lengths longer than 2 m gain shifts to longer wavelengths.

Figure 4 shows the gain spectrum of the C-band EDFA, which is characterized with macro-bending at different EDF lengths. In the experiment, the input signal power is fixed at -30 dBm and the 980 nm pump power is fixed at 200 mW. These lengths are chosen due to their gain shift characteristics as depicted in Fig. 3. It is important to note that using macro-bending to achieve gain flatness depend on suppression of longer wavelength gains. The macro-bending provides a higher loss at the longer wavelengths and thus flattening the gain spectrum of the proposed C-band EDFA. The combination of appropriate EDF length and bending radius, leads to flat and broad

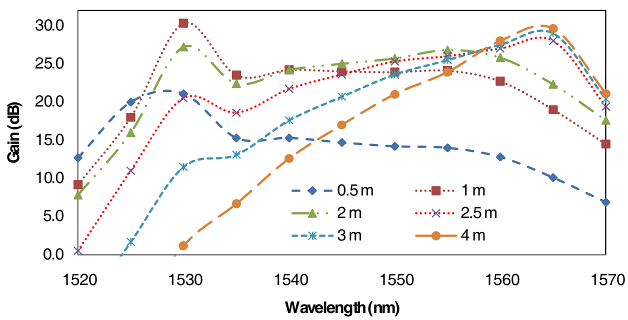

Figure 3. Gain spectrum at different EDF lengths (without macro bending).

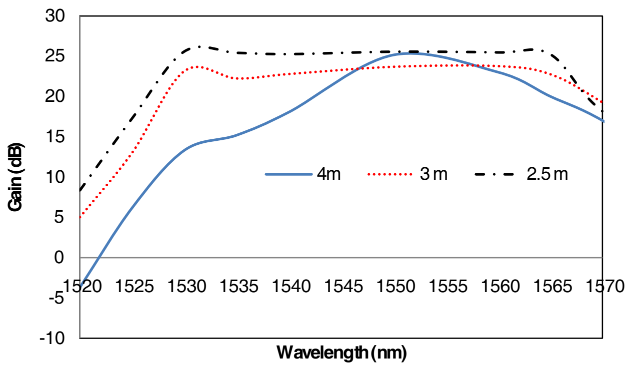

Figure 4. Gain spectrum at different EDF lengths (with macro bending).

gain profile across the C-band region. In addition, the bending loss increases proportionately with length. As shown in Fig. 4, the L band suppression for 3 and 4 m EDF exceeds the optimized value. Therefore, 2.5 m is taken as the optimized length for the proposed gain-flattened EDFA.

The macro-bending induces bending loss which is dependent on wavelength with an exponential relationship. Longer wavelengths have a higher loss compared to the shorter wavelengths. In relation to the EDFA, the macro-bending also increase the population inversion in C-band due to reduction of gain saturation effect in L-band region. Since the L-band gain cannot improve more than a limited value due to exposure bending loss, less C band photons will be absorbed by un-pumped ions to emit at higher wavelengths. This effect reduces gain saturation in L-band; in result the C-band gain increases. This increment for peak is not more than the optimized C-band EDFA (1 m) since at that level the inversion is maximum. For EDFA with bent EDF, the full inversion in shorter wavelengths take places at longer length due to limited energy transfer to longer wavelength. On the other hand, the L-band gain will reduce due to the suppression of L-band stimulated emission induced by macro-bending. The net effect of both phenomena will result in a flattened gain profile. Fig. 5 compares the gain spectrum of the EDFA with and without macro-bending at EDF length of 2.5 m.

