CLEO '91

325

Gain and excited state absorption in Neodymium doped optical fibre lasers.

P.R.Morkel, M.C.Farries & D.N.Payne.

Optical Fibre Group
Dept. of Electronics and Computer Science
University of Southampton
Southampton SO9 5NH, UK.
Tel: (0703) 559122

ABSTRACT

Gain and excited state absorption for a diode pumped Nd^{3+} doped silica fibre laser have been measured in the wavelength range 900-1400 nm. The results show a strong excited state absorption in the range 1100-1400 nm in addition to gain at 938 & 1088 nm.

296

Gain and excited state absorption in Neodymium doped optical fibre lasers.

P.R.Morkel, M.C.Farries & D.N.Payne.

Optical Fibre Group
Dept. of Electronics and Computer Science
University of Southampton
Southampton SO9 5NH, UK.
Tel: (0703) 559122

SUMMARY

Fibre lasers made from Nd^{3+} doped silica operate efficiently at 1088 nm and 938 nm, corresponding to the $^4F_{3/2}$ - $^4I_{11/2}$, $^4I_{9/2}$ transitions in glass [1,2], but not on the $^4F_{3/2}$ - $^4I_{13/2}$ transition which normally occurs at 1370 nm [3]. It has been supposed that this is due to excited-state absorption in the fibre but thus far no detailed measurements have been reported. We report here measurements of gain and excited state absorption over the wavelength range 900 - 1400 nm covering the three common transitions in Nd-glass lasers. The results confirm a strong pump-induced absorption centred at 1300 nm.

A 3.7 m length of optical fibre with 300 ppm Nd^{3+} doping (1.9 m 1/e absorbtion length) was pumped through a beam splitter with a semiconductor laser operating at 827 nm (fig.1). The total absorbed power, measured using a cutback method, was 2.2 mW. With white light counter-propagating in the fibre the effects of gain and excited state absorption under pumping were monitored through a monochromator. The total power in the 500 nm white light bandwidth was -24 μW so gain saturation effects can be ignored (small signal approximation).

The results (fig.2.) show the effect of pumping the fibre. The dashed curve shows the ratio of pumped and unpumped fibre output and indicates the regions over which stimulated emmision and excited-state absorption take place. Including the unpumped loss of the fibre gives the solid curve which therefore indicates the single pass gain or loss of the fibre as a function of wavelength. The dotted curve shows the fluorescence output of the fibre under the same pumping conditions for comparison with the gain curve. Gain is seen at 1088 & 938 nm which is consistent with the lasing properties of the fibre at these wavelengths.

At 1300 nm we see that a loss > 2dB is induced by pumping the fibre, indicating that an excited state absorption exists. That is, there exists a level above the metastable $^4F_{3/2}$ level which coresssponds to a 1300 nm transition. Only when the

$^4F_{3/2}$ level is populated by pumping is this absorption observed. Although the $^4F_{3/2}$ - $^4I_{13/2}$ fluorescence is seen to peak at around 1370 nm, no gain is seen at this wavelength. This implies that any stimulated emission is being counteracted by the excited state absorption centred on 1300 nm. Note also that the observed excited state absorption extends into the gain at approximately 1160 nm and thus limits the potential long wavelength tuning range of a laser operating on the $^4F_{3/2}$ - $^4I_{11/2}$ transition [4].

Using measurements of the spectral absorption of the fibre at a number of temperatures, we have been able to construct a partial Dieke diagram for Nd^{3+} in GeO_2 doped silica (fig.3). The excited state absorption is attributed to excitation from the $^4F_{3/2}$ level to the $^2G_{9/2}$ & $^4G_{7/2}$ levels. These levels correspond to ground state absorption in the 500-550 nm band. The effect of the glass host is to broaden the excited state absorption into a continuum extending from ~ 1100-1400 nm which precludes lasing. Note however that a low loss window in the ground state absorption at 550 nm (corresponding to a gap between the $^4G_{7/2}$ and the $^2G_{7/2}$ levels) indicates the excited state absorption will drop sharply at ~ 1.4 μm. Since fluorescence here is still significant, laser action is possible and has recently been reported in a silicate fibre laser [5].

