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GAIN-SHAPED ERBIUM-DOPED FIBRE AMPLIFIER (EDFA) WITH BROAD SPECTRAL BANDWIDTH

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ABSTRACT

An optical gain-flattening filter is incorporated within the length of an EDFA. An essentially-flat gain of 27dB is obtained over 33nm without loss of pump efficiency or saturation performance.

* On Leave from Seiko Instruments Inc., Japan

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INTRODUCTION

The Er^{3+}-doped optical fibre amplifier (EDFA) has stimulated much interest for possible application in future communication systems, since its gain band coincides with the third telecommunications window of silica fibre at a wavelength of 1.55μm[1,2]. Although Stark-splitting of the ground and metastable levels in erbium-doped glass generates a wide spectral bandwidth in an EDFA, its gain spectrum is typically irregular, with a sharp peak around 1.53μm and a broad band with reduced gain to longer wavelengths (see Figure 1, Curve A). Although the amplifier can be operated at wavelengths away from the peak gain[3], disadvantages occur due to increased spontaneous-spontaneous beat noise and possible laser action at the peak gain wavelength

The local environment for the erbium ion has a considerable effect on its gain spectrum and it is well known that an alumino-silicate host glass provides a broader gain spectrum. Previous work has further smoothed this spectrum by use of a pump wavelength of 1.48μm and careful choice of pump power[4]. However this was at the expense of a lower value of population inversion, reduced pump efficiency and a higher noise figure.

In this paper we demonstrate that by incorporating an optical filter within the length of an EDFA, the overall gain spectrum and saturation characteristics are modified to be nearly uniform over the entire 1.53-1.56μm band. We have used an optical notch-filter based on the resonant coupling between core propagating mode and cladding leaky mode. When tuned to suppress the gain spectrum at the peak wavelength, a broad-band amplifier with a 3dB-bandwidth of 33nm, a gain of 27dB and uniform saturation characteristics is obtained. This is the highest gain-bandwidth product demonstrated to date for an EDFA pumped at 980nm. In addition the amplifier efficiency is actually improved for longer signal wavelengths. We contrast the considerable advantages which are obtained by locating the filter within the amplifier length, rather than at the output.

EXPERIMENTAL

The amplifier consisted of 58 metres of alumino-silicate erbium-doped fibre which was characterised by an Er^{3+}-doping level of ~25ppm, a NA of 0.14 and λ_{cutoff} at 945nm. The signal source was an ELED which allowed measurement of gain spectra between 1.51 and 1.59μm. Its power was maintained to be less than 200nW within the gain band of Er^{3+}, thus ensuring small-signal operation. A further signal at 1.531μm from a DFB laser was mixed with the ELED signal through a 3dB fibre coupler. This large signal was sufficient to saturate the amplifier and permitted the measurement of spectral gain under saturated conditions. These two signals were combined in a dichroic fibre coupler with 38mW of pump light at 980nm from an Ar^{+}-ion pumped Ti:Sapphire laser, and injected into the amplifier fibre. All free fibre ends were angle-polished to suppress optical feedback.

An optical notch filter was incorporated in the middle of the amplifier by sandwiching a short length of amplifier fibre between a 220mm long, 0.52mm pitch mechanical grating and a flat plate. This induced a resonant coupling at a particular wavelength between core mode and cladding leaky modes which are subsequently lost. Both the centre wavelength and the strength of the filter are tunable by changing the operating angle and pressure respectively.

The amplifier output was coupled to a monochromator and detected with lock-in techniques to allow discrimination of the broad-band (ELED) and 1.53μm (DFB laser) signals by virtue of their different modulation frequencies. Output spectra were obtained under small-signal and saturated operation. In addition, spectra were obtained immediately before and after the filter. Finally, the fibre was cut back and the spectrum of the broad-band (ELED) signal measured such that the gain spectrum for each condition could be obtained.

RESULTS

Figure 1 shows amplifier gain spectra. Without filtering (Curve A), a peak gain of 32dB is obtained at 1532nm with a much reduced gain of 24dB at 1550nm. In this case the amplifier 3dB-bandwidth is only 4.5nm. With filtering applied (Curve B), the peak gain is efficiently suppressed and, in addition, the gain at longer wavelengths is <u>enhanced</u> to 27dB. This results in a remarkably uniform gain spectrum with a 3dB-bandwidth of 33nm. (Note the decrease in gain at wavelengths longer than 1570nm is due to another resonant coupling band in the filter at 1605nm).