As shown in Fig. 5, the gain spectrum is flat at wavelength region of 1530 nm to 1565 nm with the uses of 2.5 m bent EDF as the gain medium. The flat-gain profile is obtained due to the incremental gain enhancement at wavelength region shorter than 1550 nm. This

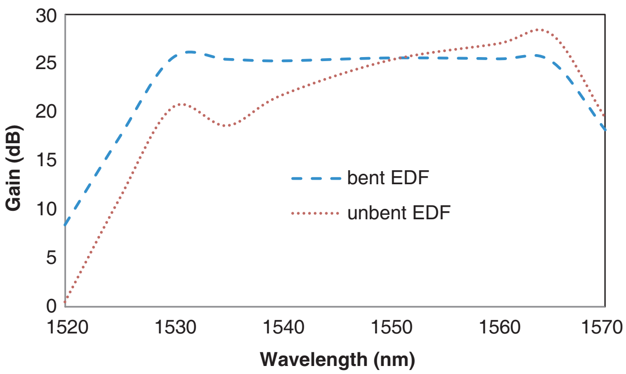

Figure 5. Gain spectrum of the EDFA with and without macro-bending at EDF length of 2.5 m.

enhancement is attributed to macro-bending effect in the EDF. The gain at longer wavelengths is also reduced due to the suppression of L-band stimulated emission induced by macro-bending. Fig. 6 compares the EDFA gain of the EDF with 1 m of un-bent EDF (considered as optimized length for C-band EDFA) and 2.5 m of macro-bent EDF (considered as optimized length for broad and flat gain C-band EDFA).

Figure 7 shows the gain spectrum of the proposed gain-flattened EDFA at various pump power. As shown in the figure, the variation in pump power does not affect the gain profile until a critical point. The gain maintains the same profile from 250 mW to 100 mW pump

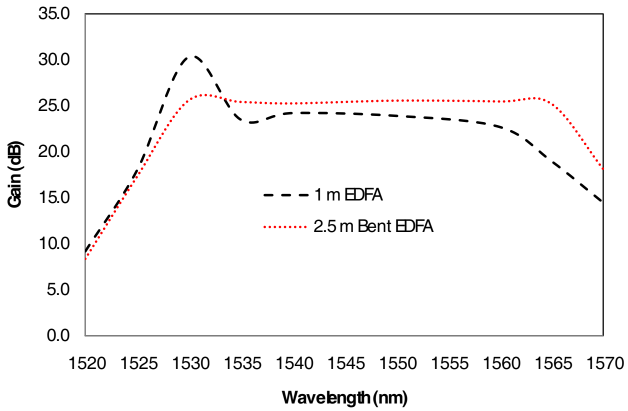

Figure 6. Comparison of gain spectrum of the proposed gain flattened EDFA with standard C-band EDFA.

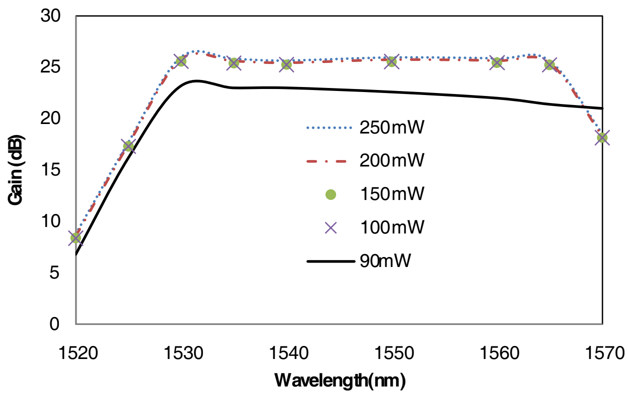

Figure 7. Gain spectrum of the proposed EDFA at different pump powers.

power. At pump powers less than 95 mW, the gain flatness is no longer observed as shown in Fig. 7 due to insufficient population inversion to flatten the gain spectrum. Fig. 8 compares the gain profile of the EDFA with macro-bent EDF at various input signal power. The input signal power is varied for 0 dBm to −30 dBm. The EDF length, bending radius and pump power are fixed at 2.5 m, 6.5 mm and 100 mW respectively. As shown in the Fig. 8, increasing the input signal power decreases the gain but improves the gain flatness as the EDFA is saturated. A gain variation within ±0.5 dB over 35 nm bandwidth in C-band region is observed for the input signal powers of −30, −20 and −10 dBm. Furthermore, at 0 dBm input signal power, a 45 nm gain bandwidth is observed.

