

Core-doped Ceramic Nd:YAG Laser

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Abstract: We report on a diode end-pumped composite core-doped ceramic Nd:YAG laser. The ceramic Nd:YAG rod consists of a centrally doped region of 1.5 mm in diameter in a 3 mm rod. An output power of 144 W was achieved with an absorbed pump power of 226 W corresponding to an opt.-opt. efficiency of 64 % by longitudinal pumping with fiber-coupled laser diodes.

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OCIS codes: (140.3580) Lasers, solid-state; (140.3480) Lasers, diode-pumped

References and links

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1. Introduction

Polycrystalline ceramic Nd:YAG laser material provides new possibilities in designing the laser medium, with respect to dopant concentration as well as distribution, size and geometry [1-5]. While the spectroscopic and thermo-optical properties of ceramic Nd:YAG as well as the principle laser properties have already been the subject of several publications, see Ref. [6-12], we report on a high power ceramic Nd:YAG laser with a transversal dopant gradient. The composite rod has a centrally doped region of 1.5 mm in diameter embedded in a 3 mm rod which is end-pumped with fiber-coupled laser diodes.

2. Experimental setup

The composite core-doped Nd:YAG laser rod (from Baikowski Chimie, France), sketched in Fig. 1, is 41 mm long and 3 mm in diameter. It has 7 mm long undoped end-caps, and a 27 mm long 0.3 % doped central active region which is 1.5 mm in diameter.

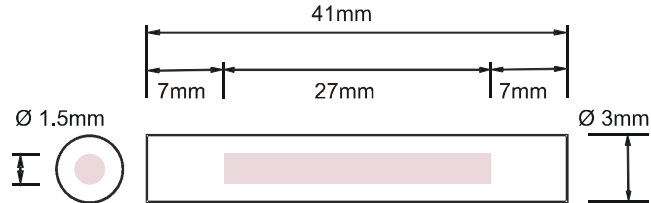


Fig. 1. Sketch of the composite core-doped Nd:YAG laser rod.

In our setup, sketched in Fig. 2, the core-doped Nd:YAG laser rod was longitudinally pumped with 10 fiber-coupled laser diodes (Jenoptik Laserdiode GmbH, type JOLD-30-CPXF-1L) with a nominal output power of 30 W each resulting in a maximum available pump power of 300 W. A bundle of ten fibers with 400 μm core diameter and an NA of 0.22 was used. Each laser diode was stabilized to an individual temperature by thermo-electrical cooling for emission wavelength tuning to achieve maximum absorption in the laser rod. The pump radiation from the fiber bundle was focused into the laser rod with a system of three plano-convex lenses ($f_1=81$ mm, $f_2=102$ mm, $f_3=52$ mm). The barrel surface of the laser rod was polished to optical quality, and therefore acts as a waveguide for the pump light due to total internal reflection because of the difference in refractive indices between YAG and cooling water [13-16]. Both sides of the laser rod were antireflection coated for the pump wavelength of 808 nm as well as for the laser wavelength of 1064 nm. With this setup the laser and thermal lensing properties of the ceramic composite core-doped Nd:YAG rod were investigated.

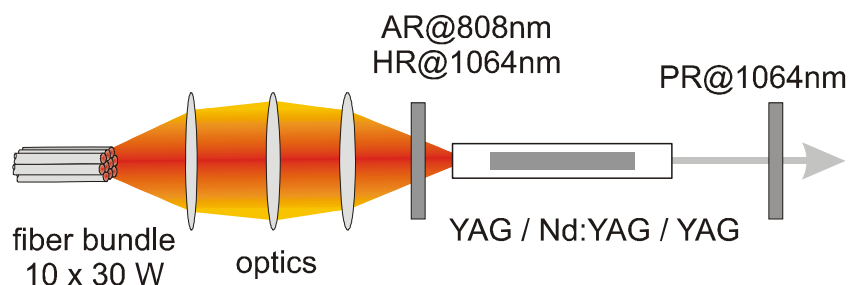


Fig. 2. Schematic set-up of the laser system.

