Wavelength Control by Angle-Tuning of the Laser Radiation in an Intra-Cavity Pumped Yb:YAG Thin-Disk Laser

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Abstract: In an intra-cavity pumped thin-disk laser the pump radiation forms a standing wave pattern inside the intra-cavity pumped disk. We demonstrate experimentally that the grating period of the standing wave pattern of the pump radiation can control the laser wavelength.

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1. Introduction

Recently we demonstrated the first Yb:YAG intra-cavity pumped thin-disk laser with a quantum defect of 1.74% [1]. The intra-cavity pumped thin-disk laser comprises two Yb:YAG thin-disk lasers. A first thin-disk laser that is pumped by diode lasers at 940 nm, pumps a second thin-disk laser with its 1030 nm laser radiation. The disk of the second laser is placed inside the resonator of the first laser and serves as its output coupler. As a consequence, the output coupling is proportional to the spectral absorption coefficient of Yb:YAG. The small-signal absorption of the intra-cavity pumped disk per round trip at 1030 nm is approximately 2% and much higher than the small-signal absorption at 1049 nm; thus the first laser would oscillate on the 1049 nm transition of Yb:YAG because of the lower lasing threshold at 1049 nm. In the beginning we used a dichroic mirror to stabilize the wavelength of the diode-pumped laser. With the dichroic mirror the laser wavelength was 1032 nm. The mirror had a reflectivity of 99% at 1032 nm and a reduced reflectivity for longer wavelengths. So 1% of the intra-cavity pump power was lost due to transmission of the dichroic mirror. With the dichroic mirror, multiple longitudinal modes were present in the optical spectrum due to spatial hole burning. The former setup is shown in Fig.1.

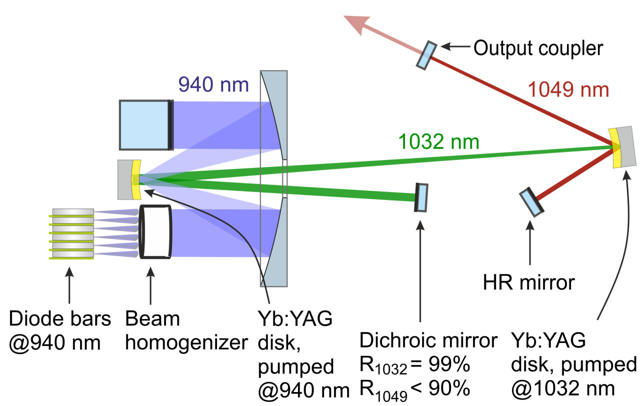

Fig. 1. Former setup of the intra-cavity pumped thin-disk laser.

Schuhmann *et al.* stabilized the wavelength of an Yb:YAG thin-disk laser by using an Fabry-Pérot interferometer that comprises of a volume Bragg grating and an output coupler [2]. We adapted this idea and replaced the dichroic mirror by a Fabry-Pérot interferometer. The Fabry-Pérot interferometer we used comprises of a volume Bragg grating with a peak reflectivity of 99.9% at 1030.4 nm and an output coupling mirror with a transmission of 3%. With this new setup the laser wavelength of the first laser with the intra-cavity pumped disk inside its resonator settled at 1030.2 nm. The spectral width of the laser radiation was below the spectral resolution (0.1 nm) of our optical spectrum analyzer.

2. Spatial Hole Burning

The nearly monochromatic pump radiation of the first laser leads to spatial hole burning of the pump radiation in the intra-cavity pumped disk. The grating period of the standing wave pattern of the 1030 nm radiation can be matched to the grating period of the standing wave pattern of the 1049 nm laser radiation. That means only those regions in the intra-cavity pumped disk can be pumped that are actually "seen" by the laser radiation. Furthermore, the higher saturation of the gain medium leads to a slightly higher efficiency. This is a similar approach as recently reported by Ge *et al.* [3]. The grating periods of the standing wave patterns are a function of the angle of incidence. Radiation that is s-polarized with respect to the plane of incidence on the intra-cavity pumped disk has a slightly different standing wave pattern than the standing wave pattern of the p-polarized radiation. For angles of incidence θ_0 smaller than 25°, the difference between the standing wave patterns is small and can be neglected. The standing wave pattern in the intra-cavity pumped disk along the axial direction has the grating period Λ_{1030} at the 1030 nm pump wavelength and the grating period Λ_L at the laser wavelength λ_L of the intra-cavity pumped laser [4]:

$$\Lambda_{1030} = \frac{\lambda_{1030}}{2\sqrt{n^2 - \sin^2\theta_{0,1030}}} \quad \text{and} \quad \Lambda_L = \frac{\lambda_L}{2\sqrt{n^2 - \sin^2\theta_{0,L}}} \tag{1}$$

Where n is the refractive index of Yb:YAG and λ_{1030} is the wavelength of the pump radiation of the intra-cavity pumped disk, $\theta_{0,1030}$ is the angle of incidence of the pump radiation on the intra-cavity pumped disk and $\theta_{0,L}$ is the angle of incidence of the laser radiation on the intra-cavity pumped disk. Setting equal the grating periods for the 1030 nm pump radiation and the 1049 nm laser radiation, yields the laser wavelength λ_{GM} whose standing wave pattern has the same grating period as the standing wave pattern of the pump radiation:

$$\lambda_{GM} = \lambda_{1030}\sqrt{\frac{n^2 - \sin^2\theta_{0,L}}{n^2 - \sin^2\theta_{0,1030}}} \tag{2}$$

For a given angle of incidence of the pump radiation $\theta_{0,1030}$ on the intra-cavity pumped disk, the wavelength of the laser can be tuned in the neighborhood of the local maximum of the emission cross section at 1049 nm by changing the angle of incidence of the laser radiation on the intra-cavity pumped disk.