It is seen that employing optical fibre spectral loss measuring techniques to fibre lasers provides a powerful diagnostic tool for understanding the behaviour of various laser transitions in the presence of excited-state absorption. In particular, we see that for efficient operation on the $^4F_{3/2}$ - $^4I_{13/2}$ transition, a host glass composition which widens the low loss window at 550 nm is desirable.

REFERENCES

[1] Mears. R.J. et al. Neodymium-doped silica single-mode fibre lasers. Electronics letters. Vol. 21,17. pp 738-740, August 1985.

[2] Alcock I P, Ferguson A I, Hanna D C, & Tropper A C. Optics Comm. Vol 58. pp 405-408 1986.

[3] Koechner. W. Solid State Laser Engineering Springer Verlag, New York.

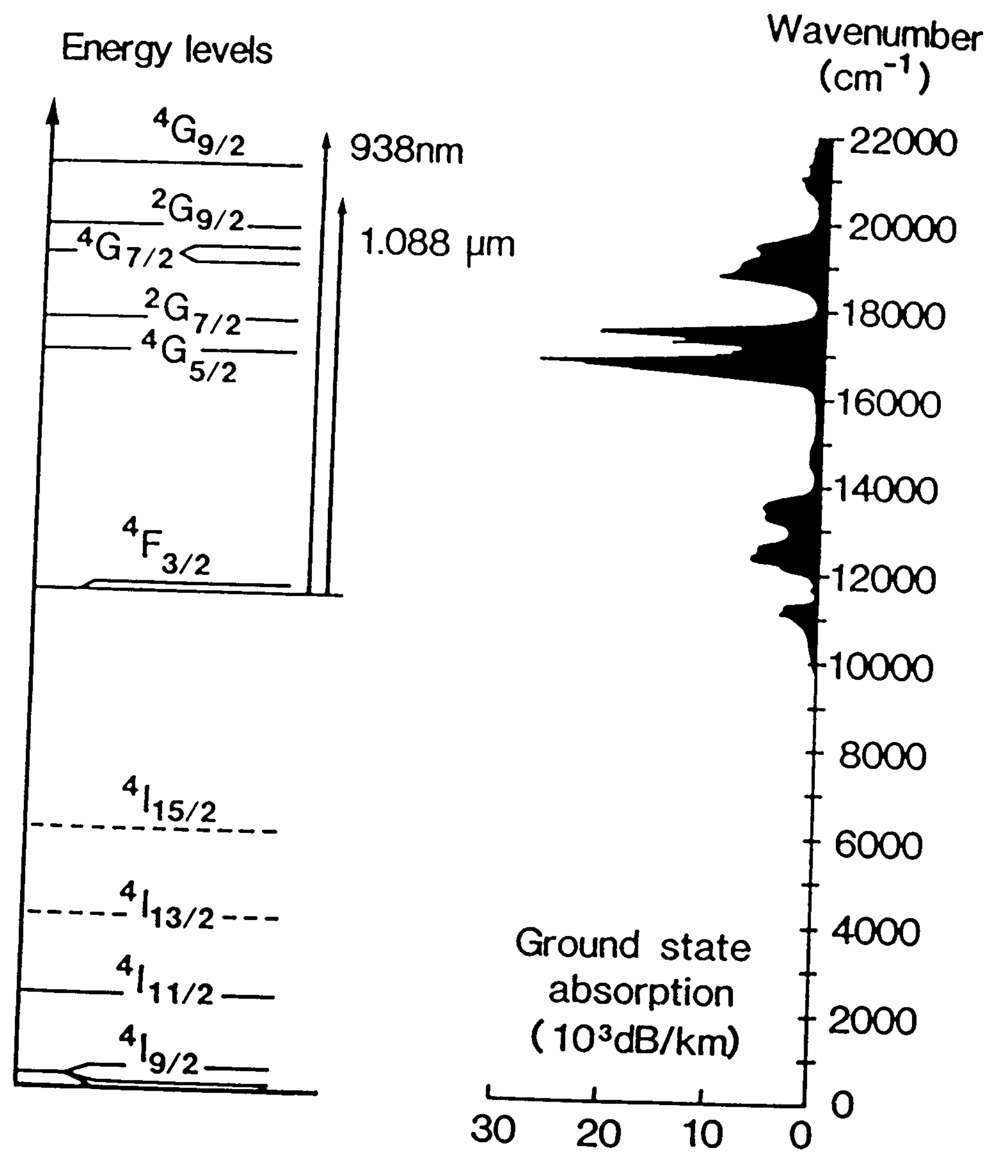
[4] Reekie. L. et al. Tunable Single-Mode Fiber Lasers. Journal of Lightwave Technology. Vol. LT-4, No. 7, July 1986.