3. Pump light absorption

The pump light distribution was calculated with commercially available raytracing software (ZEMAX) as shown in Fig. 3. The radiation emerging from the ten pump fibers was described by 2 million rays. The spectral distribution of the pump light was approximated by a Gaussian distribution with 2.5 nm width (FWHM). The crystal was segmented into 120 times 120 volume elements in transversal in 164 elements in longitudinal extension, resulting in a spatial resolution of 25 μm in transversal and 250 μm in longitudinal direction. The image of the fiber bundle about 11 mm behind the rod's pump side end surface is clearly visible. Due to the pump light guidance by total internal reflection at the rod's barrel surface, the pump light distribution becomes concentrated around the rod's axis as the light propagates through the crystal. Based on these calculations a fraction of 79 % of the pump light is absorbed in the doped core of the rod.

Experimentally the fraction of pump power absorbed in the doped core of the rod was determined by measuring the difference between the incident and the transmitted pump light. A maximum of 78 % of the diode radiation was absorbed in the laser rod, which is in good agreement with the calculations.

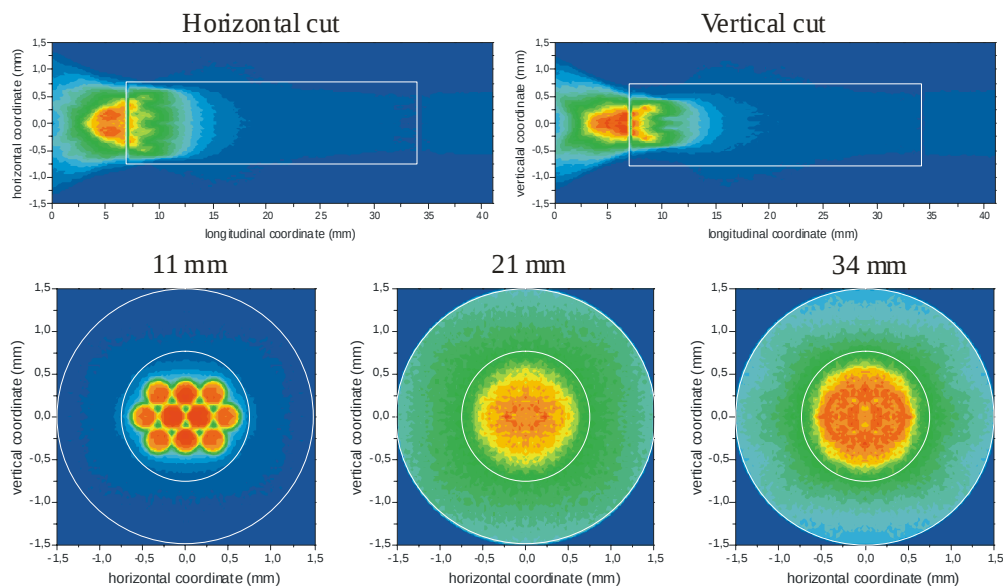


Fig. 3. Pump light distribution obtained from numerical raytracing calculations. All distances are measured from the end surface of the crystal at the pump side.

4. cw Laser Power

In order to evaluate the laser properties of the ceramic rod the cw multimode laser output was measured for different output coupler transmissions of 20 %, 25 % and 30 %. The short resonator with 60 mm length was built by a plane output coupler and a plane dichroic pump mirror, highly reflective for the laser and highly transmissive for the pump beam. The results are shown in Fig. 4. A maximum laser output power of 144 W was realized with a launched pump power of 290 W corresponding to an absorbed power of 226 W. With respect to the absorbed pump power the highest slope efficiency of 67 % and highest optical to optical efficiency of 64 % were achieved with the 25 % output coupler transmission.

