Nd:YAG ring laser with 213 W linearly polarized fundamental mode output power

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Abstract: We present a high power fundamental mode ring oscillator with four longitudinally diode-pumped laser rods and effective birefringence compensation as a laser source for the next generation of gravitational wave detection. With this setup a linearly polarized output power of 213 W in a nearly diffraction limited beam with an M^2 value of 1.15 was demonstrated.

OCIS codes: (140.3570) Lasers, single-mode (140.3580) Lasers, solid-state

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1. Introduction

High power fundamental mode lasers have a high potential in many fields of material processing and fundamental research. Specially in the future research of gravitational wave detection, a single frequency laser source with a fundamental Gaussian beam and a linearly polarized output power of nearly 200 W is needed [1,2]. So far the maximum reported linearly polarized fundamental mode output power of a diode pumped, Nd:YAG solid-state oscillator was 105 W [3]. We present a high power ring resonator with four end-pumped laser heads, sketched in Fig. 1, with a linearly polarized fundamental mode output power of 213 W as a laser concept for future gravitational wave detectors. This is from the best of our knowledge the highest linearly polarized single mode output power of a Nd:YAG oscillator.

2. Laser head design

Each of the four laser heads was longitudinally pumped with 10 fiber-coupled laser diodes (Jenoptik, JOLD-30-CPXF-1L, 600µm, NA:0.22) with a nominal output power of 30 W resulting in a maximum available pump power of 300 W. The typical laser diode operation was derated whereas approximately 75% of the nominal current value was used. Therefore, a consistent operation was realized whereas in case of a diode failure the diode current of the residual diodes can be increased to keep the laser in operation. Further an easy maintenance was attained as an online replacement of the failed laser diode is possible. Each laser diode was stabilized to an individual temperature by thermo-electrical cooling to tune the emission wavelength to meet the maximum absorption in the laser rod. To prevent hot-spots in the laser crystal resulting from direct fiber coupled pumping a pump light homogenizer was used [4]. An appropriate telescope focused the pump light into the laser rod where the pump light is

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guided by total internal reflection as the water cooled rod surface acts as a waveguide. A double pass of the pump light was realized by using a high reflective coating at one end of the rod. The used segmented laser rod consisted of two 7 mm YAG end-caps on each side and a 40 mm long 0.1 at.% Nd doped region. To achieve a stable linearly polarized output power the thermally induced birefringence caused from the high power pumping, has to be compensated. Therefore, each two of the four laser rods were combined with a birefringence compensation [5,6]. The birefringence compensation consisted of relay optics, to image the thermal lenses of two rods to each other and a 90 degree quartz rotator. To reach an output power in the 200 W range, four laser heads were combined in a ring resonator configuration. The ring resonator design was chosen for the feasibility of injection locking in order to force the system to single-frequency operation.

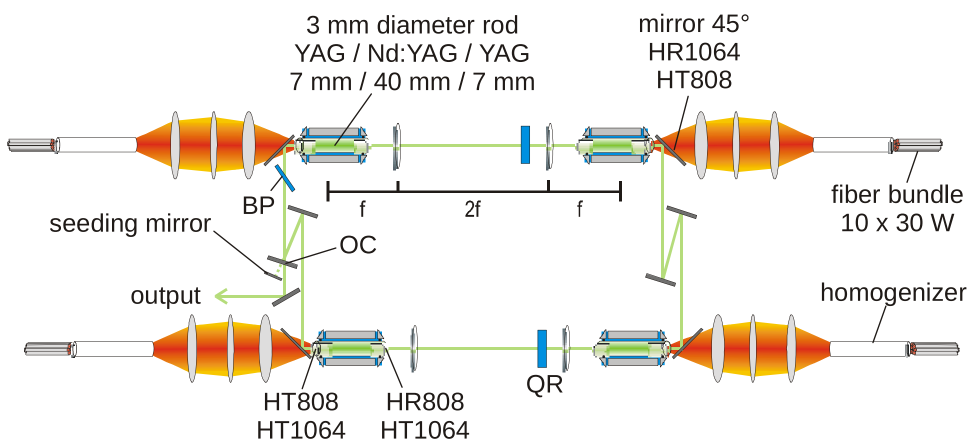

Fig. 1. Four head ring resonator with birefringence compensation in self injection seeding operation. QR: 90° quarz rotator, BP: Brewster plate OC: output coupler.

3. High power ring laser

In order to investigate the birefringence compensation and the linearly polarized fundamental mode output power, the first experiments were performed in a standing wave resonator configuration with only two laser heads. In case of the design symmetry to the finally four-head ring laser the results from the two head design were scalable, as the pump power and the resulting thermal effects will not increase. For the two-head design the same output power for linearly polarized operation as for non-polarized operation was achieved. Therefore, an efficient birefringence compensation of end-pumped laser rods was demonstrated [7]. With this setup, a linearly polarized fundamental mode output power of 114 W with a beam quality M^2-value of 1.05 was achieved.

