Optical Filters for Fibre Lasers and Amplifiers

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Abstract: The writing of arc-induced long period fibre gratings to be used as optical filters in Er/Yb fibre lasers and for gain flattening in EDFA is discussed. A new approach is presented for the production of filters with complex profiles.

1. Introduction.

The permanent development of optical communications demands the constant enhancement of fibre lasers and amplifiers, as well as all the optical associated components needed to improve its characteristics. Gain flattening filters and amplified spontaneous emission (ASE) filters in erbium doped fibre amplifiers (EDFAs), tuning of the output wavelength of a fibre laser and band rejection filters are some examples of applications where long period fibre gratings (LPFGs) can be applied with success.

It is well known that one of the most used optical fibre for achieving gain is the erbium doped fibre (EDF), since its operating wavelength coincides with the third window for optical fibre communications around 1550 nm. In some cases, the use of a co-dopant, like ytterbium (Yb^{3+}), can bring benefits to the desired application. For example, the erbium/ytterbium system broadens the choice of pump source in Er^{3+} doped optical amplifiers because Yb^{3+} exhibits a broad absorption band between 800 and 1100 nm [1]. In this system, the optical pumping is based on the Yb($^2F_{7/2}$)? Yb($^2F_{5/2}$) absorption, arising this way the Er^{3+} pumping from energy transfer from Yb^{3+} to Er^{3+} : Yb($^2F_{5/2}$) to Er($^4I_{11/2}$). However, if the rate of multiphonon relaxation process Er($^4I_{11/2}$)? Er($^4I_{13/2}$) is not fast enough, a back transfer process from Er($^4I_{11/2}$) to Yb($^2F_{5/2}$) may occur. Thus, undesirable emission at around 1064 nm can happen, due to the energy levels of Yb^{3+}. In this cases, to maintain a good performance of the device, we can use filters that have a high isolation peak-loss centred at 1064 nm, a wide bandwidth and low loss at both wavelengths of 980 and 1550 nm, the optimum pumping wavelength for avoiding the excited state absorption (ESA) effect and the emission wavelength, respectively. In this paper we show that LPFGs fabricated using the electric-arc technique provide an adequate solution to this problem of designing optical filters with complex characteristics.

2. Filters for Er/Yb Fibre Lasers.

LPFGs were produced using the electric arc technique [2]. This method of fabrication has several advantages over others, namely, it does not require that the fibre be photosensitive and the arc-induced gratings possess high thermal stability [3]. However, the writing of gratings at short wavelengths puts forward several problems. Usually, fibres are multimode for those wavelengths and therefore the filters on them are very sensitive to bending (even to micro-bends during their inscription) making difficult to control the background loss. Furthermore, the well-known process of increasing the tension or the current to widen a spectrum or to have a deeper peak-loss also results in an increased background loss. Moreover, a technical problem arises when periods of about 240 μm are required since in those cases we are working almost in the limit of the technique. This, in turn reduces the reproducibility since high tensions need to be used to increase the coupling strength. Therefore, transposing what is known about the writing of LPFGs in the third telecommunication window to this particular issue is not straightforward.

A non-commercial set-up was used to write the arc-induced LPFGs [4]. Although several fibres were tested for LPFGs inscription only the DSF from Corning revealed appropriate characteristics. Gratings with low background loss (< 0.3 dB) at the wavelengths of interest were obtained. However, their isolation loss and bandwidth were often lower than 10 dB and less than 8 nm, respectively. Figure 1 shows the spectrum of one of those gratings (m = 72,7 g, I < 10 mA, t = 0.8 s, Λ = 238 µm) centred at 1060.9 nm, with an isolation peak-loss of about 13.5 dB and a bandwidth of ~5 nm. The loss at 980 nm was negligible and at 1550 nm was lower than 0.2 dB.

In order to increase the bandwidth and the isolation peak-loss two chirped gratings (m = 36.3 g, I < 12 mA, t = 1.5 s) were written. The period of the first grating was changed between 242.5 and 247.5 µm in steps of 0.2 µm starting at 245.0 (it was first increased, from center to right). The period of the second was chirped from center to left (247.5 ± 2.5 µm, 0.2 µm). Figure 2 shows the spectrum of the concatenated gratings. The filter has a peak-loss centred at 1060.9 nm with an isolation loss higher than 20 dB and a bandwidth of ~12 nm. The loss at 980 and 1550 nm was lower than 0.6 and 1.0 dB, respectively.

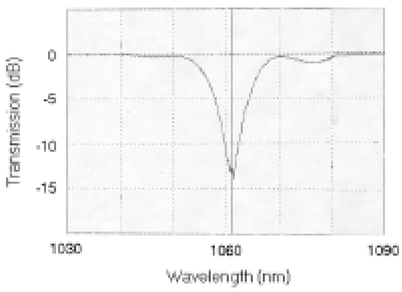

Fig. 1 – Transmission spectrum of a 238-µm grating.

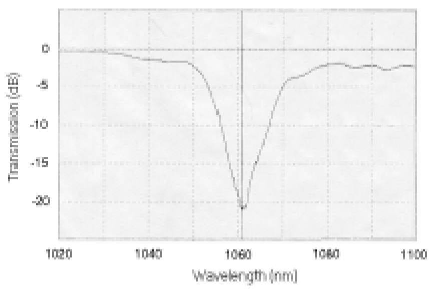

Fig. 2 – Spectrum of two concatenated chirped gratings.

