EDFA Gain Flattening Using Long-Period Fibre Gratings Based on the Electric Arc Technique

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Abstract: We have flattened the gain spectrum of a commercial Erbium-doped fibre amplifier, obtaining a curve with approximately 3 dB of ripple, from 1524 nm to 1551 nm, using long-period fibre gratings as equalising optical filters. The fabrication principle of the long-period fibre grating is based on the electric arc technique.

1. Introduction.

The gain flattening of Erbium-doped fibre amplifiers (EDFA) has been a research issue in recent years, with the development of high capacity wavelength division multiplexing (WDM) optical communication systems. For single channel systems, the gain variation is not a problem. However, as the number of channels increases, the transmission problem arises because a conventional EDFA has intrinsic non-uniform gain. They typically present gain peaking at about 1530 nm and the useful gain bandwidth may be reduced to less than 10 nm. The gain of EDFAs depends on a large number of device parameters such as erbium-ion concentration, amplifier length, core radius and pump power. To increase the gain-bandwidth of an amplified lightwave system several methods can be used [1], but equalising optical filters operating as spectrally selective loss elements appear to be the best candidates [2].

The fabrication principle of these band-rejection filters is based on the ability to induce large index changes in hydrogen loaded germanosilicate fibres by exposing the cores to ultraviolet light, typically in the 242-248 nm range. For long period gratings (typically on the order of hundreds of microns), these photoinduced periodic structures couple light from the fundamental guided mode to forward propagating cladding modes [2]. The modes decay rapidly as they propagate along the fibre owing to scattering losses in the cladding-air interface and bends in the fibre. Since the coupling is wavelength selective, this long-period fibre grating (LPFG) acts as a wavelength dependent loss element.

LPFGs have, typically, periods in the range of 200 – 700 µm and are based on the coupling between the fundamental mode and the co-propagating cladding modes. Their transmission spectra is characterised by dips at wavelengths that satisfy the resonance condition [2]:

$$l = \left(n_{core} - n^{i}_{cladding}\right)\Lambda \,, \qquad (1)$$

where l is the resonance wavelength, n_{core} and $n^{i}{}_{cladding}$ are the effective refractive indexes of the fundamental mode and of the i^{th} order cladding mode, respectively, and Λ is the grating period.

We have written LPFGs in standard photosensitive and non-photosensitive fibres using the novel electric arc technique for WDM systems [3]. This method of fabrication is flexible and easy to implement. The LPFGs obtained have low background loss and possess high thermal stability [4]. Recently, we have proposed the annealing of intrinsic stresses and the creation of new stresses during the electric arc discharges as the main mechanism for their formation [5].

2. Long-period fibre grating fabrication and characterization.

In this section we describe succinctly the electric arc technique and the implemented LPFG to equalise the EDFA gain. The gratings inscription consists on positioning an uncoated fibre between the electrodes of a splicing machine. One end of the fibre is fixed to a translation stage controller (MTS), which moves with a precision of 0.1 μm. At the other end a mass (1.4 g or 5.1 g) is attached to keep the fibre under a constant axial tension. An electric discharge during 1-2 s is then produced with a current less than 10 mA. Afterwards, the fibre is moved by the grating period followed by a new electric discharge. The displacement-discharge process is then repeated 15-150 times. A computer controls the whole process of LPFG fabrication. We have used only one grating centred at about 1531 nm for equalisation of the EDFA. The LPFG was fabricated with 57 periods of 611 μm, using a current of about 9 mA during 1.7 s and a mass of 5.1 g.

3. EDFA Gain Flattening.

To observe the effect of the implemented gain-flattening filter on the EDFA gain spectrum we have used the set-up presented in Fig. 1. We have inserted two WDM channels at the EDFA input (Fig. 2-1) that are unequally amplified by the EDFA (Fig. 2-3), due to its non-uniform gain curve (Fig. 2-2) in the considered band. Before equalisation, the EDFA gain excursion is approximately 15 dB, from 1524 nm to 1551 nm (27 nm bandwidth). Using the implemented LPFG (see transmission spectrum in Fig. 2-4), the gain ripple over that bandwidth is reduced to approximately 3 dB, and the two WDM channels are similarly amplified (Fig. 3).

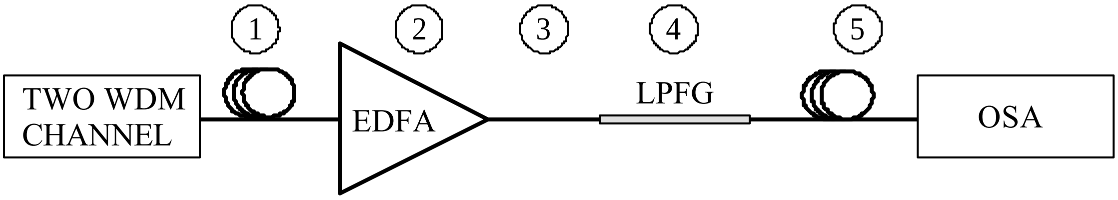

Fig. 1 – Set-up used to verify the EDFA gain equalisation.