[5] Po, H. et al. Nd^{3+} fibre lasers at 0.905, 1.06 & 1.4 m. Paper FD4, Report of 1986 ann. mtg. Opt. Soc. Am 1986 p103.

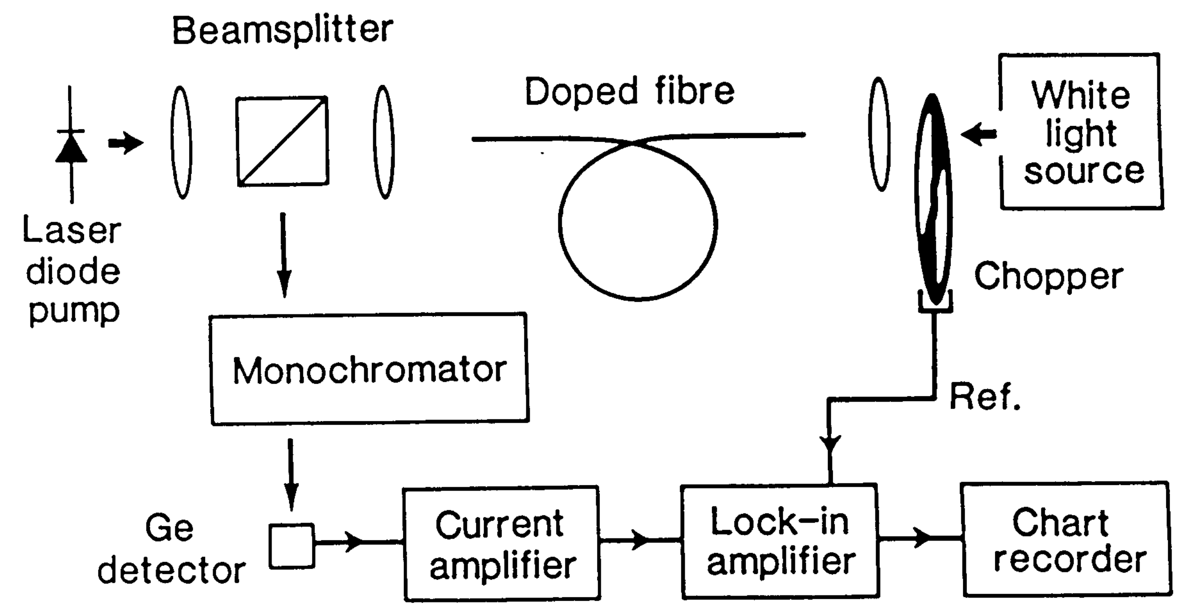
Fig.1. Experimental setup.

