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859

Dysprosium Doped Ga:La:S Glass for an Efficient Optical Fibre Amplifier Operating at 1.3μm

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Abstract

We present experimental results which indicate that a Dy^{3+}-doped Ga:La:S glass fibre amplifier may be operated efficiently at 1.3μm with an optimum device length significantly shorter than a comparable Pr^{3+}-doped one. Moreover, the efficiency exceeds that obtained from the Pr^{3+}-doped ZBLAN devices currently available.

Introduction

Despite its success as an optical power amplifier[1], Pr^{3+}-doped ZBLAN has failed to provide a reasonably efficient small signal fibre amplifier for operation within the second telecoms window. This is predominantly due to the low quantum efficiency (~3%) for the 1.3μm transition in Pr^{3+}-doped ZBLAN glass. Incorporation of Pr^{3+}-ions into a lower phonon energy glass, such as Gallium-Lanthanum-Sulphide, has been shown to increase dramatically the quantum efficiency of the 1.3μm transition to ~30%[2] (based on a branching ratio of 0.5, this value corresponds to a total radiative quantum efficiency of ~60%). However, initial fibres made from such materials are expected to have a relatively large background loss, making the optimum device length a critical parameter. In this paper we present experimental results that indicate the quantum efficiency for the 1.3μm transition in Dy^{3+}-doped Ga:La:S glass is ~19%. Furthermore the large cross sections for this transition imply relatively short device lengths and indeed numerical modelling indicates an optimum device length one tenth that of a comparable Pr^{3+}-doped one. This substantially relaxes the background loss requirements of the fibre.

Results and Discussion

The energy level diagram for the Dy^{3+}-ion is shown in figure 1. The transition of interest for 1.3μm emission is from the $^6H_{9/2}$-$^6F_{11/2}$ doublet to the ground state $^6H_{15/2}$. Despite the relatively small energy gap ($1800cm^{-1}$) between this doublet and the next lowest energy level ($^6H_{11/2}$) we have measured the 1.3μm emission spectrum from Dy^{3+}-doped Ga:La:S glass. The peak emission wavelength (λ_{pk}) is ~1320nm with a FWHM ($\Delta\lambda$) of 85nm. This peak emission wavelength is significantly shorter than the 1340nm peak obtained from Pr^{3+}-doped Ga:La:S glass.

Shown in figure 2 is the ground state absorption cross section for the $^6H_{9/2}$-$^6F_{11/2}$ doublet, obtained by scaling the measured infra-red absorption spectrum using the known Dy^{3+}-ion concentration. The emission cross section obtained from a M^{c}Cumber transform of the absorption spectrum is shown in figure 2, where we have followed the method of Miniscalco and Quimby in order to estimate the free energy factor[3]. Also shown for comparison is the measured emission spectrum. The agreement between the measured emission spectrum and the emission cross section as calculated by the M^{c}Cumber technique is satisfactory and justifies its use in this case.

Using the peak emission cross section and linewidth we can estimate the radiative rate ($W_{1.3\mu m}$) for the 1.3μm transition from[4]

$$W_{1.3\mu m} = \frac{8\pi n^2 c \Delta\lambda\, \sigma_{pk}}{\lambda_{pk}^4} \qquad -1$$

which gives a value $W_{1.3\mu m}$~3300sec^{-1}. We have measured the total lifetime for the doublet at ~59μs for Dy^{3+}-doped Ga:La:S glass. Thus we calculate the quantum efficiency for the 1.3μm transition ($QE_{1.3\mu m}=\tau W_{1.3\mu m}$) to be ~19%. This value compares with ~3% and ~30% for the 1.3μm transition of Pr^{3+}-ions in ZBLAN and Ga:La:S glass respectively[2].

Using the measured absorption and emission cross sections from figure 2, along with the radiative and non-radiative rates, we have modelled the expected small signal performance of a Dy^{3+}-doped Ga:La:S glass fibre amplifier. Within the model, the energy level diagram is simplified to that of a 3 level system and the propagation equations are solved for pump and signal along with the forward and backward propagating ASE. Thus, we neglect bottlenecking effects at any of the other energy levels, namely $^6H_{11/2}$ and $^6H_{13/2}$, since we anticipate the use of a co-doping scheme involving Tb^{3+} and/or Eu^{3+} along with the Dy^{3+} ions in order to shorten the lifetime of these energy levels through resonant energy transfer.

