Photon-Avalanche Upconversion of Red Light into Blue Light in a Thulium-Doped Fluorozirconate Fibre

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Abstract

We report the investigation of the photon-avalanche effect in heavily Thulium-doped fluorozirconate fibre. Pumping at red wavelengths, which are not resonant with the ground-state absorption, gives blue emission at 450nm and 480nm.

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Summary

Room temperature, continuous-wave, blue upconversion lasers based on Thulium doped fluorozirconate fibre have previously been demonstrated at 480nm[1] and 450nm[2]. Here we report the spectroscopic investigation of photon-avalanche pumping of these blue emissions, which is not reliant on resonant ground state absorption and so allows new pumping wavelengths.

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The avalanche effect may occur where an efficient cross-relaxation energy- transfer leads to a build up of population in an excited-state from which a resonant absorption occurs to a higher level. Such avalanche pumping has already been used to obtain laser action in several different systems[3]. The energy level diagram for Tm with the avalanche pumping scheme is shown in fig.1. The non-resonant absorption from the ground state populates the $^3F_2$ level which relaxes non-radiatively to the $^3H_4$ level. From here many excitation routes are possible including resonant excited state absorptions from $^3F_4$ to $^1G_4$ and $^3H_4$ to $^1D_2$, and several cross-relaxations processes which help to feed population into the $^3F_4$ level. The overall effect is to build up a large population in the long-lived $^3F_4$ level such that the pump absorption changes dramatically from a very low to a very high value. The dominant radiative transitions give rise to fluorescence at 450nm ($^1D_2$ to $^3F_4$) and 480nm ($^1G_4$ to $^3H_6$).

The fibre used in these experiments, which was heavily doped with Tm (3.2wt.%) and had a 5μm core diameter with a numerical aperture of 0.17, was grown by CNET. Kyton Red and DCM dye lasers were used as the pump source. The pump absorption, fluorescence rise time and output intensity were measured as the pump power was increased and characteristic avalanche behaviour, such as a threshold and high order pump dependance, was observed. Rise times of over 100ms were observed near the avalanche threshold which is considerably longer than any of the normal lifetimes of the levels involved. At high pump powers the pump absorption and fluorescence signal were seen to show decaying oscillations before a steady state was achieved. Excitation spectra show peaks resonant with excited state absorptions at 649nm and 633nm rather than the ground state absorption

(657nm) and the time evolutions of the excitation and fluorescence spectra show the effect of the build up of excited state populations.

In summary, we have observed for the first time avalanche upconversion in Tm:ZBLAN fibre. The excitation spectra show that this allows new pumping wavelengths for obtaining blue emission. We aim to test the possible laser performance of an avalanche pumped Tm:ZBLAN fibre and to investigate other pumping wavelengths which may give an avalanche effect and which may be more conveniently available than those which rely on ground state absorption.

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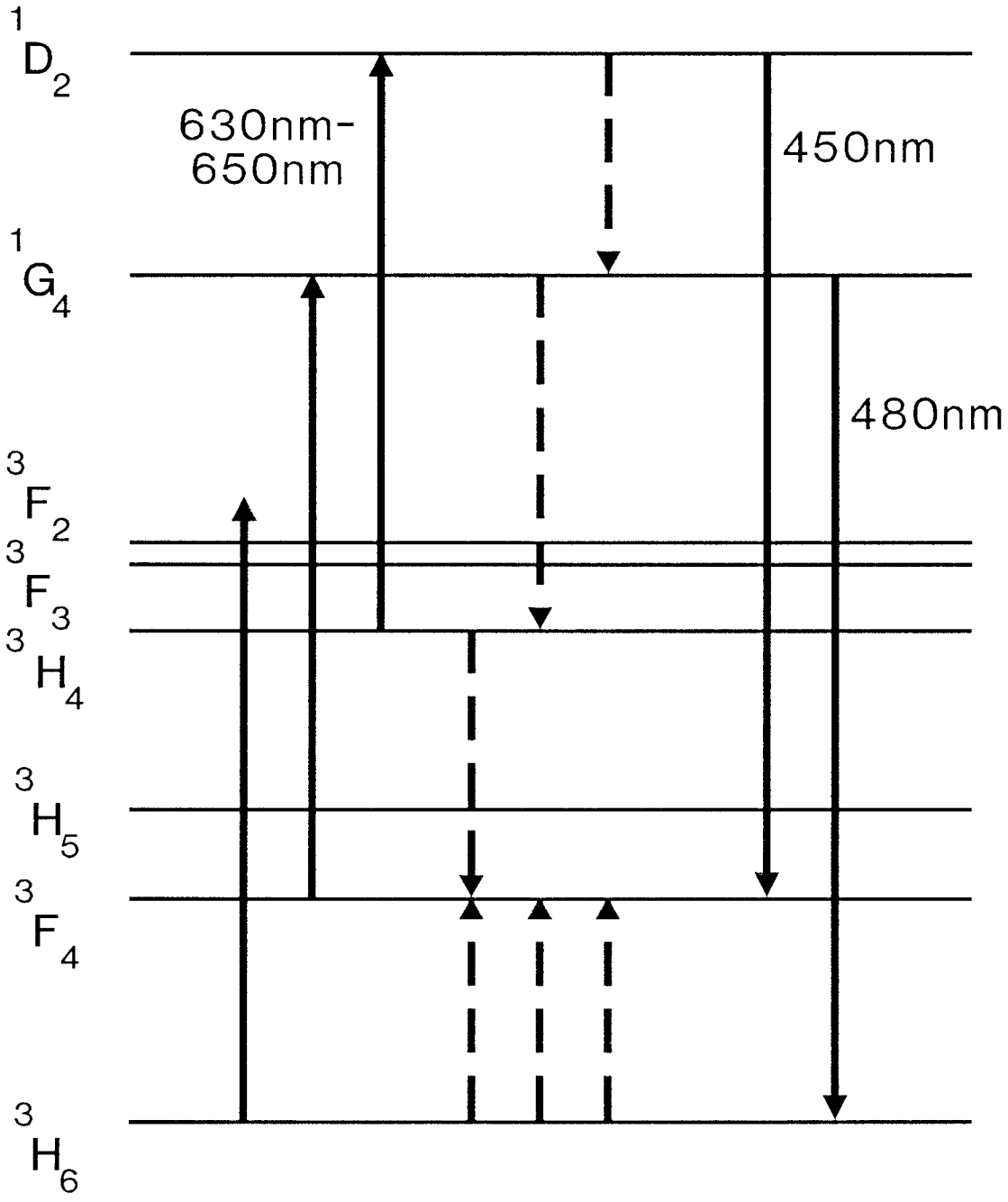
Figure Captions

Fig. 1 Avalanche upconversion in Tm:ZBLAN


$^1D_2$
630nm-
650nm
450nm
$^1G_4$
480nm
$^3F_2$
$^3F_3$
$^3H_4$
$^3H_5$
$^3F_4$
$^3H_6$