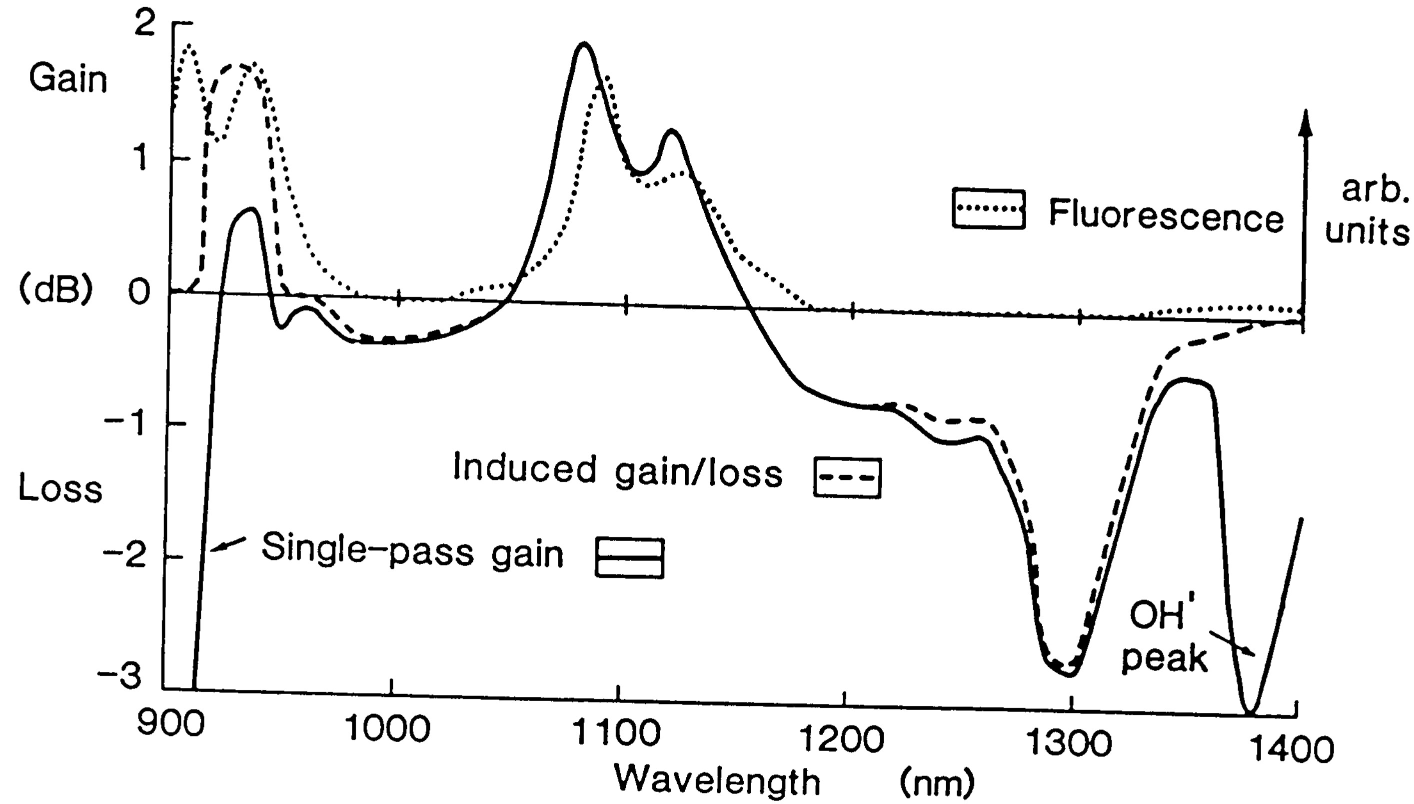
Fig.2. Induced gain, net single pass gain and fluorescence vs. wavelength.

Fig.3. Partial Dieke diagram for Nd^{3+} in GeO_2 doped silica. Solid lines represent measured levels.



Energy levels
4G9/2
2G9/2
4G7/2
2G7/2
4G5/2
4F3/2
4I15/2
4I13/2
4I11/2
4I9/2
938nm
1.088 μm
Wavenumber (cm-1)
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Ground state absorption (10³dB/km)
30
20
10
0


Beamsplitter
Doped fibre
White light source
Laser diode pump
Chopper
Monochromator
Ref.
Ge detector
Current amplifier
Lock-in amplifier
Chart recorder


Gain
(dB)
Loss
2
1
0
−1
−2
−3
Fluorescence
arb.
units
Induced gain/loss
Single−pass gain
OH'
peak
900
1000
1100
1200
1300
1400
Wavelength (nm)