The device is pumped at 1240nm, and the fibre parameters are NA=0.4, cutoff wavelength 900nm, device length=1.3m and Dy^{3+}-doping level 500ppm. The effect of background loss on the amplifier gain is also included within the model and we adopt a co-directional pumped configuration. The predicted small signal gain is shown in figure 3 and compared with the expected performance of a 500ppm Pr^{3+}-doped Ga:La:S amplifier with similar NA and cutoff wavelength and utilising an optimised fibre length of 12m for 0.1dB/m background loss. Also shown are the experimental results of Yamada *et al*[5] for a Pr^{3+}-doped ZBLAN fibre amplifier using a double pass pump configuration.

In the case of low background loss (0.1dB/m) the Pr^{3+}-doped Ga:La:S device has a superior performance compared to a Dy^{3+}-doped one. However this level of background loss is rather optimistic for Ga:La:S fibre and we see from figure 3 that a background loss as high as 1dB/m does not strongly affect the performance of the Dy^{3+}-doped device. This is not the case for the Pr^{3+}-doped Ga:La:S device where this level of background loss is clearly shown in figure 3 to decrease the maximum available gain by ~10dB. Although increases in the Pr^{3+} concentration above 500ppm may shorten the device length, this is only achieved at the expense of a decrease in the amplifier efficiency due to ion-ion interactions. We estimate that the optimum length for a Dy^{3+}-doped device is about one tenth that for a comparable Pr^{3+}-doped one.

One further advantage of the Dy^{3+}-doped Ga:La:S glass is the shorter peak emission wavelength when compared with Pr^{3+}-doped Ga:La:S, thus the peak of the amplifier gain curve will be closer to the zero dispersion wavelength found in standard telecom fibre (1310nm).

Conclusion

We have presented results that indicate a Dy^{3+}-doped Ga:La:S optical fibre amplifier may be operated efficiently at 1.3μm with an optimum device length significantly shorter than a comparable Pr^{3+}-doped one. Furthermore the efficiency easily exceeds that available from the current Pr^{3+}-doped devices making a practical laser diode pumped 1.3μm optical fibre amplifier a distinct possibility.