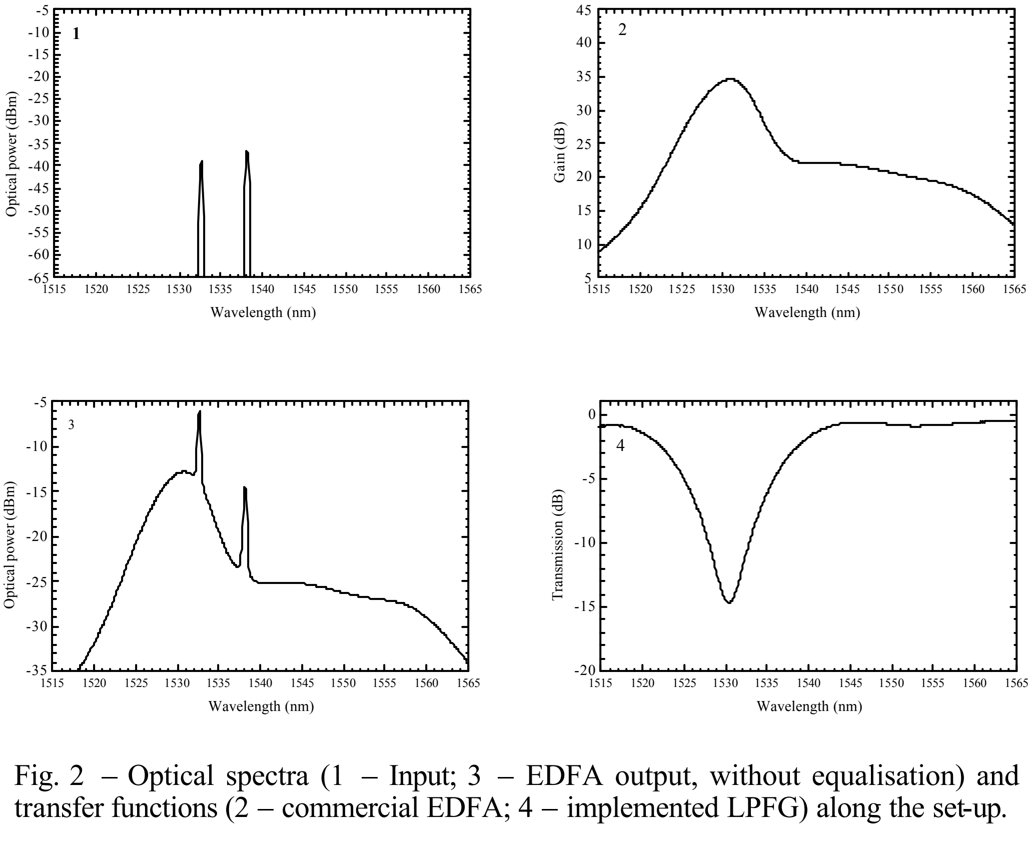

Fig. 2 – Optical spectra (1 – Input; 3 – EDFA output, without equalisation) and transfer functions (2 – commercial EDFA; 4 – implemented LPFG) along the set-up.

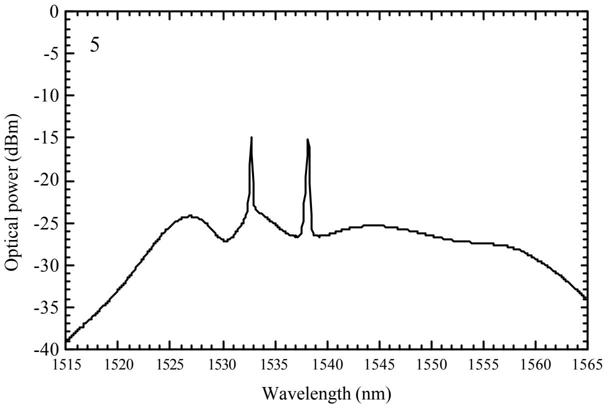

Fig. 3 – Optical spectrum (5 – Output, after equalisation).

4. Conclusions.

A gain-flattening filter has been produced using the electric arc technique enabling the assembly of a low gain ripple EDFA for WDM systems. The gain excursion is less than 3 dB for WDM signals over the 1524 nm to 1551 nm range (27 nm bandwidth). The gain flatness and the total bandwidth can be further improved with a better fitting of the LPFG.

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