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Wideband and flat-gain amplifier based on high concentration erbium-doped fibres in parallel double-pass configuration

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***Abstract.* A wideband and flat gain erbium-doped fibre amplifier (EDFA) is demonstrated using a hybrid gain medium of a zirconia-based erbium-doped fibre (Zr-EDF) and a high concentration erbium-doped fibre (EDF). The amplifier has two stages comprising a 2-m-long ZEDF and 9-m-long EDF optimised for C- and L-band operations, respectively, in a double-pass parallel configuration. A chirp fibre Bragg grating (CFBG) is used in both stages to ensure double propagation of the signal and thus to increase the attainable gain in both C- and L-band regions. At an input signal power of 0 dBm, a flat gain of 15 dB is achieved with a gain variation of less than 0.5 dB within a wide wavelength range from 1530 to 1605 nm. The corresponding noise figure varies from 6.2 to 10.8 dB within this wavelength region.**

Keywords: *double-pass amplifier, wideband amplifier, zirconia-based erbium-doped fibre.*

1. Introduction

The tremendous growth of the internet and data traffic has created an enormous demand for broadband dense wavelength-division-multiplexed (DWDM) optical communication systems. Since the silica-based transmission fibres have a wideband operating window ranging from 1400 – 1700 nm, optical amplifiers with a wider amplification bandwidth are required to cover the full range of the DWDM systems [1 – 3]. To extend the wavelength range, several glass hosts such as tellurite [4], multicomponent silicate [5], bismuth oxide based glass [6 – 9] and zirconia-oxide based glass [10] have been developed for an erbium-doped optical amplifier (EDFA). Recently, a zirconia-based erbium-doped fibre (Zr-EDF) with a highly doped erbium ion concentration has been introduced for realising an efficient and compact optical amplifier, where the combination of both Zr and Al ions is used to achieve a high erbium doping concentration of 2800 ppm in the glass host without any phase separations of rare-earths [11]. A highly doped silica based erbium-doped fibre (EDF) with an erbium ion concentration of 2200 ppm is also commercially available [8].

In this paper, a hybrid wideband optical amplifier with a flat-gain characteristic is proposed using a combination of Zr-EDF and EDF as the gain medium. The amplifier consists of two stages where Zr-EDF and EDF operating in the C-band and L-band, respectively, are used. The performance of the amplifier is investigated in both linear and parallel configurations. A chirp fibre Bragg grating (CFBG) is incorporated in each stage to allow the double-pass operation. A flat-gain output is achieved with the parallel configuration, in which a C-band Zr-EDF amplifier is combined with an L-band EDF amplifier using a C/L-band wavelength division multiplexing (WDM) coupler for multiplexing and demultiplexing the channels in the 1525 – 1565-nm and 1570 – 1615-nm wavelength regions.

2. Experimental

Figure 1a shows the proposed wideband EDFA in a double-pass parallel configuration. At the input of the optical amplifier, a C/L-band WDM coupler is used to separate the WDM signals to C- and L-bands. The C- and L-band signals are amplified by a 2-m-long Zr-EDF and a 9-m-long EDF, which are forward pumped by a 980 nm and 1480 nm laser diode, respectively. The Zr-EDF used is drawn from a fibre perform. The preform was fabricated using, in a ternary glass host, zirconia – yttria – aluminum codoped silica fibre through a solution doping process along with modified chemical vapour deposition (MCVD). The peak absorption of the Zr-EDF at 978 nm was measured to be 14.5 dB m^{-1}, which is equivalent to the erbium ions concentration of 2800 ppm. The EDF used has an erbium ion concentration of about 2200 ppm. At the end of each stage, a broadband CFBG operating at a C- or L-band is incorporated to reflect the C- or L-band signals for double-pass operation. These signals are combined together by the C/L-band WDM coupler at the input port of the amplifier before they are routed to the output port via optical circulator (see Fig. 1a). The insertion loss of the WDM couplers is assumed to be 0.9 and 1.8 dB in the C- and L-band region, respectively.

The performance of a hybrid amplifier with a serial configuration (Fig. 1b) is also investigated for comparison purpose. The serial amplifier uses similar components as those of the proposed parallel amplifier (Fig. 1a). The C-band CFBG is placed in between the two stages to act as a reflector for the C-band EDFA. It reflects the C-band signal for double-pass

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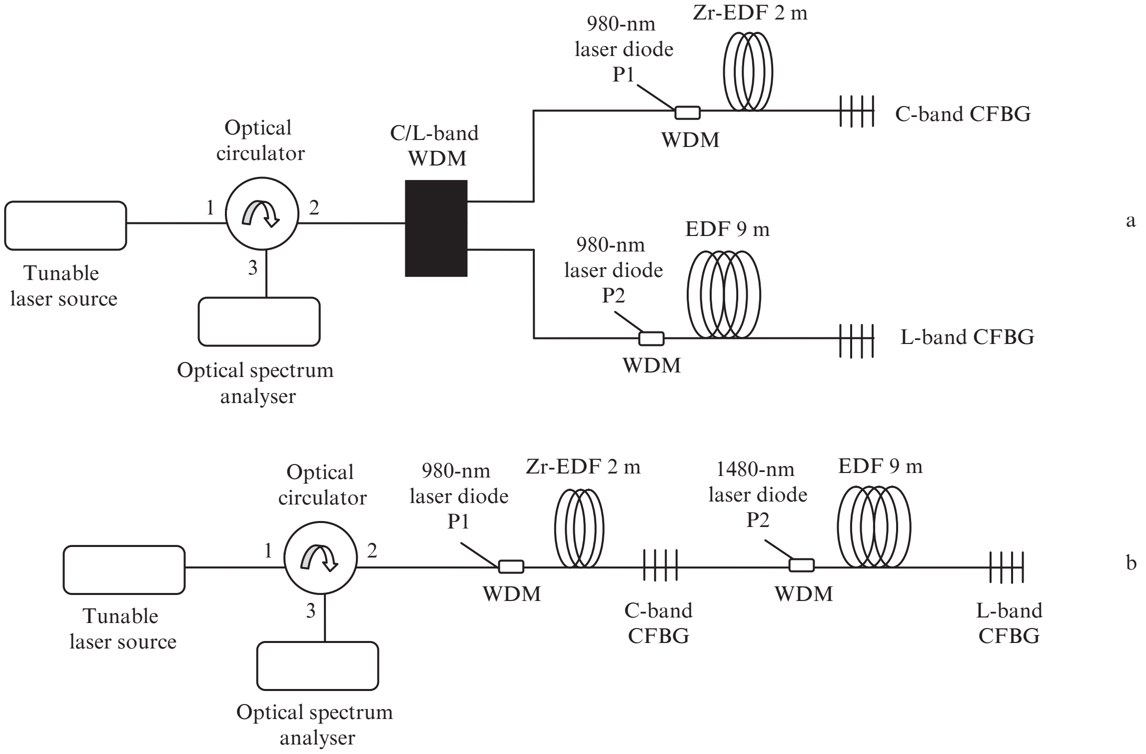


Figure 1. Two-stage double-pass EDFAs in (a) parallel and (b) serial configurations.

operation and allows the L-band signal to be transmitted so that it can be amplified by the second stage of the amplifier. The amplified signal is then reflected back into the system by the L-band CFBG. Figure 2 shows the transmission spectra of both CFBGs used in both configurations. As shown in the figure, the C-band CFBG has a reflectivity of more than 90% centred at a wavelength of 1545 nm with a bandwidth of about 40 nm, while the L-band CFBG has a reflectivity of more than 98% centred at 1592 nm with a bandwidth of about 50 nm. In this experiment, the gain and noise figures of both EDFAs are characterised using a tunable laser source (TLS) used in conjunction with an optical spectrum analyser (OSA).

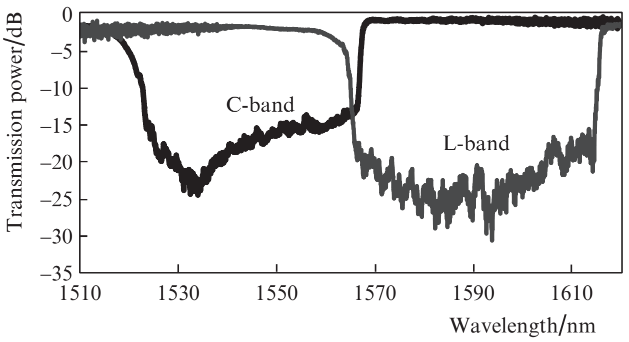


Figure 2. Transmission spectra of CFBGs for C- and L-bands.

3. Results and discussion

Figure 3 compares the measured gain and noise figure characteristics of the proposed parallel and serial double-pass amplifiers. In the experiment, the 980-nm and 1480-nm pump powers are fixed at 112 and 150 mW for C-band and L-band operations, respectively, while the input signal power is fixed at 0 dBm. As shown in the figure, wideband operation is achieved in both amplifiers, which operate in the wavelength region from 1525 nm to 1615 nm. The gain of the parallel amplifier is maintained at 15 dB within a wavelength region from 1530 nm to 1605 nm with a gain variation of less than 0.5 dB. On the other hand, the serial amplifier shows a lower gain, which varies from 9 to 14.6 dB in the C-band region while showing a slightly higher gain within 10 to 17.6 dB in the L-band region as compared to that of the parallel one.