Acknowledgements

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References

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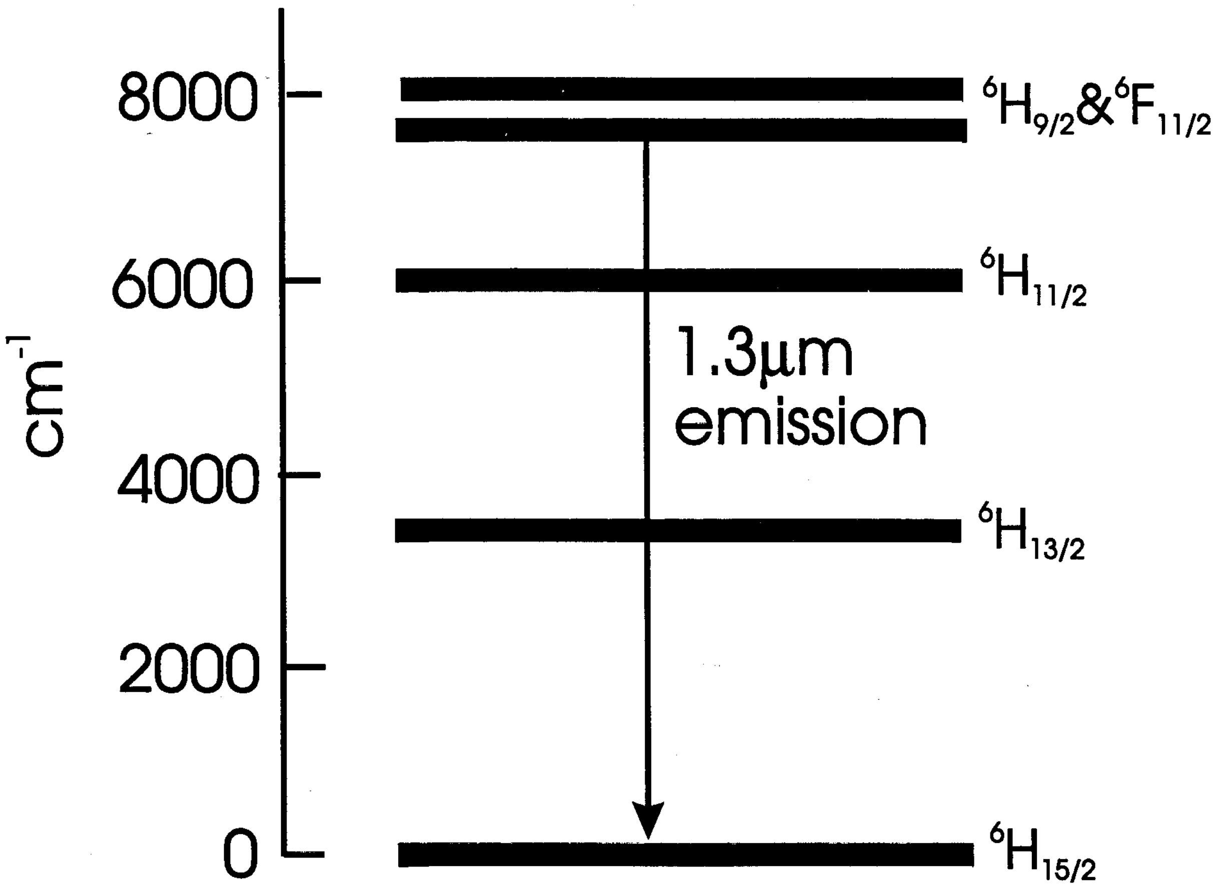
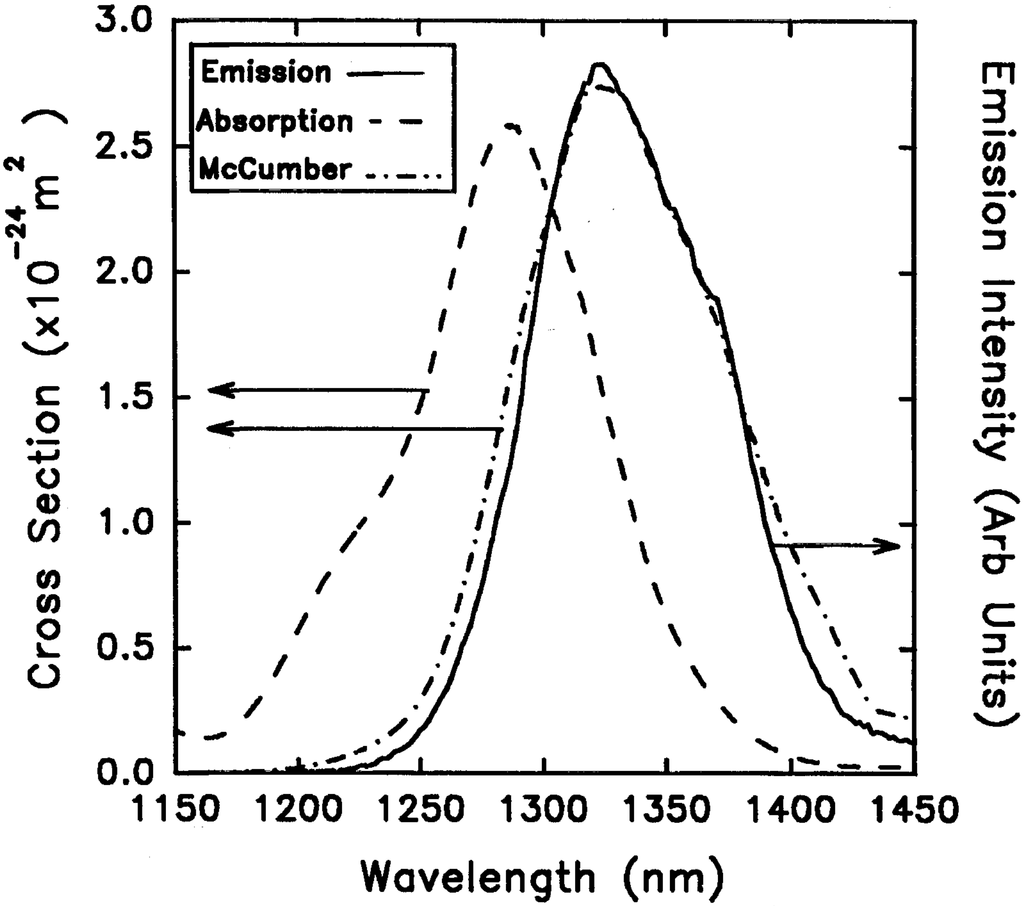
Figure Captions

