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1.2dB/cm Gain in an Erbium:Lutecium Co-doped Al/P Silica Fibre

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Abstract

We report a peak gain of 1.2dB/cm at 1535nm in an Erbium:Lutecium codoped Al/P/Si fibre fabricated using a standard MCVD and solution doping technique. This is the highest gain per unit length yet reported in an Erbium doped fiber amplifier. The incorporation of Lutecium into the glass is shown to reduce the erbium ion clustering within the fiber.

The highest gain per unit length yet reported from an erbium doped fibre amplifier is 1dB/cm, obtained in a silicate glass fiber fabricated using a cullet-in-tube technique[1]. However, the background loss of this fiber was unacceptably high, primarily due to the high level of Iron contamination introduced through the original glass starting materials. This problem could be easily solved by using a standard MCVD preform fabrication technique, allowing the full potential for these heavily doped fibers to be explored. In this paper we report the properties of heavily doped P/Al/Si fibers fabricated using the solution doping technique. This glass composition is attractive due to the high rare earth solubility, particularity compositions with high levels of aluminium. We present results on two fibers, one a standard P/Al/Si composition[2] similar to that used in Er:Yb (fiber 1), the other has in addition a quantity of Lutecium (Lu) as a co-dopant (fiber 2). The approximate Er:Lu ratio in solution is ~1:10.

The peak absorptions for the two fibers (table 1) are 140dB/m for the Lu co-doped fiber and 95dB/m for other, both measured at 1535nm. The background loss for the two fibres is less that 0.5dB/m at 1200nm and the cut-off wavelength is around 1500nm in both cases. The saturation characteristics of the fibers have been measured using a high power 1535nm fiber laser and are shown in figure 1. We note that the unbleachable losses are low in both cases with the Lu co-doped fiber having an unbleachable loss corresponding to around 4% of the small signal absorption value, significantly less than the value obtained for fiber 1 (around 6%). The most likely source of unbleachable losses in these fibers is the presence of erbium ion clusters or ion pairs[3]. The fast energy transfer process occurring within these clusters leads to a high saturation power for some fraction of the erbium ions giving rise to an "unbleachable" loss. It would thus appear that fiber 2 has a lower fraction of clustered erbium ions, perhaps surprising given that the erbium concentration is substantially higher in this fiber. Normally the degree of erbium ion clustering increases with an increase in the erbium ion concentration[3]. We explain the reduction in the clustering and hence unbleachable loss in this fiber as due to the presence of the Lu co-dopant. Indeed we have recently seen similar effects in Yb:Er co-doped fibers, where the presence of Yb ions appears to significantly reduce the level of erbium ion clustering.

The small signal gain at 1535nm, as a function of 980nm pump power (Ti: sapphire laser) is shown in figure 2 for the Lu co-doped fiber. The fiber length is 12 cm and we measure a maximum gain of 14dB for around 300mW pump, corresponding to a small signal gain of 1.17dB/cm the highest figure yet reported for an erbium doped fiber amplifier. Using an absorption coefficient α=1.4dB/cm (figure 1) and a ratio for the emission /absorption cross section of 0.95[4] we estimate the gain coefficient g=1.33dB/cm. The gain may be calculated $G=(N2*g - N1*\alpha)$[5]. From figure 1 we estimate the maximum inversion, N2=0.96 (assuming 4% of the ions are unbleachable) giving a maximum small signal gain G=1.22dB/cm. This value is in reasonable agreement with our measured value in figure 2 at 270mW pump.

The measured quantum conversion efficiency (QCE) for fiber 2 is shown in figure 3, where we have obtained a maximum QCE of 8% in a 16cm length of fiber. A relatively low QCE in such highly doped fibers is a sign of homogeneous upconversion[6], confirmed by a shortening of the metastable lifetime when the fiber is pumped at high powers. At high pump rates the fluorescence decay curve may be fitted to a double exponential with decay constants of 250μs and 6ms, as compared with the single exponential decay at low powers (9.5ms). Although the onset of homogenous upconversion can be reduced by significantly changing the glass composition, as achieved in planar waveguide devices, this can be at the expense of the fluorescence bandwidth. Significantly, the incorporation of small amounts of lutecium does not adversely affect the gain spectrum and may have applications in reducing erbium ion clustering in Ge/Al/Si fibers which are more susceptible to clustering than P/Al/Si ones .

