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High-Power Ho:YAG Laser in-band Pumped by Laser Diodes at 1.9 µm and Wavelength-Stabilized by a Volume Bragg Grating

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Abstract: The first high-power Ho:YAG laser wavelength-stabilized by a volume Bragg grating is reported. A maximum output power of 15 W and a slope-efficiency of 37 % were achieved using in-band diode pumping. The spectrum of the Ho:YAG laser showed a stable narrow bandwidth operation. In free-running operation a maximum output power of 46 W and a slope efficiency of 62 % were achieved. The emitted wavelength of the free-running laser was 2118 nm and 2096 nm in wavelength-stabilized operation. In free-running Q-switched operation the maximum output pulse energy at a repetition rate of 250 Hz was 6.2 mJ, limited only to avoid damage of the optical surfaces.
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OCIS codes: (140.3070) infrared and far-infrared lasers; (140.3480) diode-pumped lasers; (140.3540) Q-switched lasers; (140.3580) solid-state lasers; (160.5690) Rare-earth-doped materials; (230.1480) Bragg reflectors

1. Introduction

Many laser applications require not only high-power continuous wave (CW) and q-switched operation, but also call for spectral stability and narrow linewidths to achieve highly reliable systems [1]. These features are required for various applications such as LIDAR, high resolution spectroscopy, free-space communication and military applications [2]. Another promising field is the nonlinear frequency conversion to the 3 – 12 µm spectral range based on the excitation of optical parametric oscillators (OPO). Ho:YAG laser systems are very attractive for pumping OPOs based on $ZnGeP_2$ (ZGP). Current experimental setups for pumping OPOs require an additional seed-laser for wavelength-stabilization. Using a volume Bragg grating (VBG) for wavelength-stabilization, the overall-complexity of the nonlinear frequency conversion laser systems may be reduced.

To date, to our knowledge, spectral narrowing of a diode pumped high-power Ho:YAG laser by a VBG has not yet been reported. So far, only in-band pumping of a free-running Ho:YAG laser by laser diodes operating at 1.91 µm has been shown [3]. In 1995, it has already been demonstrated by Nabors et. al. that efficient in-band pumping of Ho:YAG lasers by laser diodes at 1.9 µm is generally possible with a simple experimental setup [3]. A maximum output power of 0.7 W with a corresponding slope efficiency of 35 % was achieved. The approach of in-band pumping has many advantages, e.g. the low quantum defect of about 10 %. It leads to a reduction of the losses caused by excited state absorption and upconversion processes and the heat dissipation within the Ho:YAG crystal per unit absorbed pump power is also reduced by a factor of three to five compared to commonly used thulium, holmium codoped systems pumped at 800 nm [3].

Recent improvements of high power diode lasers operating at 1.9 µm meet the technical requirements for a more powerful excitation of Ho-ions. With a linear array consisting of 19 emitters on a 1 cm long bar an output power of 16.9 W in cw operation has been achieved [4]. The first GaSb-based laser diode stack emitting at 1.9 µm with a maximum output power of 160 W served as pump source in our experiments.

2. Experimental setup and results

The used 52 mm long 1 % doped Ho:YAG rod was water cooled to 15 °C. Both sides of the laser crystal were anti reflection (AR) coated for the laser wavelength (2.1 µm) and the pump wavelength (1.9 µm). The laser resonator is formed by a plane mirror and the VBG. The plane mirror was AR coated for the pump wavelength and highly reflective (HR) coated for the laser wavelength. In order to achieve a double pass of the pump light, a plane pump light reflector was introduced between the Ho:YAG rod and the VBG. In the setup the VBG served as the wavelength selective element and as the output coupler. The VBG (8 x 8 x 5.5 mm³) was also AR coated for the laser wavelength on both sides. Its reflectivity was about 95 %. The compact resonator was only 65 mm long, a schematic of it is shown in fig. 1.