The improved amplifier gain around 1550nm is due to the effect of the filter on the ASE. The ASE spectrum is very similar to the gain spectrum and thus filtering at its peak wavelength of the gain rejects most of the spectral power of the ASE. This is because the exponential build-up of the ASE is suppressed at the middle of the fibre and thus the power of the ASE is reduced throughout the latter half of the fibre. Consequently, a substantial proportion of the Er^{3+}ions are retained in the excited state and reserved for amplification of the signal. Effectively, the gain available within the gain peak is distributed evenly across the amplifier pass band. Figure 2 shows the filter loss spectrum and the overall change in the amplifier gain spectrum. The difference between the two curves represents the increase in the spectral gain obtained in the latter half of the fibre owing to the filtering of the ASE.

The location of the filter in the amplifier is important for optimum pump efficiency. If the filter is located at the output of the amplifier, there will be no increase in the spectral gain at any wavelength, since the filter has no effect on the build up of ASE within the amplifier. Furthermore, since the effect of the filter at the output is purely passive, the output power within the filter band is simply reduced by the filter attenuation. This causes an accompanying reduction of the amplifier saturation power within this band.

This last point can be seen with reference to Figure 3 where the amplifier gain characteristics at 1531nm with and without internal filtering are given (Curves A & B). From the figure it can be seen that 3dB gain compression occurs for output powers around 1mW in both cases, thus defining an output saturation power of 0dBm.

By contrast, we take the (calculated) example of an optical notch filter with a Lorentzian spectrum applied at the output of the same EDFA. To obtain a 3dB-bandwidth of ~30nm, the filter attenuation should be 8dB at 1531nm, with a 3dB-bandwidth of 4nm. The small-signal gain spectrum for such a system is given in Figure 1 (curve C). As expected, a smooth gain spectrum is obtained, but with no increase in gain at longer wavelengths. However, the gain saturation characteristics at 1531nm are markedly different, as shown in Figure 3 (curve C). A 3dB gain-compression now occurs for output powers around only -8dBm owing to the attenuation of the filter (i.e. 8dB) at the output of the EDFA.

Figure 4 shows the small-signal and saturated gain spectra for the gain-shaped amplifier. From this figure it is clear that the gain profile remains uniform even when the amplifier gain is saturated. Thus this type of amplifier is ideal for WDM application.

CONCLUSION

We have demonstrated the effectiveness of spectral gain shaping in an EDFA by incorporating an optical filter within the length of the amplifier. A gain of 27dB and 3dB-bandwidth of 33nm are obtained for 38mW of pump power at 980nm. If the position of the filter is carefully chosen, it improves the pump efficiency at wavelengths away from the peak and does not lower the amplifier saturation output power.

Improvements in pump efficiency may be achieved by further fibre optimisation, for instance a confined Er^{3+} distribution in the core[5,6].

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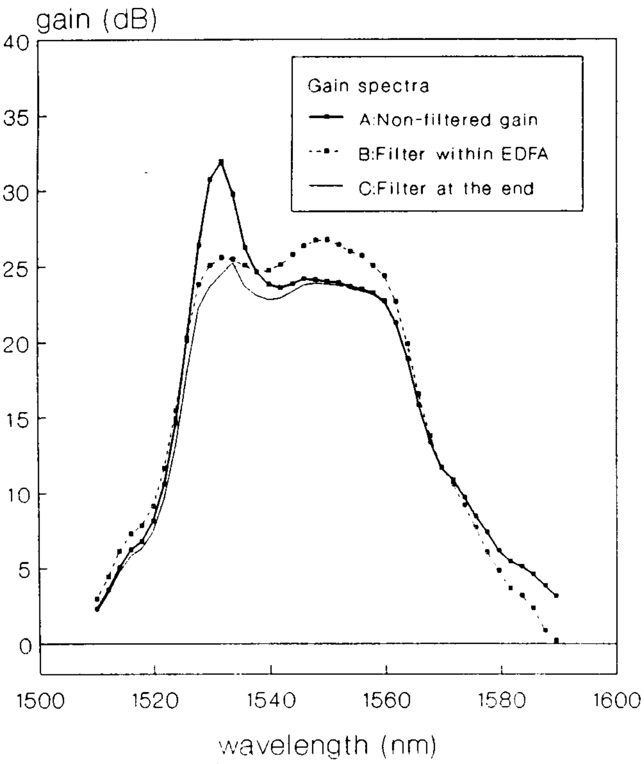

Fig.1 Amplifier gain spectra showing gain flattening due to filtering.

