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Cr-SENSITIZED RARE EARTH GARNET LASERS AT ROOM TEMPERATURE

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We report on fundamental laser properties of Cr-sensitized Nd, Tm, Ho, and Er-garnets as YAG, YSAG, YSGG, GSAG, and GSGG. Due to the Cr-sensibilization the lasers have high efficiencies under laser and flashlamp pumping.

1. Introduction

In garnets, with a low crystal field for the octahedral site, Cr\(^{3+}\) is known as a suitable, tunable four-level laser ion \(^{111}\), as well as an efficient sensitizer for Nd\(^{3+}\) \(^{121}\). The sensitizing effect is not only restricted to the acceptor Nd\(^{3+}\), but is also useful for several rare earth ions like Tm\(^{3+}\), Ho\(^{3+}\), and Er\(^{3+}\) \(^{131}\). The excellent sensitizing effect of Cr\(^{3+}\) is due to a resonant dipole-dipole interaction with the rare earth ions Nd\(^{3+}\), Tm\(^{3+}\), Ho\(^{3+}\), and Er\(^{3+}\).

2. Cr,Nd:GSGG

In spite of the statistics of the Cr-Nd-spacings, Cr- and Nd-concentrations of \(1*10^{20} \text{ cm}^{-3} \) insure an efficient dipole-dipole transfer with a quantum efficiency of 86 % \(^{2}\). Under laser pumping into the \(^{4}T_2\) Cr absorption band power slope efficiencies up to 41 % have been observed \(^{2}\). Under flashlamp pumping the absolute efficiency is typically a factor of 2 to 3 higher than in Nd:YAG.

The remaining problem is the strong thermal lensing of Cr,Nd:GSGG when compared to Nd:YAG. However, garnets like YSAG (\(Y_3Sc_2Al_3O_{12}\)) and YSGG (\(Y_3Sc_2Ga_3O_{12}\)), with physical properties closer to YAG, still exhibit Cr-broad band emission, which sensitizes Nd and might be useful systems to test.
3. Cr,Tm: garnets

In YSAG and YSGG scandium and yttrium match well for the ionic radii of Cr and Tm respectively, so that reasonable values of the distribution coefficients can be expected. Even in YAG with a rather narrow Cr$^{3+}$ emission at a strong crystal field site, Cr$^{3+}$ sensitizes Tm$^{3+}$ because of an overlap of the Cr-emission and Tm-absorption.

However, relatively high Tm concentrations (8$\times$10$^{20}$ cm$^{-3}$) must be used in order to obtain a high transfer efficiency from Cr to Tm and a efficient down conversion of pump photons /3/ at quantum efficiencies of nearly 2 (first two steps of fig.1). As a result, the $^3H_4 \rightarrow ^3H_6$ ground state laser transition of the Tm$^{3+}$ has strong resonant reabsorption losses and behaves like a 3 level laser system. As a consequence we obtained up to now only power slope efficiencies of less than 1 % under laser pumping ($n_{Cr}$=2.5$\times$10$^{20}$ cm$^{-3}$, $n_{Tm}$=4$\times$10$^{20}$ cm$^{-3}$). However, this laser system is not yet optimized.

4. Cr,Tm, Ho-garnets

When operating the Ho laser at 2 $\mu$m wavelength the Ho concentration can be chosen low (5$\times$10$^{19}$ cm$^{-3}$) to avoid big reabsorption losses. Figure 1 shows the pumping scheme of double cross pumping Ho via Cr and Tm.

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3. Cr,Tm: garnets

4. Cr,Tm, Ho-garnets
The down conversion within the Tm system leads to a high pump quantum efficiency. Under laser pumping we achieved power slope efficiencies of more than 40% for the 2 μm output when pumping at 647.1 nm (see fig. 2). This is a direct proof of the efficient down conversion rate.

![Fig. 2: 2 μm Ho laser with a power slope efficiency of 41% when pumped at 647.1 nm.](image)

We also achieved cw diode laser pumping of the 2 μm Ho laser in YAG at 300 K. The diode laser pumps the $^3\text{H}_6 \rightarrow ^3\text{H}_4$ transition of Tm$^{3+}$ near 785 nm. Thresholds as low as 2.7 mW and power slope efficiencies of nearly 20% have been demonstrated (see figure 3).

![Fig. 3: Output versus input power of a diode laser pumped 2 μm Ho-laser at room temperature](image)
With Cr,Tm,Ho:YAG we obtained also high power slope efficiencies under laser pumping (n=33 %) and also reasonable efficiencies for flashlamp pumping. Figure 4 shows a typical result.

The flashlamp pumped 2 μm laser appears to be a useful source. The slope efficiency is more than 1 % and the threshold (20...30 J) is also in a suitable energy range. In the experiment of fig.4 the output power was limited by the mirror coatings. We could easily obtain several hundreds millijoules of output, which however yields immediately to damage of the mirrors. An upper limit of the repetition rate (5 Hz) was due to the power supply. With proper optics we expect at least an improvement of one order of magnitude in output power.

5. Cr,Er-garnets

The Er\textsuperscript{3+} laser is working likewise under flashlamp pumping /5/ and cw laser excitation at wavelengths between 2.6 μm and 2.9 μm in YAG and YSGG crystals. Fig.5 shows a typical result of a cross pumped 300 K cw Erbium laser at 2.707 μm. We pumped with the red lines of a Krypton laser into the $^4T_2$-absorption band of Cr\textsuperscript{3+}. 

Conclusions

We have obtained a variety of Cr-sensitized rare earth lasers with Nd, Tm, Ho, and Er at wavelengths 1.06 µm, 1.7-1.8 µm, 1.9-2.1 µm and 2.6-2.9 µm. The results on laser pumping (especially diode laser pumping) and flashlamp pumping demonstrate the potential use of these lasers in a variety of applications such as materials processing, medical systems, and eyesafe measurement techniques.

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