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T. Becker, G. Huber. OPTIMIZATION AND DYNAMICS OF $2\mu\text{m}$ Tm-AND Ho-LASERS. Journal de Physique IV Proceedings, 1991, 01 (C7), pp.C7-353-C7-356. 10.1051/jp4:1991793 . jpa-00251036

HAL Id: jpa-00251036

<https://hal.science/jpa-00251036>

Submitted on 1 Jan 1991

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OPTIMIZATION AND DYNAMICS OF $2\mu\text{m}$ Tm-AND Ho-LASERS

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*Institut fuer Angewandte Physik, Universitaet Hamburg, Jungiusstr. 11, D-2000 Hamburg 36, Germany***Abstract**

We have grown several Cr,Tm:YAG and Cr,Tm,Ho:YAG-crystals in order to optimize the dopant concentrations. We observed slope efficiencies of 1.8% for Cr,Tm:YAG and 4% for Cr,Tm,Ho:YAG. Output energies >3 Joules were measured for both crystals. The dynamical behaviour of Tm- and Ho-lasers is very different and is explained by a simple model. The influence of the dynamics on the Q-switch performance of Cr,Tm:YAG and Cr,Tm,Ho:YAG is analyzed.

Introduction

Cr,Tm:YAG and Cr,Tm,Ho:YAG are known as efficient laser materials in the near IR with wavelength of 2013nm and 2123nm, respectively. [1-6]. Due to the strong absorption of biological tissue at these wavelengths, Ho- and Tm-lasers are interesting for eye-safe measurements and medical applications. The aim of this work is to optimize the dopant concentrations for both $2\mu\text{m}$ -lasers and to analyze the different dynamical behaviour.

Fig. 1: Pumping scheme of Cr,Tm:YAG and Cr,Tm,Ho:YAG

Experimental Setup

All flashlamp pumped laser experiments were carried out in a nearly hemispherical resonator consisting of a 1m concave high reflector and a plane output coupler. The rods were mounted inside a silver elliptical reflector with a spacing of 10mm between the rod and the cerium doped 3mm-bore-diameter flashlamp. Because the rods are shorter than the arc, all input energies were corrected with the corresponding length ratios. The repetition rate was 1Hz and the cooling water temperature was 20°C. The pump pulse duration τ_p was varied between 200 and 1200 μsec with output mirror transmission T between 5% and 65%.

Cr,Tm:YAG

In order to optimize the Cr- and Tm-concentrations in Cr,Tm:YAG we have grown several crystals with different concentrations of Cr (0.7%–3%) and Tm (3%–9%) and investigated the flashlamp pumped laser performance.

Fig. 2: Optimization of Cr-concentration for Cr(x%),Tm(5%):YAG. The insert shows a flashlamp pulse and a typical Cr,Tm:YAG output pulse

At a fixed Tm-concentration of 5% the Cr-concentration for laser rods with 5mm diameter can be chosen between 1.3% and 3% without a drastic change in the laser performance (see figure 2). For laser rods with 3mm diameter we obtained the best results with Cr-concentrations between 2% and 3%.

Fig. 3: Optimization of Tm-concentration for Cr,Tm:YAG

The best Tm-concentration was determined to be between 5% and 7% (see Figure 3). At lower Tm-concentrations the Cr-Tm-energy transfer and the Tm-Tm-cross relaxation are less efficient. At 9% Tm-concentration the threshold energy increases due to the reabsorption losses, but the slope efficiency remains nearly unchanged. The maximum slope efficiency of 1.8% was obtained with a Cr(2%):Tm(7%):YAG at 25% output coupler transmission and a pumping pulse duration of 800 μ s. The maximum output energy was >3J at 280J input energy.

Cr,Tm,Ho:YAG

We varied the Tm-concentration between 3% and 14% at fixed Cr- and Ho-concentrations of 2% and 0.36%, respectively (see figure 4). Slope efficiencies of 4% and output energies >4 Joule were obtained with a Tm-doping of 6%.

Fig. 4: Optimization of Tm-concentration for Cr(2%),Tm(x%),Ho(0.36%):YAG. The insert shows a flashlamp pulse and a typical Cr,Tm,Ho:YAG output pulse

The laser performance of the rods with 14% Tm doping is not as good as the performance of 6% Tm rods. This is caused by the fast energy migration in the Tm 3H_4 -level and nonradiative energy transfer to impurities. For the same reason the Tm-lifetime of the upper laser level decreases with increasing Tm-doping. The importance of the sensitizer Cr is shown in figure 4. Without Cr the threshold energy increases from 27J to 125J and the slope efficiency decreases drastically from 4% to 0.07%.

Dynamical Behaviour

Independent of the doping a Tm-laser is emitting a train of irregular spikes as it is typical for low-gain-lasers with long lifetime of the upper laser level. Depending on the doping a Cr,Tm,Ho:YAG laser is emitting a more or less smooth output pulse. The higher the Tm-concentration the smoother is the output pulse of the Ho-laser (see figures 4 and 5).

The behaviour can be explained by a simple model, which is described by three equations.

$$dN_T/dt = W - N_T/\tau_{TH} + N_H/\tau_{HT} - N_T/\tau_T$$

$$dN_H/dt = +N_T/\tau_{TH} - N_H/\tau_{HT} - N_H/\tau_H - N_H \cdot N_p \cdot g$$

$$dN_p/dt = +N_H \cdot N_p \cdot g - N_p/\tau_R$$

N_T, N_H = Number of excited Tm- and Ho-ions, N_p = Number of Photons, W = Pumping rate, τ_{TH}, τ_{HT} = Transfer times between Ho and Tm ions, τ_T, τ_H = Tm and Ho-lifetime, g = Coefficient for gain, τ_R = Lifetime of photons in the resonator.

With the overlap integral of the fluorescence – and absorption – spectra we calculated the transfer times to be of the order of μs . With this transfer rates Tm is strongly damping the Ho-inversion and consequently the photon number oscillations, too. Faster interaction times cause both the Tm- and Ho-inversion to oscillate and slower interaction times cause the Ho-inversion to oscillate independent of Tm.

Q-Switch Properties

For the Q-switch experiments we placed an AR-coated $LiNbO_3$ -crystal and a brewster-quarz-plate between the laser rod and the HR-mirror. The output mirror had transmission of 65% at $2\mu m$ and the pump pulse length was $650\mu s$. The Q-switched Tm-laser produces a pulse with a FWHM of 30–40nsec and a maximum output energy of 50mJ (see figure 5). If the output energy exceeds 15–20mJ the $LiNbO_3$ -crystal sometimes shows starting degradation due to surface and bulk damage.

Fig. 5: Q-switch properties of Cr(3%),Tm(5%):YAG

The Q-switched Ho-laser produces a train of up to 15 pulses within a time periode of $200\mu sec$ after the Pockels cell is switched off. The first pulse has a FWHM of 30–40nsec which increases for following pulses up to 200nsec. The total output energy is about 150mJ. This behaviour is caused by the fact that approximately 50% of the excitation energy remains stored in the Tm-inversion after the first Q-switch-pulse has removed the Ho-inversion. This stored energy can be transferred to the Ho-ions producing additional pulses.

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