In conclusion we have fabricated heavily doped Er-Lu/P/Al/Si fibers that indicate the incorporation of lutecium significantly decreases the unbleachable losses in these fibers. In a fiber with 1.4dB/cm absorption we have measured almost 1.2dB/cm gain at 1535nm, the highest gain per unit length yet reported for an erbium doped fiber amplifier. Homogeneous upconversion limits the quantum conversion efficiency in this fiber to around 8%.

Acknowledgements

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Table 1: Properties of erbium doped P/Al/Si fibers

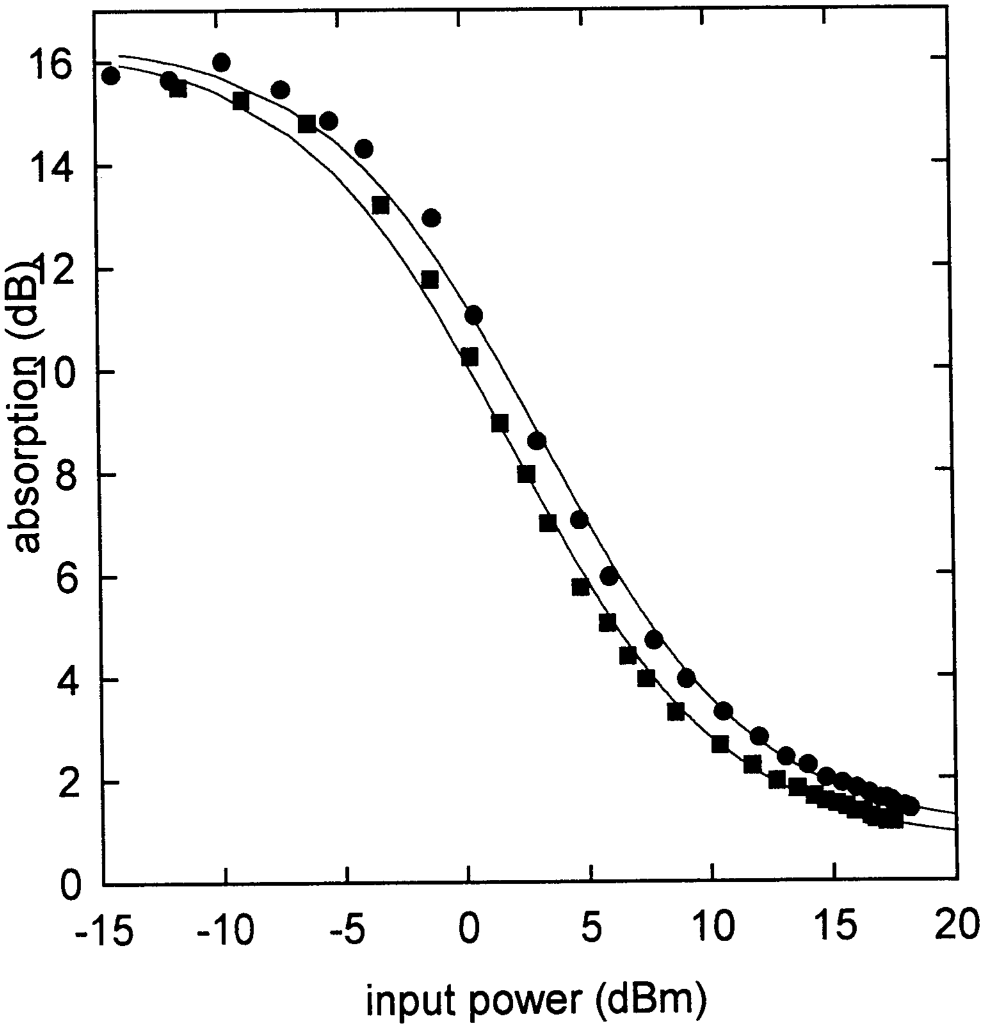
Fiber	composition	Peak Absorption	Unbleachable Loss
1	P/Al/Si	95dB/m	6%
2	Lu/P/Al/Si	140dB/m	4%

Figure captions

Fig 1. Saturation characteristics for fiber 1(●) and fiber 2(■) measured at 1535nm. The fiber lengths are 17cm and 11cm respectively.