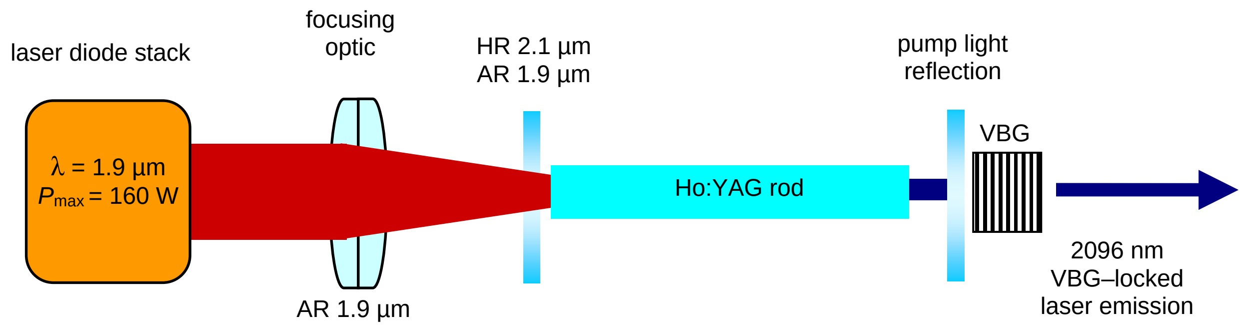

Fig.1. Experimental setup of the VBG-locked Ho:YAG laser

A diode stack of (AlGaIn)(AsSb) laser diodes with an output power of up to 160 W at 1.91 µm was used as pump source. The laser diode stack was water cooled to 18 °C and the center-wavelength of the diode stack spectrum was 1.91 µm for the maximum diode output power. The bandwidth of the spectrum was about 22 nm. The wavelength-shift from threshold to maximum output power was about 40 nm. The emitted pump light of the GaSb diode stack was focused into the 1 % doped Ho:YAG crystal by an AR coated multi lens optic with a focal length of 20 mm.

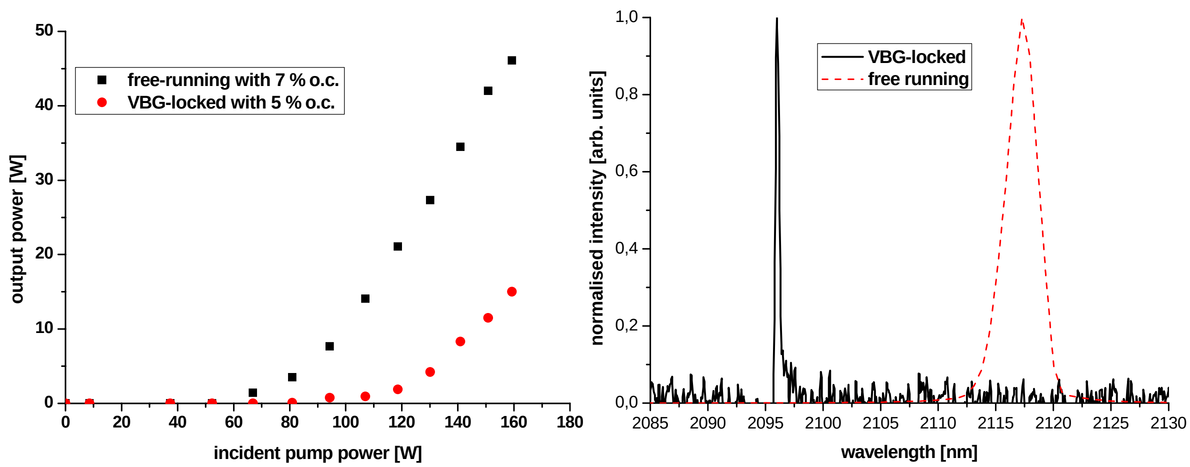

Fig. 2. Left: characteristic lines of the Ho:YAG laser in free-running and VBG-locked operation.
Right: spectra of the Ho:YAG laser in free-running (dashed line) and VBG-locked (solid line) operation.

On the left side of fig. 2 the characteristic curves of the Ho:YAG laser in free-running and VBG-locked operation are shown. The maximum laser output power in free-running operation was 46 W using a plane output coupler with 7 % transmission instead of the VBG. The corresponding slope efficiency with respect to the incident pump power was 62 % and the optical-to-optical efficiency was nearly 30 %. In VBG-locked operation a maximum output power of 15 W and a slope efficiency of 37 % were achieved. When the Ho:YAG laser is locked to 2096 nm the reabsorption within the crystal is higher which results in a higher threshold. Nevertheless there is a great potential for power scaling using VBGs designed for different wavelengths, different transmissions of the VBG, or other crystal lengths and doping concentrations, respectively.

The emission spectra of the free-running and the VBG-locked Ho:YAG laser are shown on the right side of fig. 2. With a plane mirror as output coupler the laser emits at 2118 nm with a linewidth of 3 nm. When using the VBG, its feedback forces the wavelength of the Ho:YAG laser to its design wavelength of 2096 nm. The spectrum had a linewidth of only 0.35 nm (full width at half maximum, FWHM). Heating of the VBG may cause a wavelength shift of the laser. This effect was measured to be well below 1 nm.

In free-running operation, also Q-switching experiments were carried out. Two additional intracavity components were embedded in the Ho:YAG laser system. A lens (f = 240 mm) which was AR coated for the laser wavelength and an acousto-optic modulator (AOM) under Brewster's angle were introduced between the plane pump light reflector and the plane output coupler. The lens increases the mode diameter within the resonator and therefore the photon density and the stress on the surfaces of the components are reduced. With this resonator a maximum output power of 12 W was achieved with a 30 % output coupler.

Up to 6.2 mJ of output pulse energy at a repetition rate of 250 Hz were achieved, limited by possible damage of the optical components only. The pulse length was around 180 ns.

3. