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MODELLING OF MODE OVERLAP IN LONGITUDINALLY PUMPED SOLID STATE LASERS**C. PFISTNER, P. ALBERS and H.P. WEBER***Institute of Applied Physics, University of Berne, Sidlerstr. 5, CH-3012 Berne, Switzerland*

Abstract - In our paper we investigated the influence of the mode overlap on the efficiency of longitudinally pumped solid state lasers. In a theoretical part we enhanced an existing model for four level lasers from idealized cylindrical modes to arbitrary pump and laser modes in a random relative position. Theoretical predictions were confirmed experimentally with an end-pumped Nd:YAG rod operated at 1064 nm. To investigate the effect of misalignment on the efficiency we used a Ti:Sapphire pump laser which could be displaced relative to the laser beam. In a second experiment a diode laser equipped with coupling optics served as the pump source for the same resonator. This resulted in a 20 % decrease in slope efficiency compared to the Ti:Sapphire pumped system due to the limited mode overlap produced by the diode coupling optics.

1. Introduction

Longitudinal diode laser pumping of solid state lasers allows higher efficiencies compared to flashlamp pumping due to better spectral and geometrical mode overlap /1/. The efficiency of longitudinally pumped systems critically depends on the quality of the geometrical mode overlap which can be separated into two parts. Firstly, it is given by the relative alignment of the two modes and, secondly, it depends on the structure of the laser and pump beam, respectively. In a first experiment we investigated the alignment sensitivity of the laser efficiency using Gaussian beams which were displaced relative to each other in an end-pumped resonator. In a second step we compared the efficiency of the Nd:YAG rod either pumped by a Ti:Sapphire or a diode laser to establish the influence of the mode structure on laser performance.

2. Theoretical considerations

An existing model /2/ describes longitudinally pumped four level lasers by solving the rate equations assuming TEM₀₀ mode of zero divergence, with the pump and laser beams exactly aligned. We enhanced this model to describe pump and laser modes of arbitrary field distribution in a random relative position /3/. The relation between pump power P_p and corresponding laser output power P_L is given by formula (1).

$$P_p = \frac{1 + C_1 \int \frac{r_L(x,y,z)}{1 + C_2 r_L(x,y,z) P_L} dV}{C_3 \int \frac{r_p(x,y,z) r_L(x,y,z)}{1 + C_2 r_L(x,y,z) P_L} dV} \quad (1)$$

where r_p and r_L are the pump and laser field distributions, respectively, and C_1, C_2 and C_3 are constants containing crystal data and resonator parameters like output coupling and round trip losses.

3. Experimental Setup

To measure the influence of the geometrical overlap on the laser efficiency we used the end-pumped system shown in Fig.1. The 4.5 mm long, 1.1 at.% doped Nd:YAG rod was operated in a quasi plano-concentric resonator. The output coupling mirror had a radius of curvature of 15 cm. With a resonator length of 14.7 cm this resulted in a laser beam waist of $80 \pm 10 \mu\text{m}$. The output coupling transmission was 5%. The beamsplitter allowed an on-line pump mode control.

Fig.1. Experimental set-up

To investigate the misalignment sensitivity of the laser efficiency the crystal was pumped by a Ti-Sapphire laser which could be displaced relative to the laser; the pump waist was kept at $70 \pm 5 \mu\text{m}$.

In a second case the pump was a 500 mW diode laser (Siemens Laserarray SFH 48E1) equipped with coupling optics. To measure the pump field distribution we scanned the diode laser radiation with a $5 \mu\text{m}$ pinhole in front of a large area Si photodiode.

4. Experimental Results and Discussion

The input-output diagram of the first experiment with optimally aligned Gaussian modes is

given in Fig.2. The output coupling transmission of 5% leads to an optical slope efficiency of 53%. The experimental data were fitted in terms of equation (1) with the round trip losses L serving as the fit parameter. L was determined to be 1%. We estimated an accuracy of ± 5 mW for the experimental data and a relative accuracy of 10% for the model due to simplifying assumptions. Under these conditions there is a good agreement between experimental results and calculated values.

Fig.2. Theoretical curves and experimental data for laser output power versus incident pump power for optimally aligned Gaussian modes. The optical slope efficiency is 53 %.

With the pump power kept constant at 200 mW we obtained the dependence of the laser output power on the relative shift, shown in Fig. 3. In the experiment the laser switches from TEM_{00} to TEM_{01} at an absolute shift of $55 \pm 5 \mu\text{m}$ before multi-mode operation starts at $70 \pm 5 \mu\text{m}$ which makes calculations with our model impossible. Within the accuracy discussed before the achieved data can be fitted to the theoretical model if for every displacement only the laser mode yielding the higher output power is considered. This mode is the one with the highest gain and lowest losses.

Fig.3. Laser output power as a function of relative shift between pump and laser beam.

Fig. 4. shows the input-output curves for pumping with a Ti-Sapphire and a diode laser of equal spot size. To fit the experimental results for diode laser pumping we used the scanned

pump field distribution and determined the round trip losses L to be 1.1% with the other parameters kept constant. Hence the resonators for Ti:Sapphire and diode pumping can be considered as equal within the accuracy of the model. Therefore the decrease in slope efficiency from 53% to 43% can be explained in terms of the limited mode overlap due to the special geometry of the diode pump mode.

Fig.4. The experimental input-output data achieved with a Ti-Sapphire and a diode pump laser of equal spot size. The corresponding optical slope efficiencies are 53 % and 43 %, respectively.

5. Conclusion

Within an accuracy of 10% the presented model describes the influence of the geometrical overlap on laser efficiency. The overlap can be divided into two parts: On one hand it consists of the geometry of the pump mode itself, on the other hand the overlap is influenced by the alignment of pump and laser beams. In the first case, the model can be used to estimate the quality of coupling optics theoretically without high experimental effort and so it helps to simplify the design of such optics. In the second case the model permits evaluation of critical parameters to establish the alignment requirements for longitudinally pumped systems. This can be helpful for the design of multiple end-pumped systems /4/ which are necessary to achieve high output power.

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