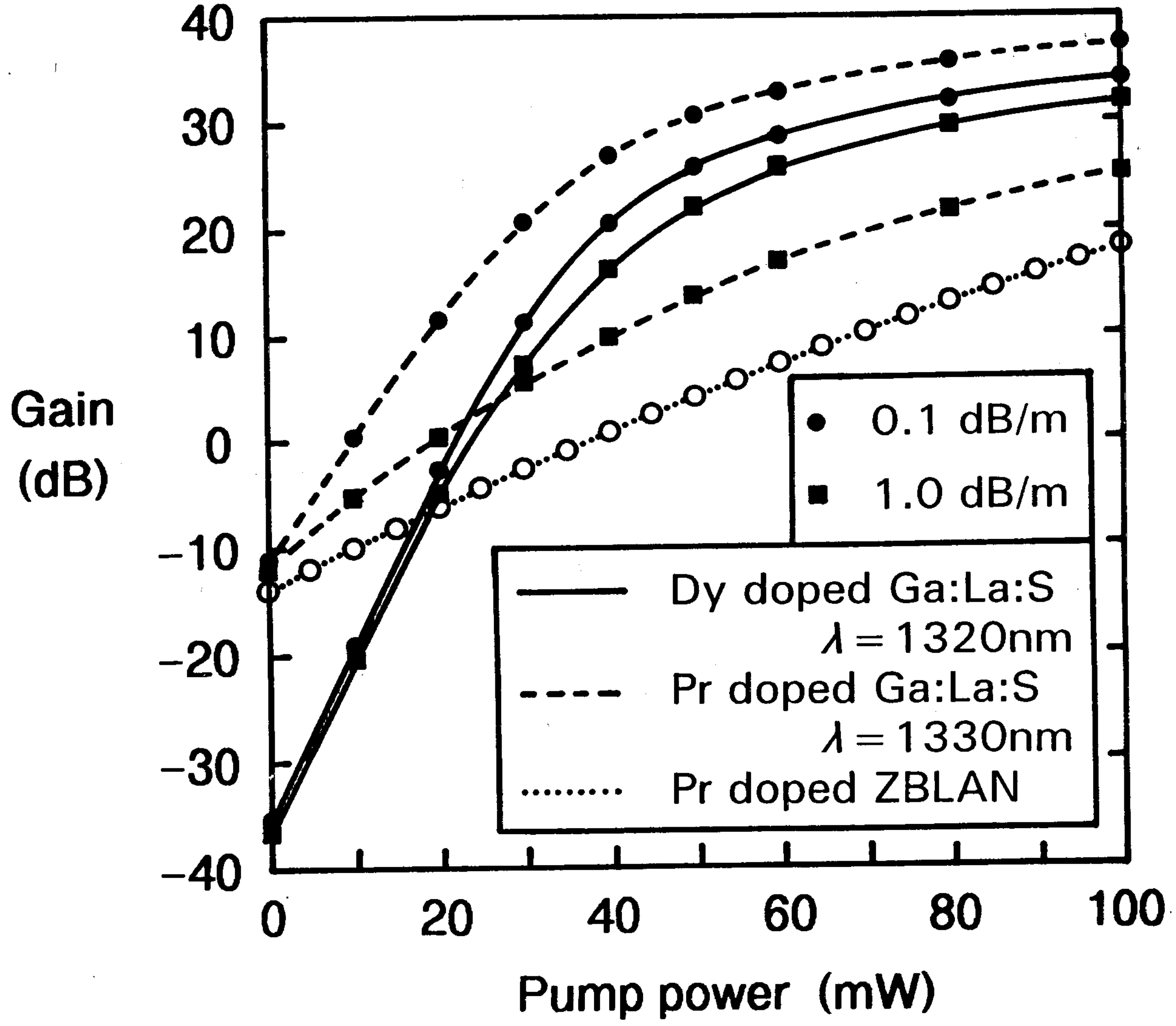
1. Dy^{3+}-ion energy level diagram.

2. Absorption and emission cross sections for Dy^{3+}-doped Ga:La:S glass. The emission cross section obtained by a $M^cCumber$ transform of the absorption is compared with the measured emission spectrum.

3. Numerical modelling results for Dy^{3+}- and Pr^{3+}-doped Ga:La:S glass fibre amplifiers with background loss ●=0.1dB/m and ■=1dB/m. The Pr^{3+}-doped ZBLAN data are experimental results of ref 5.


cm^{-1}
8000
6000
4000
2000
0
$^6H_{9/2}$&$^6F_{11/2}$
$^6H_{11/2}$
1.3µm emission
$^6H_{13/2}$
$^6H_{15/2}$


Emission
Absorption
McCumber
Cross Section (x10^{-24} m^2)
Emission Intensity (Arb Units)
Wavelength (nm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1150
1200
1250
1300
1350
1400
1450


Gain
(dB)
40
30
20
10
0
−10
−20
−30
−40
0
20
40
60
80
100
Pump power (mW)
● 0.1 dB/m
■ 1.0 dB/m
Dy doped Ga:La:S
λ = 1320nm
Pr doped Ga:La:S
λ = 1330nm
Pr doped ZBLAN