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SPECTRAL GAIN CROSS SATURATION AND HOLE-BURNING IN WIDEBAND ERBIUM-DOPED FIBRE AMPLIFIER AMPLIFIERS

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ABSTRACT

Cross saturation characteristics are investigated in broadband 1.48μm pumped and 980nm pumped, "gain-shaped" EDFAs. "Gain-shaping" is shown to give a more uniform spectral gain compression on saturation. In addition room temperature spectral gain hole-burning is observed for the first time.

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ABSTRACT Cross saturation characteristics are investigated in broadband 1.48μm pumped and 980nm pumped, gain-shaped" EDFAs. "Gain-shaping" is shown to give a more uniform spectral gain compression on saturation. In addition room temperature spectral gain hole-burning is observed for the first time.

INTRODUCTION One of the major applications of erbium-doped fibre ampliifers (EDFA) is likely to be in WDM systems[1]. In this case it is desirable to flatten and maximise the gain bandwidth of the EDFA. To date two techniques have been employed, either by the use of a pump wavength of ~1.48μm combined with careful choice of pump power and fibre length[2] or by "gain-shaping", incorporating an optical filter in the middle of the amplifier[3]. Applied to either alumino-silicate, germano-alumino-silicate or ZBLAN[4] EDFAs results in 3dB gain bandwidths of ~35nm. In addition it is important to understand and optimise the cross saturation characteristics of the EDFA. Thus the number of WDM channels can be maximised whilst the gain penalty for each channel and interchannel crosstalk effects are minimised.[5,6].

In this paper, we report an efficient, 1.48μm diode pumped fibre amplifier. The use of a germano-alumino-silicate erbium-doped fibre aswell as careful choice of pump power, pump wavelength and fibre length creates an amplifier characterised by a 25dB gain and 35nm 3dB bandwidth for only 15mW of pump power. Cross saturation characteristics are investigated for saturating signals at various wavelengths across the gain band and different pump powers. In general the gain spectrum decreases non-uniformly, with shorter wavelengths suffering the largest penalty. In addition saturation characteristics show little dependence on the saturating wavelength, only small spectral gain hole-burning is observed confirming the near homogeneous nature of the erbium transition in germano-alumino-silicate glass. Comparison with similar results for a "gain-shaped", 980nm pumped EDFA shows this to be a preferable technique yielding a more uniform decrease in gain spectrum.

EXPERIMENTAL The amplifier consisted of 35m of germano-alumino-silicate erbium-doped fibre which was characterised by an Er^{3+}-doping level of ~160ppm, a NA of 0.2 and λ_{cutoff} at 930nm. The signal source was an ELED which allowed measurement of gain spectra between 1.52μm and 1.57μm. Its power was maintained to be less than 200nW within the gain band of Er^{3+}, thus ensuring small-signal operation. A further signal from either a DFB-LD or a tunable external cavity LD was mixed with the probe 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[3]. Pump light at ~1.485μm was obtained from 2 diode lasers. This was combined with the two signals via a dichroic fibre coupler and injected into the amplifier fibre. All free fibre ends were angle-polished to suppress optical feedback.

The amplifier output was coupled to a monochromator and detected with lock-in techniques to allow discrimination of the broad-band (ELED), saturating signals (DFB or tunable laser) and ASE by virtue of their different modulation frequencies. Output spectra were obtained for various pump powers, under both small-signal and saturated operation and for several wavelengths of saturating signal. At the end of experiments, the fibre was cut back and spectrum of the broad-band (ELED) signal measured such that the gain spectrum could be obtained.

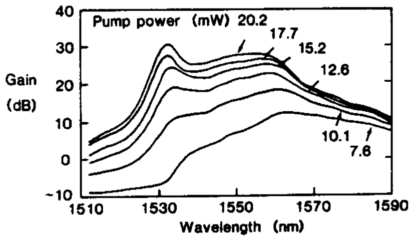

Figure 1 Gain spectra of EDFA in small signal operation for different pump powers at 1485nm.

RESULTS Figure 1 shows small-signal gain spectra obtained for various pump powers. It can be seen that a pump power between 15.2 to 17.7mW gives the broadest gain. In the case of a pump power of 15.2mW a peak gain of 25dB and 3dB bandwidth of 35nm are obtained. This corresponds to a gain efficiency of ~1.6dB/mW.