Fig. 2. Measured small signal gain for 12cm length of fiber 2 pumped at 980nm.

Fig. 3. Measured quantum conversion efficiency for 16cm length of fiber 2 measured with 270mw of 980nm pump.



16
14
12
10
8
6
4
2
0
-15
-10
-5
0
5
10
15
20
absorption (dB)
input power (dBm)

Fig 1

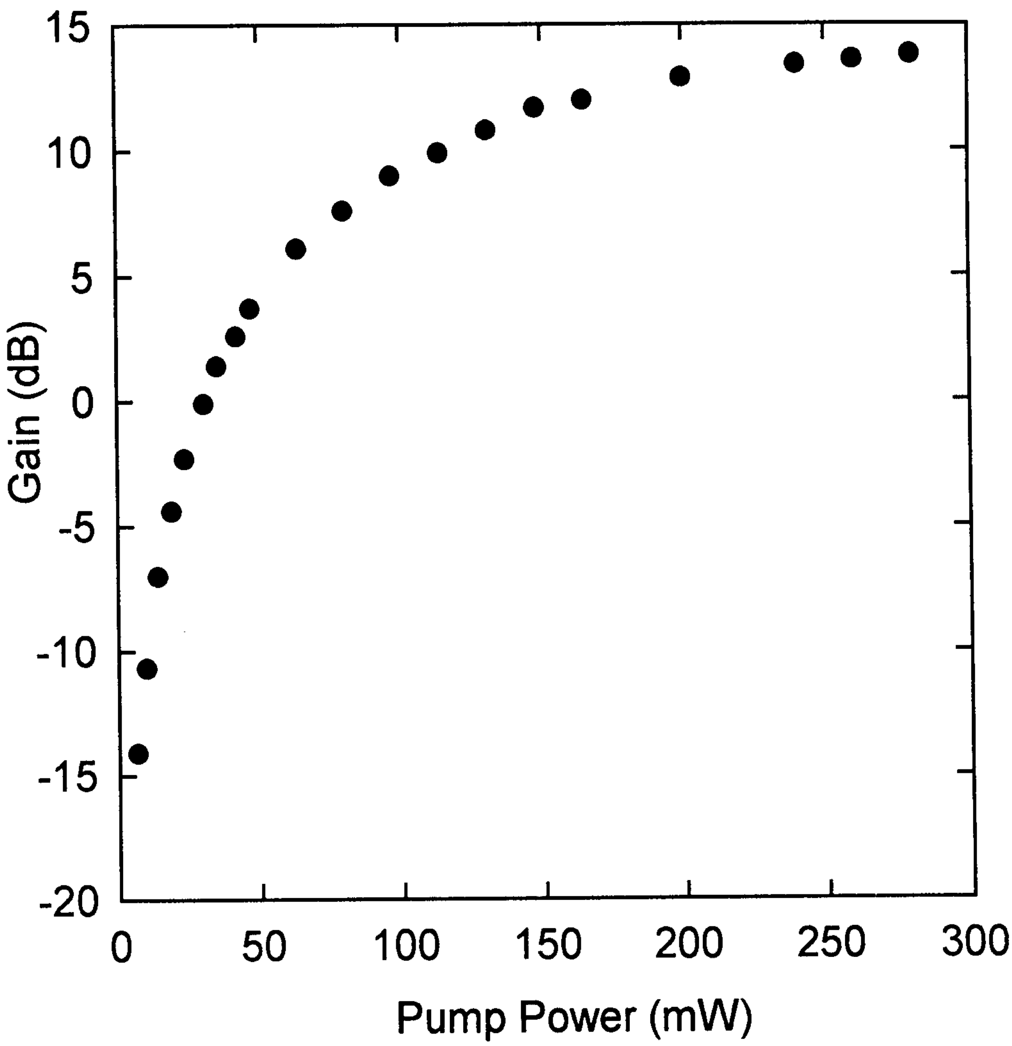


Fig 2

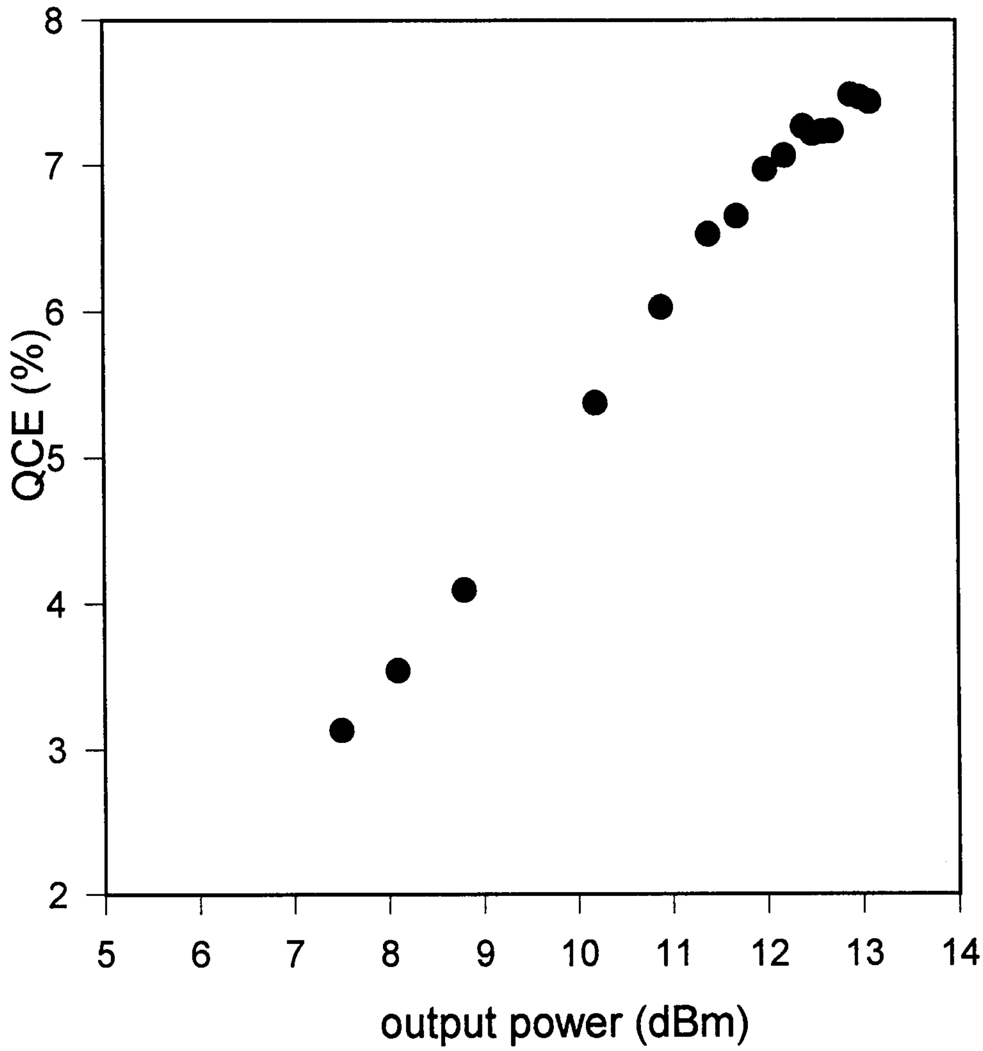


Fig 3