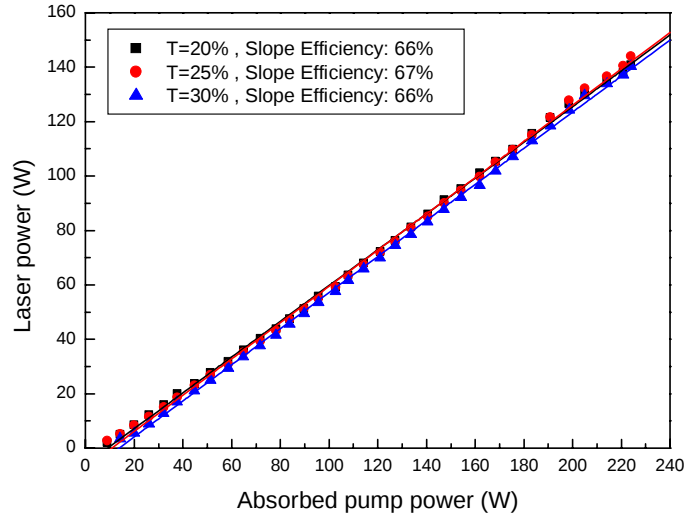


Fig. 4. Laser output vs. diode pump power for the core-doped crystal for different output coupler transmissions of 20 %, 25 % and 30 %.

5. Thermal lensing

In order to verify the thermal lensing properties of the core-doped ceramic Nd:YAG rod the stability range of the plane-plane resonator was investigated for different distances of the output coupler to the laser rod and the ABCD matrix formalism was used to calculate the focal length of the thermal lens as described in Ref. [17]. The stability range was measured systematically for the core-doped ceramic Nd:YAG rod as shown in Fig. 5. The refractive power of the thermal lens increased from 6.2 m^{-1} at 65 W absorbed pump power to 21.3 m^{-1} at 223 W. Consequently the refractive power per launched pump power was estimated to be $96 \text{ m}^{-1}\text{kW}^{-1}$ via linear regression. The strong thermal lens was introduced by the higher pump light density in the core comparable to mode selectively pumped lasers [18-22].

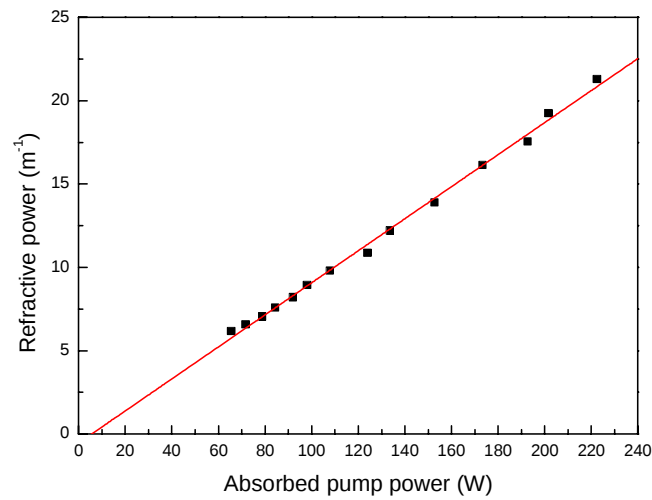


Fig. 5. Refractive power of the thermal lens vs. absorbed pump power.

6. Summary

In summary we presented the first demonstration of a high-power, ceramic composite core-doped Nd:YAG laser. An output power up to 144 W with an optical to optical efficiency of 64 % with respect to the absorbed pump power was realized in a diode end-pumping configuration. That is to the best of our knowledge the highest efficiency achieved with a ceramic laser material so far. We also investigated the refractive power of the thermal lens of the composite core-doped ceramic Nd:YAG to be $96 \text{ m}^{-1}\text{kW}^{-1}$.

Acknowledgements

The work was funded by the German Ministry of Education and Research under contract 13N8299.