To improve the above results we have produced a multi-grating filter, i. e., a filter composed of several gratings with different periods. This filter possesses nine consecutive gratings of 15 periods each ranging from 241 to 249 µm. The period differs by 1.0 µm from sub-grating to sub-grating. The resultant spectrum is shown in figure 3. As it can be seen the peak-loss is centred at 1062.6 nm, its isolation loss and bandwidth is, respectively, ~13 dB and ~11.6 nm. The outside-band loss is lower than 0.7 dB. Apart from the common parameters to the electric arc technique (tension, current and time), there are several others that can affect the final spectrum of the filter such as the number of sub-gratings, its length, period and chirp. All these parameters can be modified from sub-grating to sub-grating and even gaps can be included in between. Moreover, a different number of discharges can be produced in the same physical region of the fibre as in an apodisation scheme. The complexity of this approach demands a better knowledge of the interplay between these variables and therefore further investigations are required. This powerful tool can lead to astonishing results in applications such as the fabrication of special filters, as the one discussed above, as well as in the gain equalization of amplifiers.

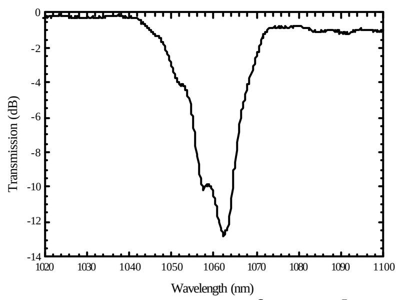

Fig. 3 – Spectrum of a "multi-grating" filter.

3. EDFA Gain Flattening.

Arc-induced LPFGs have been used to flatten the spectrum of an EDF source and of an EDFA with a peak-to-peak fluctuation of 2 dB (Fig. 4) [4] and 3 dB (Fig. 5) [5], respectively. In order to further

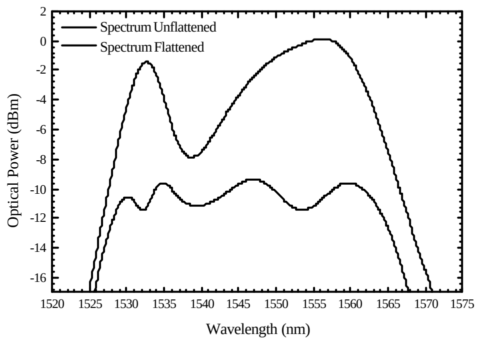

Fig. 4 – Broadband EDF source.

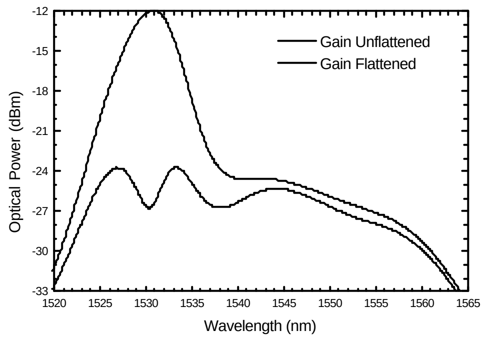

Fig. 5 – Commercial EDFA with equalized gain.

improve the gain ripple there are two approaches: one involves the writing of LPFGs with low isolation loss (< 3 dB) and narrow bandwidth (< 6 nm), i. e., weak gratings. These requirements were fulfilled by a 400 µm-LPFG written in a Corning dispersion-shifted-fiber, whose core is doped with 12 mol% of Ge, using a mass of 1.4 g and arc discharges of 9 mA during 1 s each. Figure 6 shows the growth of the peak-loss of this grating, positioned at about 1547 nm, as the number of arc discharges is increased in steps of 50 up to 150. The evolution of the "third peak" of the flattened spectrum (Fig. 4) with the increasing strength of this new grating is also shown. As it can be seen due to the low growth rate of the grating there is a good control of the equalization process. Therefore, by increasing the number of weak gratings it is possible to obtain gain equalization with low ripple, although, at the cost of ending up with a long filter. The second approach consists on a better fitting to the initial EDFA gain curve what can be accomplished by increasing the bandwidth of the gratings using multi-grating filters. Afterwards, if necessary, weak gratings can also be concatenated. The combination of these two kinds of gratings seems to be very promising for gain flattening.

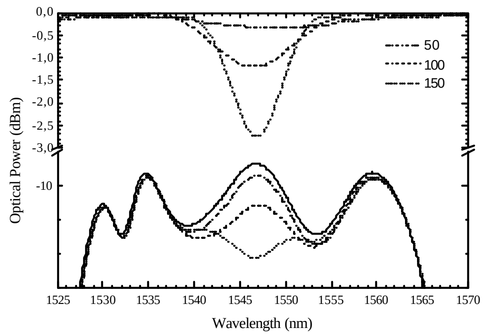

Fig. 6 – Evolution of the transmission spectrum of the weak grating with the number of arc discharges and the correspondent change of the EDF flattened spectrum.

4. Conclusions.

A new approach to produce shorter filters with complex profiles was presented. This technique was used to write a band rejection filter for Er/Yb fibre lasers. We also demonstrate the feasibility of weak gratings and it is expected that when combined with multi-grating filters they can lead to state-of-the-art EDFAs gain flatteners. The high thermal stability of arc-induced LPFGs and the possibility to write them directly in active fibres should also be mentioned.

Acknowledgments.

G. Rego is thankful for the grant through the Program PRODEP III - Medida 5 - Acção 5.3. - Formação Avançada de Docentes do Ensino Superior, integrada no Eixo 3.

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