Multi-Photon Effects in Rare-Earth-Doped Fibres

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Abstract

Energy transfer and frequency upconversion has been measured in optical fibres doped with less than 1% Yb^{3+} and 1% Er^{3+}. Efficient conversion of near infrared radiation (0.85-1.08um) into green(550nm), red(680nm) and infrared fluorescence has been observed and applications discussed.

Introduction

Co-doping of Er^{3+} with Yb^{3+} is known to improve the performance of Er-glass lasers via resonant, and phonon-assisted energy transfer from Yb^{3+} to Er^{3+} ions[1]. Furthermore, co-doping may provide a route to semiconductor-laser-pumped optical fibre amplifiers and lasers for telecommunications applications. The efficiency of energy transfer is mainly governed by dipole-dipole interactions[2], which fall off as R^{-6}, where R is the mean ion separation. Energy-transfer quantum efficiencies approaching 100% have been achieved in bulk laser glasses doped with >5% Yb^{3+} and 0.3% Er^{3+}. Here we show that in optical fibres doped with less than 1% of the dopant ions in the silica matrix, efficiencies of 50% may be achieved because clustering of the dopant ions in the silica matrix leads to a relatively-high local dopant concentration[3].

Energy-transfer in fibres co-doped with Yb^{3+}/Er^{3+} also leads to photon accumulation, which may be exploited for frequency-upconversion[4] and in fibre sensors.

Experiment

Two fibres with average Yb^{3+} and Er^{3+} concentrations of 1900ppm and 560ppm; and 4500ppm and 1100ppm, were fabricated by a solution-doping technique[5]. The absorption spectrum of the first fibre is shown in Fig.1. Fluorescence spectra from the $^4I_{13/2}$ level were obtained by pumping with a dye-laser, Raman-shifted in a hydrogen cell with a tuning range from 600nm to 1100nm. The pulse width was 6ns and the peak power launched into the fibres varied between 1W and 10W. The resulting fluorescence after passing through a monochrometer to remove the unwanted pump radiation was detected by an InGaAsP photodiode. The fibre length was typically 10cm. The higher energy-levels in Er^{3+} were excited by a Q-switched Nd-YAG laser operating at 1.064um and the fluorescence was detected by a photomultiplier.

Results

1) Fluorescence from the $^4I_{13/2}$ level

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Fluorescence spectra from the $^4I_{13/2}$ level in Er^{3+} were obtained by exciting either the $^2F_{5/2}$-level in Yb^{3+} (904nm) or the $^4F_{9/2}$ level in Er^{3+}(650nm). The measured fluorescence intensity from fibre 1, normalised to the absorbed pump power and corrected for absorption of the fluorescence in the fibre is shown in Fig. 2. It is seen from Fig. 2 that approximately 50% of the absorbed pump radiation results in fluorescence around 1535nm in erbium by energy transfer from ytterbium, the remainder producing fluorescence around 975nm in the ytterbium itself. No difference in transfer efficiency could be detected between fibres 1 and 2. The relative fluorescence efficiency is an order of magnitude higher than that predicted from the mean ion separation expected at these dopant levels[4]. We therefore assume that clustering of Yb^{3+} and Er^{3+} ions occurs in these fibres, thus reducing the effective ion separation.

2) Fluorescence from the $^4S_{3/2}$ and $^4F_{9/2}$ levels

The fluorescence spectrum due to frequency upconversion of 1064nm pump light is shown in Fig. 3. A conversion efficiency of 10^{-5} into green fluorescence was obtained with a peak pump power of 5W. The fluorescence intensity from the $^4F_{9/2}$-level as a function of input intensity is shown in Fig.4. Decay times were obtained for the $^4S_{3/2}$ and $^4F^{9/2}$-levels of 0.6 ,and 1.0us, respectively. Although the intensity of the visible fluorescence is several orders of magnitude less than in the infrared, the availabilty of very good detectors enables the fluorescence to be easily detected and the fibre may thus be used as a remote temperature sensor based on the difference in temperature dependence of the efficiency of green and red fluorescence[5].

Conclusions

Fluorescence from the $^4I_{13/2}$, $^4I_{9/2}$ and $^4F_{9/2}$ levels due to energy transfer from Yb to Er has been measured in silica optical fibres. The efficiency of energy transfer is estimated to be 50% and the efficiency of frequency-upconversion was measured as 10^{-5} with an input power of 5W at 1.064um. These processes may find many applications in active devices and fibre sensors.

References

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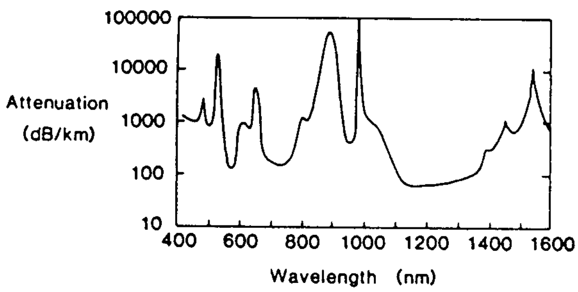

Fig. 1. Absorption spectrum of fibre doped with 4500 ppm Yb^{3+} and 1100 ppm Ev^{3+}

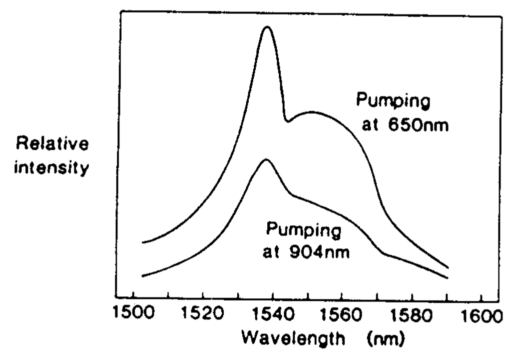

Fig.2. Fluorescence spectrum from the $^4I_{13/2}$ level in Er^{3+} under ecitation at 650nm and 904nm.

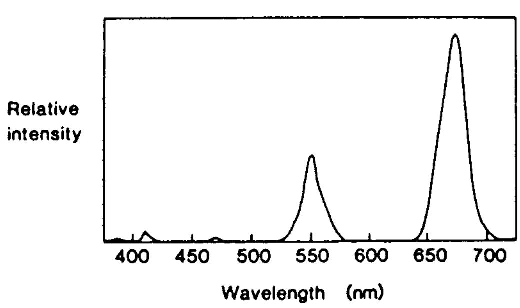

Fig 3 Visible fluorescence spectrum excited at 1064nm in an Yb^{3+}/ Er^{3+} -- doped fibre.

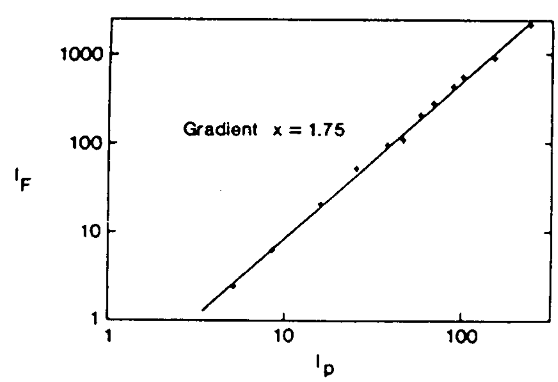

Fig.4 Fluorescence intensity from the $^4F_{9/2}$ level as a function of input intensity.