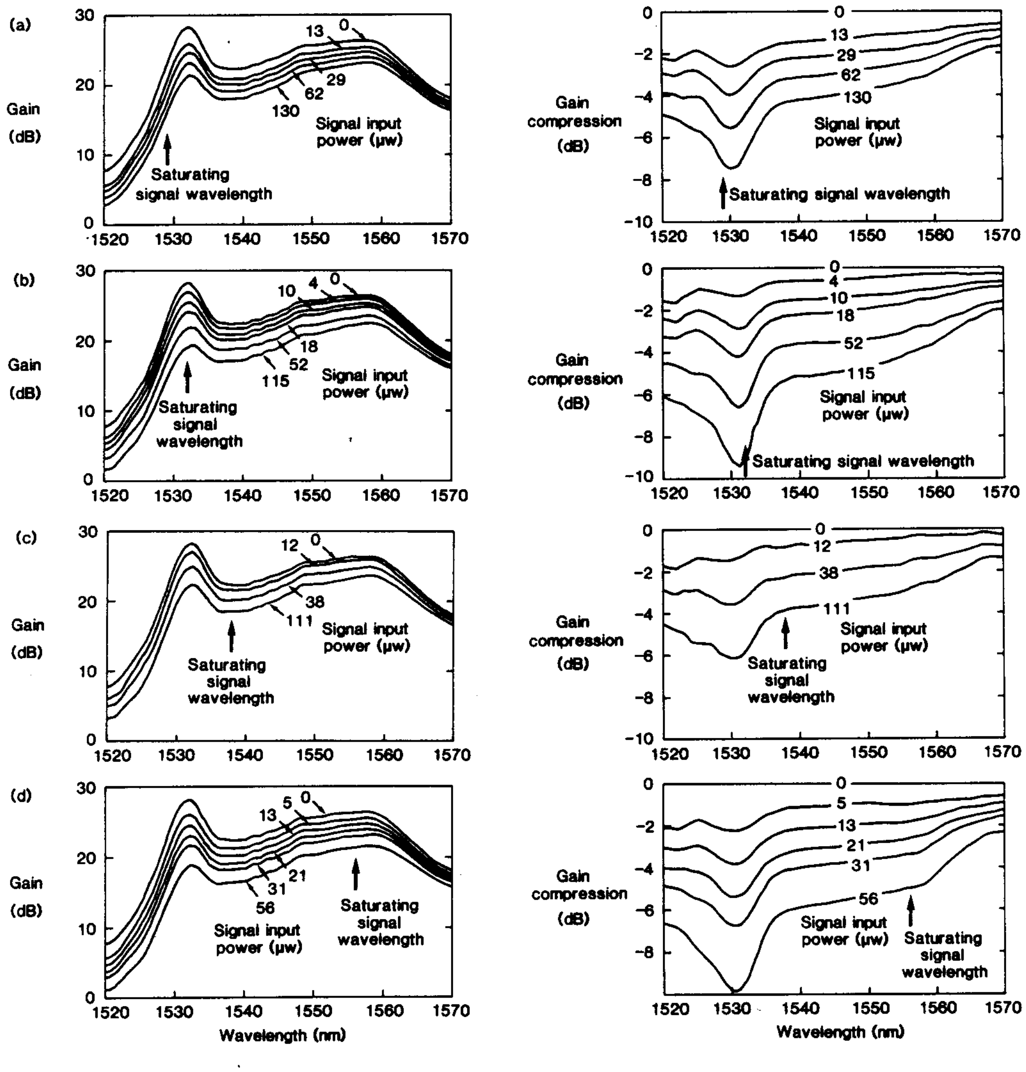

Fig. 2 Gain spectra and corresponding gain compression obtained with a pump power of 17.7mW and increasing saturating signal power at the wavelengths (a) 1529nm, (b) 1432nm, (c) 1538nm and (d) 1556nm.

Figure 2 shows gain spectra and corresponding gain compression obtained with a pump power of 17.7mW and increasing signal input power at the wavelengths (a) 1529nm, (b) 1532nm, (c) 1538nm and (d) 1556nm. These were selected to correspond to either a peak or dip in the homogeneous emission profile[7] and thus maximise any inhomogeneous effects observed. From the figure it is clear that for all signal wavelengths the gain spectrum distorts on saturation, with the shorter signal wavelengths around 1.532μm incurring the largest gain compression. This is undesirable for WDM systems. Also from the figure it can be seen that the gain compression curves for different signal wavelengths are similar, thus confirming the homogeneous character of erbium in germano-alumino-silicate glass.

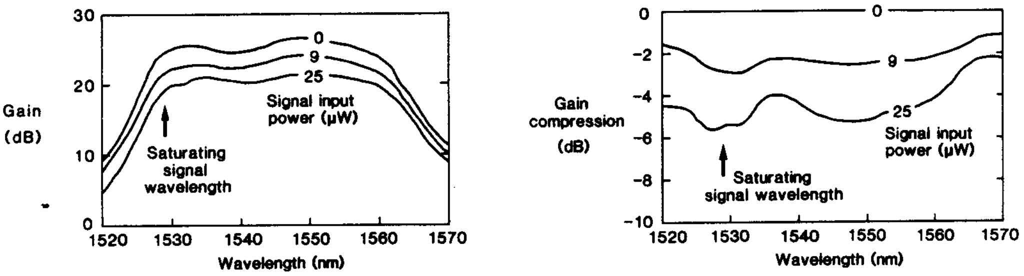

Fig.3 Gain spectra and corresponding gain compression for a "gain-shaped" amplifier[3] and with saturating signal at the wavelength of 1529nm.