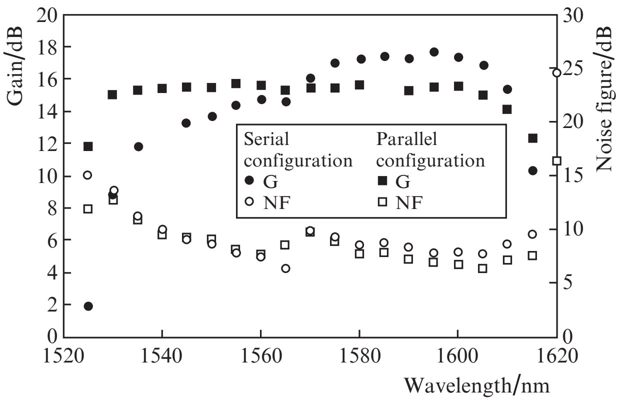
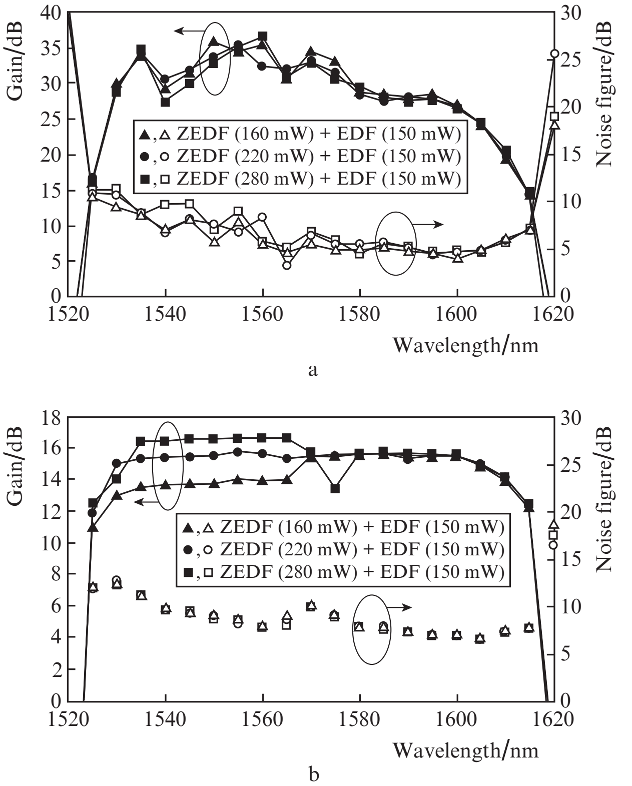


Figure 3. Gain and noise figure of a parallel and serial amplifiers at the input signal power of 0 dBm.

In the serial amplifier (Fig. 1b), the reflected forward L-band ASE passes through the C-band CFBG and is amplified by the first stage amplifier, which in turn suppresses the amplifier's gain in the C-band region. Furthermore, at 1570 nm, the gain for the serial configuration suddenly increases due to the shift in the amplification medium length from 2 m to 9 m. On the other hand, the noise figure of the parallel amplifier varies from 7.4 to 11.2 dB within the wavelength region of 1530 nm to 1615 nm. These values are relatively smaller compared to those of the serial amplifier except for wavelength of 1565 nm. At around 1565 nm, the insertion loss of C/L-band WDM is the highest and, therefore, the noise figure is relatively higher at this region. Compared to the parallel amplifier, the L-band noise figure in the serial amplifier is higher due to the backward ASE from the second stage, which is reflected back to the gain medium and thus reduces the population inversion at the input part of the L-band EDFA.

Figure 4 shows the gain and noise figure spectra for the parallel amplifier at various pump powers for the C-band stage. As shown in Fig. 4a, the C-band small signal gain (–30 dBm) varies as the pump power increases from 160 mW to 280 mW. For instance, at the input signal wavelength of 1550 nm, the gain decreases from 36.5 dB to 33 dB as the pump power changes from 160 mW to 280 mW. The small signal variation is most likely due to the saturation effect. The L-band small signal gain and noise figure spectra are almost unchanged. At the input signal power of 0 dBm, the C-band gain reduces as the pump power increases from 160 mW to 280 mW. The optimum pump power for flat gain is observed to be around 220 mW (Fig. 4b). The gain is observed to be lower at higher input signal power due to saturation effect.

The noise figure spectrum is seen to be unaffected by the change in the pump power of the C-band amplifier. At a small input signal of –30 dBm, the noise figures are maintained below 10 dB within a wavelength range from 1535 nm to 1615 nm. Meanwhile, at a high input signal power, the noise figure is slightly higher but the values are still maintained below 10 dB within a wavelength range from 1540 nm to 1615 nm. The noise figure increment is attributed to a lower gain at high input signal.



a

b

Figure 4. Gain and noise figure spectra of the amplifier in a parallel configuration at different pump powers of the amplifier in the C-band at the input signal power of (a) –30 dBm and (b) 0 dBm.

The flat-gain amplifier has a possible application in a DWDM system, which operates at a high input power of around 0 dBm due to many channels. A commercially available EDF (EDFL-1480-HP, Nufern with absorption of 15 dB m^{-1} at 980 nm) can also be used to replace Zr-EDF.

4. Conclusions

A wideband and flat-gain optical amplifier is demonstrated utilising a hybrid gain media of Zr-EDF and EDF in a parallel double-pass configuration. A CFBG is used in both C- and L-band stages to allow double pass operation and to increase the attainable gain. At the input signal power of 0 dBm, a flat gain of 15 dB is achieved within a wavelength region from 1530 to 1605 nm. The corresponding noise figure varies from 6.2 to 10.8 dB over this wavelength region. Compared to a serial amplifier, the gain flatness and bandwidth as well as noise figure of the proposed parallel amplifier are better.

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