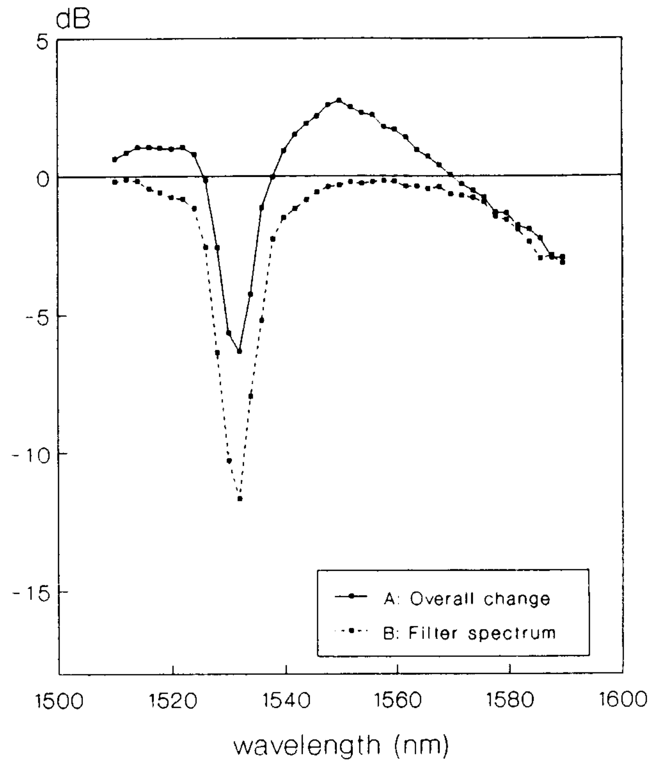

Fig.2 Overall change in the gain spectrum when filter is applied within the EDFA compared with filter loss spectrum.

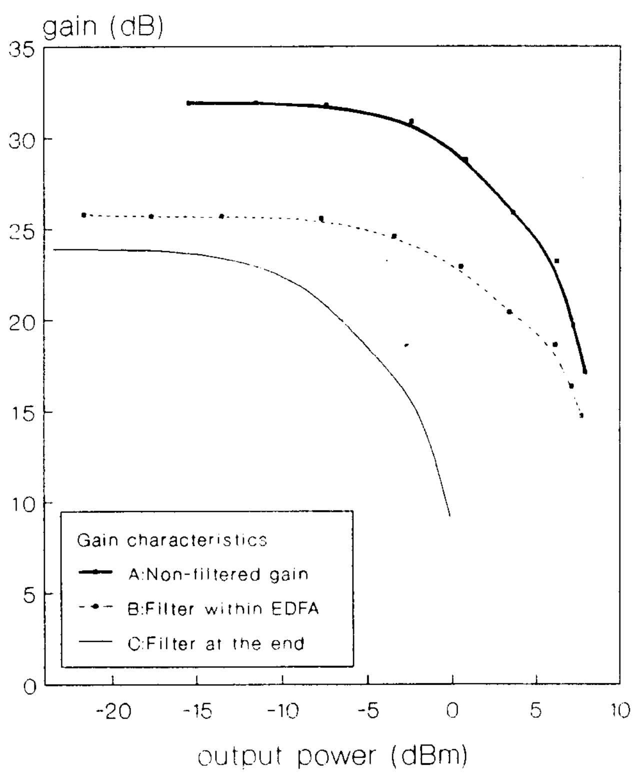

Fig.3 Gain and saturation characteristics of the EDFA at 1531nm, contrasting effect of filter applied within the amplifier and at the end.

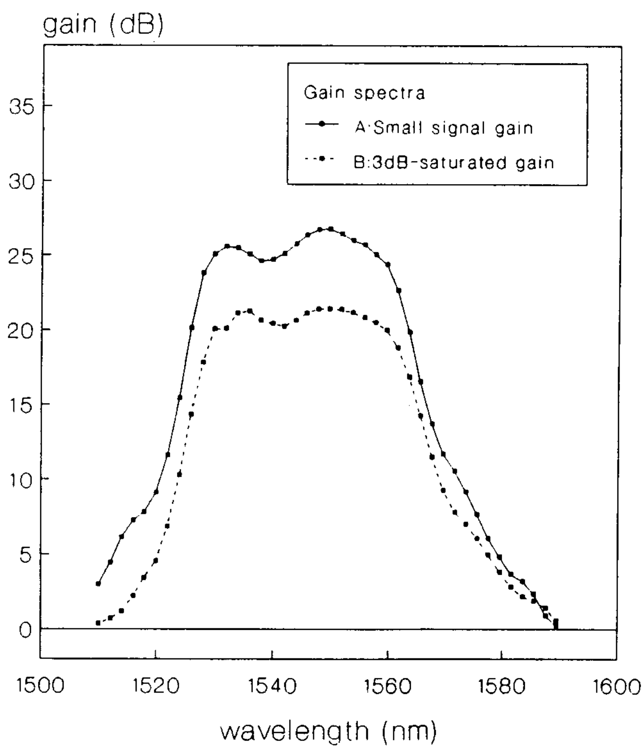

Fig.4 Flattened-gain spectra for small signal and 3dB-saturated operation.