Figure 3 plots similar data for a "gain-shaped", 980nm pumped amplifier[3]. In this case the gain spectrum decreases more uniformly making it a preferable technique. In addition it may be possible to further optimise the performance by exact location of the "gain-shaping" filter.

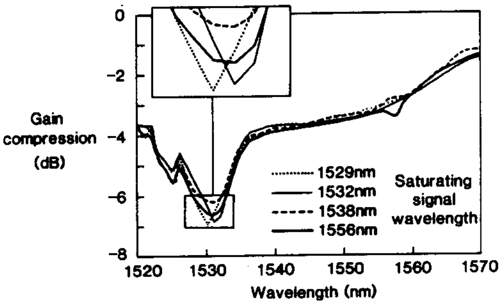

Fig. 4 Gain compression for different wavelengths of saturating signal but with the same degree of saturation. Small spectral hole burning can be observed.

Figure 4 compares in more detail gain compression data of figure 2. Data is selected for the four saturating wavelengths and at the same degree of saturation. The differences are subtle with the saturating signals at 1529, 1532 and 1556nm creating a spectral hole at each of their respective wavelengths, whilst the signal at 1538nm results in a reduced gain compression at 1532nm. This is the first observation of room temperature spectral hole-burning in alumina co-doped EDFAs. However the effect is small, resulting in a less than 1dB change in gain compression across the gain band and will thus be of little consequence in future WDM systems.

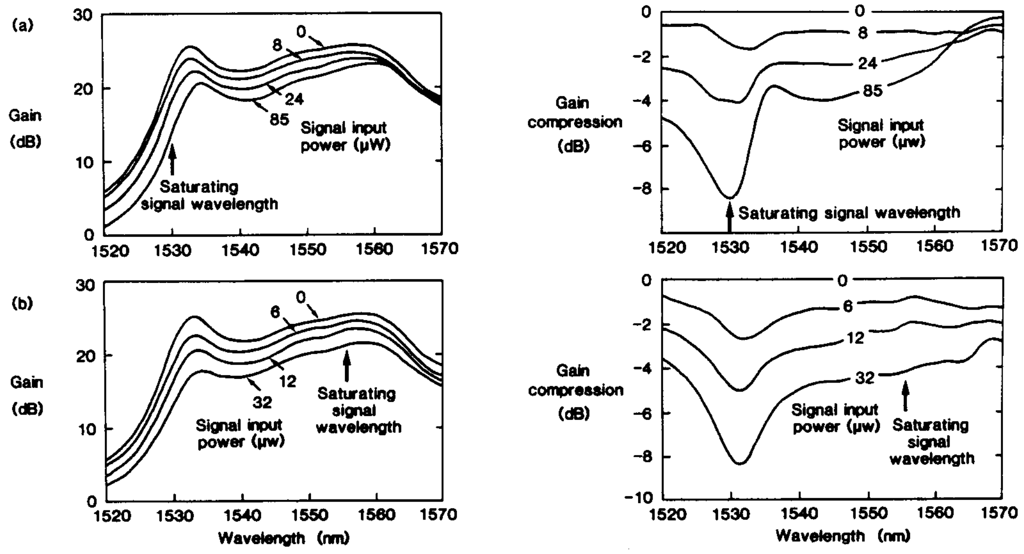

Fig.5 Gain spectra and corresponding gain compression obtained with a pump power of 15.2mW and increasing saturating signal power at the wavelengths (a) 1530nm and (b) 1555nm. A shift in the wavelength of maximum gain compression is observed in curve (a) due to spectral hole burning.

Figure 5 shows additional data obtained for a reduced pump power of 15.2mW. In this case the saturating signal wavelength was (a)1530nm and (b) 1556nm. For the saturating signal at 1556nm we note that the compession data is similar to that presented previously in figure 2(d). The wavelength of maximum gain compression, 1532nm, is seen to correspond to both the peak emission and absorption wavelength. However for the saturating signal at 1530nm we note that for small gain compression the peak compression occurs at 1532nm, whilst at deeper compression a spectral hole occurs and the peak gain compression occurs at the signal wavelength. In addition gain compression is relieved around 1538nm, a wavelength corresponding to a midpoint between Stark components[7].

CONCLUSION Either "gain-shaping" and 980nm pumping or 1.48μm pumping can be used to give a broad spectral gain. Both types of EDFA exhibit gain spectra which change when saturated. However, a 980nm "gain-shaped" amplifier exhibits a lower cross-saturation effect than a 1.48μm pumped amplifier. For example, for 1.48μm pumping a large signal at 1556nm sufficient to cause 5dB of gain compression at that wavelength, causes 10dB of gain compression at 1530nm. On the other hand for a "gain-shaped", 980nm pumped amplifier a 5dB compression at 1556nm gives only a 5.5dB compression at 1530nm.

In addition, we have made the the first observations of room temperature spectral gain hole-burning in EDFAs pumped by broad linewidth (~10nm) pump sources. The effect is small and gives rise to a less than 1dB change in gain compression across the gain band and confirms the near homogeneous nature of the erbium transition in germano-alumino-silicate glass. This effect will be of little consquence to future WDM systems.

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