3. Experiments

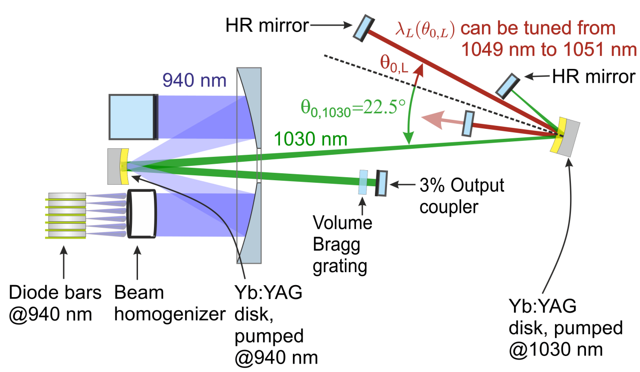

Fig. 2. Setup of the intra-cavity pumped thin-disk laser. The angle of incidence $\theta_{0,L}$ was gradually changed from 7.2° to 10.3°.

The setup of the laser is modified such that the 1030 nm pump radiation hits the intra-cavity pumped disk under an angle of $\theta_{0,1030} = 22.5°$ (see Fig.2). The angle of incidence of the laser radiation on the intra-cavity pumped disk was gradually changed. For each angle of incidence, we measured the output power and the optical spectrum from 1045 nm to 1055 nm. The diode pumper power was 220 W and both lasers operated in transverse multimode.

The red crosses in Fig.3(a) stand for the wavelength of the peak intensity of longitudinal modes in the optical spectrum. It can be seen that the laser oscillates on two longitudinal modes for angles of incidence smaller than 8.4°. For larger angles of incidence only one mode is present. The wavelength of the mode becomes shorter for larger angles of incidence. We suppose that the laser adapts its wavelength so that its standing wave pattern has the same period as the standing wave pattern of the pump. The calculated laser wavelength λ_{GM} that leads to the same grating period as the pump radiation (see Equation (2)) is depicted by the blue line in the same figure.

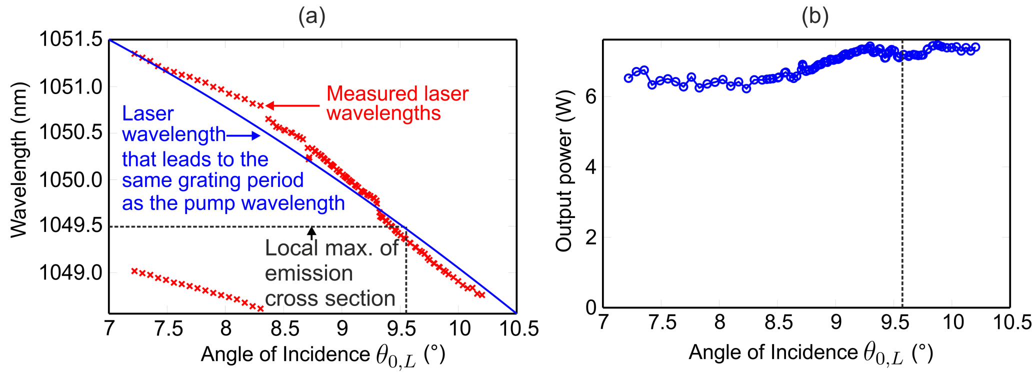

Fig. 3. (a) The laser wavelength λ_{GM} that leads to the same grating period as the pump wavelength is shown by the blue line. Red crosses indicate peaks in the measured optical spectrum. The dashed lines indicates the local maximum of the emission cross section for the laser.

For angles of incidence between 9° and 10°, the laser wavelength that leads to the same grating period as the standing wave pattern of the pump is in the neighborhood of the maximum emission cross section at 1049.5 nm. Hence the efficiency of the laser should be higher in comparison to other angles of incidence. Fig.3(b) shows the measured output power as a function of the angle of incidence of the laser radiation on the intra-cavity pumped disk. The output power is roughly 10% higher when the laser wavelength is tuned towards the maximum of the emission cross section. Furthermore the spectral power density has more than doubled because the laser is oscillating on one longitudinal mode only. In future experiments we will setup the intra-cavity pumped laser with a fundamental mode resonator, so the intra-cavity pumped laser should oscillate on a single-frequency only.

References

1. C. Vorholt and U. Wittrock, “Approaching the thermodynamical limit of optical pumping — Intra-cavity pumped thin disk laser with very low quantum defect,” (CLEO EUROPE/IQEC), (2013).
2. K. Schuhmann and M. Larionov, “VBG stabilization of efficient high-power frequency-doubled disk laser,” Advanced Solid-State Lasers Congress (ASSL), (2013).
3. L. Ge, O. Malik, and H.E. Treci, “Enhancement of laser power-efficiency by control of spatial hole burning interactions,” Nature Photonics, 8, 871875, (2014).
4. C. Vorholt, Photonics Laboratory, Muenster University of Applied Sciences, Stegerwaldstraße 39, 48565 Steinfurt, Germany, and U. Wittrock submitted a manuscript called ”Spatial hole burning in thin-disk lasers,” to Applied Physics B.