2 µm Ho:YAG and Cr:ZnSe Thin Disk cw Lasers

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Summary

A Thulium fiber laser pumped Ho:YAG thin disk cw laser with an output power of 15 W at a 2% Ho in YAG concentration and 7 W at 1.6% as well as a Thulium fiber laser pumped Cr:ZnSe thin disk cw laser with an output power of 0.4 W will be presented. Comparison of the output power to a Rigrod formula with Boltzmann occupation factors will be shown.

Introduction

Holmium- or Chromium-doped crystals emit in the 2 µm ‘eye-safe’ wavelength range and are therefore attractive for use in remote sensing, laser material processing as well as laser surgery or therapy [1]. In the present report a single mode Thulium fiber laser at 1.908 µm will be used to pump a Ho:YAG thin disk laser [2] with two different Ho concentrations in a multi-pass pumping scheme via a multimode transfer fiber to generate a flat pump intensity distribution on the disk. With a 24 pump pass concept an efficient absorption of the pump light in the Ho:YAG disk material will be achieved. Furthermore, the same multi-pass pumping concept will be used to pump a Cr:ZnSe thin disk cw laser [3], but in this case, directly with the single mode Thulium fiber laser.

Experimental results of the Ho:YAG and Cr:ZnSe thin disk cw lasers

The single mode Tm fiber laser (IPG, 50 W) is focussed into a 600/660 µm polyimide transfer fiber before entering the Ho:YAG disk laser module (Dausinger + Giesen GmbH) [4, 5]. The Ho concentration of disk 1 is 2% (thickness of 500 µm). The disk 2 has a 1.6% Ho concentration (thickness of 500 µm). The pump beam spot size for the Ho:YAG disk is adjusted to a diameter of approximately 2 mm. The transmission of the output mirror has been changed between 1 and 5%. The output power of the Ho:YAG thin disk cw laser is shown in figure 1 for an optimized output transmission between 2 and 3%. For a pump power of 47 W the output power reached 15 W with a maximum efficiency of 37%. It can be recognized that the output power still shows a linear power scaling dependence in contrast to the 1.4% Ho concentration disk.

For the Cr:ZnSe thin disk cw laser with a disk thickness of 250 µm the pump spot size has to be reduced to 0.75 mm to reach threshold. An output power of 0.4 W with an emission close to 2.35 µm and a linewidth of 30 nm has been accomplished so far.

Fig 1. Output power of Ho:YAG (left) and Cr:ZnSe (right) thin disk cw laser versus pump power
Simplified Rigrod simulation for the Ho:YAG system

For the Ho$^{3+}$-ions only two transitions in the two $^5I_7$ and $^5I_8$ manifolds are necessary to describe the absorption and amplification processes. With the Boltzmann occupation factors of the involved Ho$^{3+}$-Stark levels and the reflection coefficients $R$ of the crystal facets, the laser output intensity normalized to the saturation intensity will be calculated for a disk with a relatively large thickness [6]:

$$I_{\text{out}} = \frac{g_n}{\pi} \left( \frac{\alpha_n}{\pi} \cdot I_p(0) \cdot (1 - \Gamma) \cdot (1 + R_{\text{in}}^n \cdot \Gamma - f_\ell \cdot L) + \ln \left( \frac{R_{\text{in}}^n \cdot R_{\text{out}}^n}{R_{\text{in}}^n \cdot R_{\text{out}}^n} \right) \right); \quad \Gamma = \left( R_{\text{in}}^n \cdot R_{\text{out}}^n \right)^{1/2} \cdot \exp \left( -\alpha_{\text{in}} \cdot f_\ell \cdot L \right) \quad (1)$$

The Boltzmann population factors for the Ho$^{3+}$-laser and pump levels are taken from the literature: $f_n = 0.154$, $f_\ell = 0.017$, $f_p = 0.0994$, $f_d = 0.0994$ [7] with $f_\ell = f_n/(f_n + f_d)$, $f_p = f_\ell/(f_\ell + f_d)$. The gain and absorption can be calculated from the products of the cross-sections (eff. pump absorption $5 \times 10^{-21} \text{ cm}^2$, eff. stimulated emission $12 \times 10^{-21} \text{ cm}^2$), the Ho in YAG concentration and the Boltzmann factors. The 2% Ho concentration is set to $3 \times 10^{20} \text{ cm}^{-3}$. In figure 2 the laser output intensity is depicted for the 2% and 1.6% Ho concentration with $I_p(0) = 1$ and a disk thickness of $L = 400 \mu\text{m}$. For the 2% of Ho concentration case the experimental laser intensity of 0.5 kW/cm$^2$ (power 15 W, beam diameter 2 mm) is shown in figure 2, too.

![Figure 2](image_url)

Fig 2. Simulation of laser intensity versus reflectivity of output coupling coefficient (left diagram) for 2% and 1.6% Ho in YAG concentrations and laser intensity versus disk thickness (right diagram) for the 2% Ho in YAG concentration and a 2% output coupling coefficient

Conclusions

Holmium doped YAG and Chromium doped ZnSe are promising laser materials for thin disk laser concepts in the 2 µm range. A cw laser output power of 15 W has been achieved with an efficiency of 37% for a Ho in YAG concentration of 2% with scaling opportunities to higher power. For the Cr:ZnSe thin disk cw laser an output power of 0.4 W at 2.35 µm has been realized so far.

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References