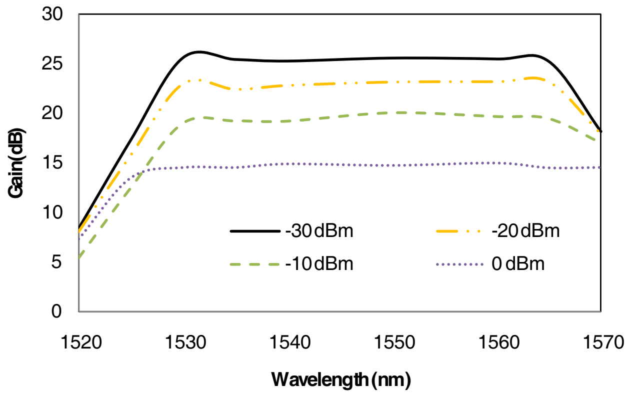

Figure 8. Gain spectrum of 2.5 m bent EDF at various input signal powers.

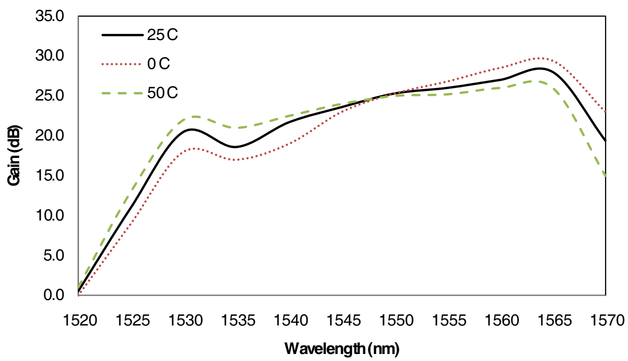

Figure 9. Gain profile of 2.5 m un-bent EDFA at different temperatures.

Figure 9 shows the gain spectrum of the EDFA without bending at different temperatures. In the experiment the EDF length is fixed at 2.5 m and the input signal and pump power are fixed at −30 dBm and 100 mW, respectively. It is found that gain of the amplifier increases at shorter wavelengths and decreases at the longer wavelengths with the increment of temperature. Comparing this result with macro-bending loss spectrum at different temperatures of Fig. 2 leads us to an interesting conclusion. Bending loss's slope with respect to wavelength follows the same behavior with gain profile at different temperatures. For example at higher temperature, gain at L-band increases while the bending loss at L-band also increases. These two effects complement each other in order to suppress the temperature sensitivity of the proposed design. This new approach can be used to design a temperature insensitive EDFA for application in a real optical communication system which operates at different environments but still maintaining the gain characteristic regardless of temperature variations.

However, this relationship does not apply to a very high temperature. Fig. 10 shows the gain spectrum of the EDFA with macro-bent EDF at various ambient temperatures under the same condition as the previous experiment of Fig. 9. The temperature in this experiment is varied from 0 to 150°C. As shown in Fig. 10, the gain spectrum is maintained within the temperature range of 0 to 100°C. However, as the temperature is increased up to 150°C, the gain at extended L-band region decreases slightly and gain at shorter wavelengths also increases.

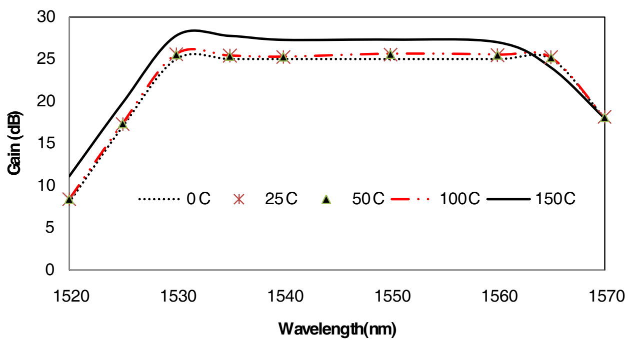

Figure 10. Gain profile of 2.5 m macro-bent EDFA at different temperatures.

4. CONCLUSION

A new approach is proposed to achieve broad and flat gain in C-band EDFA. Furthermore, the proposed design achieves temperature insensitivity over a range of temperature variation. The gain flatness is optimized when the bending radius and fiber length are 6.5 mm and 2.5 m respectively. This simple approach is able to achieve ± 0.5 dB gain flatness over 35 nm with no dependency on temperature variations. It is a cost effective method which needs 100 mW pump power and does not require any additional optical components to flatten the gain, thus reducing the system complexity.

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