Characterization of two-photon processes by Photoacoustic Spectroscopy

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In the present work, it is demonstrated that photoacoustic spectroscopy can be used to characterize two-photon transfer processes in $LiNbO_3$: Er/Yb. The photoacoustic response of the material, compared to the luminescence spectrum, can be used to determine the macroscopic coefficient which describes the two photon up-conversion dynamics. The value obtained (C_{26} = 1.0 10^{-15} cm^3 s^{-1}) agrees with theoretical estimations from Judd-Ofelt calculations.

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It has been recently demonstrated [1] the operation of optical amplifiers based on $LiNbO_3$:Er^{3+}/Yb^{3+} which provide optical amplification at 1.5 μm ($^4I_{13/2} \rightarrow {}^4I_{15/2}$ Er^{3+} transition). It has been also demonstrated that pumping via energy transfer after Yb^{3+} excitation at 980 nm improves the amplifier performance [2].

While at moderate pumping levels, the pumping mechanism corresponds to a one-photon process, at high pumping levels two photon processes become relevant. At 980 nm pumping, the main two-photon process corresponds to cooperative up-conversion involving Er^{3+} + Yb^{3+} excited states. This mechanism obviously affects the excited state population dynamics and an adequate description of their efficiency is needed for a realistic evaluation of the amplifier characteristics.

An examination of the Er^{3+}/Yb^{3+} energy levels and the effects of the two photon cooperative energy up-conversion shows that new de-excitation channels, with sizable non-radiative contributions, are activated.

In the present work, it is demonstrated that these two-photon processes modify the photoacoustic response of the material, and this information is used to determine the efficiency of the two photon up-conversion terms. The value obtained (C_{26} = 1.0 10^{-15} cm^3 s^{-1}), agrees with estimations from Judd-Ofelt calculations [3].

Experimental

Materials

The Er^{3+}/Yb^{3+} codoped crystal used in this work was grown by the Czochralski method with automatic diameter control by crucible weighting system [4]. Dopant concentrations in melt were 0.5 and 1.5 mol %, Er^{3+} and Yb^{3+} respectively. Rare-earth concentrations in the crystal were 0.63/1.95 mol % Er^{3+}/Yb^{3+} respectively, as determined from x-ray Fluorescence Spectrometry.

Apparatus

A Titanium-Sapphire laser pumped with an Argon ion laser was used as CW infrared excitation source. The excitation beam was modulated at 40 Hz using a mechanical chopper.

The luminescence and photoacoustic excitation spectra were taken synchronously. Both signals were averaged and recorded using an EG&G lock-in amplifier model 7220 DSP. The luminescence signal was analyzed through an ARC monochromator model SpectraPro 500-i and then detected by an InGaAs photodiode. The photoacoustic signal was detected by using a resonant piezoelectric transducer [5].

Results and discussion

Figure 1 shows the energy levels of Er^{3+} and Yb^{3+} ions and the different energy transfer mechanisms operating after 980 nm pumping [3].

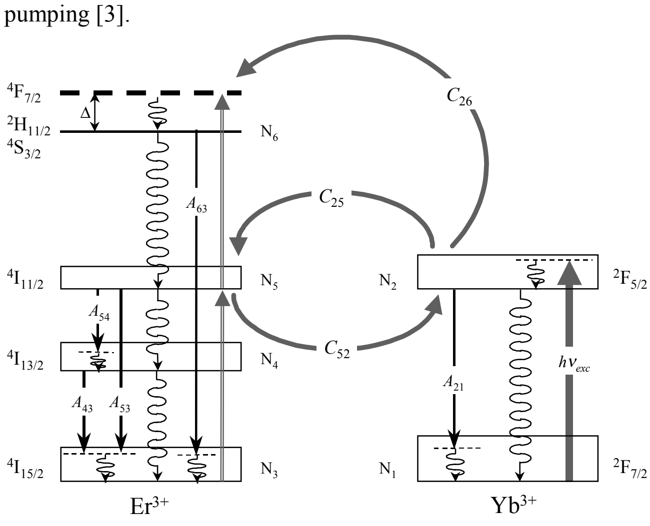

Fig. 1 Schematic energy level diagram including the cross relaxation mechanisms and the dominant emissions after selective ytterbium excitation.

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