In order to scale the output power to the 200 W level, the four-head ring resonator was realized. Therefore, the standing wave resonator was duplicated which resulted in a stable ring resonator design where the stability range and the laser mode size are comparable to the investigated standing wave resonator. To operate the system in a unidirectional mode without injection locking, the so called self-injection seeding was applied. Therefore, a highly reflective mirror (seeding mirror) was used in one of the laser output ports. The mirror reflected the laser light back to the output coupler and a part of the light was coupled into the ring resonator where the light was amplified. The arising circulated light in one direction and the decrease of light in the other one, forced the laser to circulate in a unidirectional instead of the bidirectional mode. The output power of the self-injection seeded operation is shown in Fig. 2. With this setup a maximum linearly polarized laser output power of 243 W with an M^2 -value less then 3 was achieved. The small decrease of output power at the pump power range of 800 to 900 W can be explained by slightly different absorption in the different laser heads caused from the diode-current dependent wavelength shift of the laser diodes. This resulted in some different thermal lenses in the four laser heads. Due to the difference of the thermal lenses the mode size and stability range where changed and therefore the output power and the M^2-value varied. By using the ABCD matrix formalism it can be calculated, that in case of the eight lenses (four imaging and four thermal) inside the resonator the system becomes asymmetric if the focal length of the thermal lenses changes to each other. Therefore, the modes sizes can become different in the different laser heads.

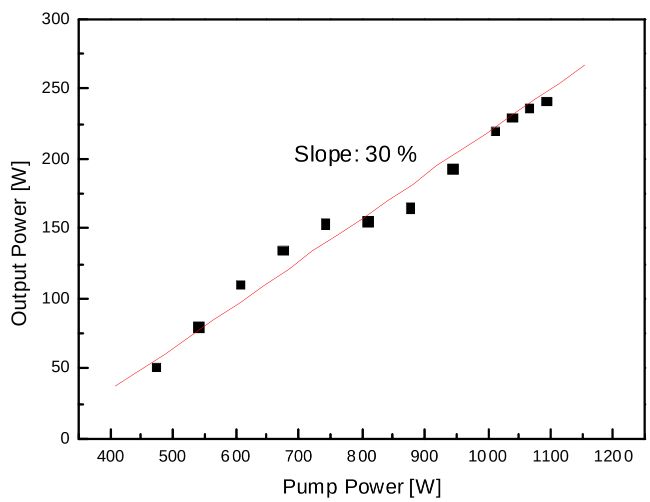

Fig. 2. Laser output power versus total pump power of the self-injection seeded four-head ring resonator.

In order to suppress higher order modes, a mode aperture was used in the focus region of the relay optic. Therefore, higher order modes were suppressed and a stable fundamental mode operation was achieved. Figure 3 shows the output power versus pump power with the aperture in place. Due to the increase of pump power the laser mode size at the position of the aperture increased from approximately 150 to 160 µm. This resulted in a slight decrease of output power but a substantial beam quality improvement. With the mode aperture in place, a maximum linearly polarized output power of 213 W with an M^2-value of 1.15 was achieved. This is to the best of our knowledge the highest linearly polarized fundamental mode output power of a Nd:YAG laser oscillator. The optical to optical efficiency was 23 %.

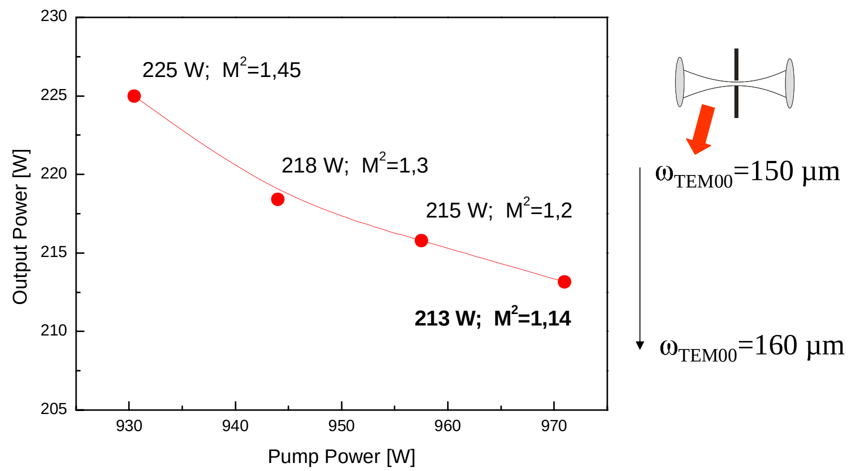

Fig.3. Laser output power versus total pump power and beam quality values with mode aperture inside the resonator. The right Fig. sketched the increase of the laser mode size and the aperture position.

4. Summary

In summary we presented a four-head ring resonator with a linearly polarized fundamental mode output power of 213 W at 1064 nm and an M^2-value of 1.15. The presented laser design showed the possibility to de a suitable laser source for future gravitational wave detectors. According to further resonator optimization injection locking will be applied to achieve single frequency operation.

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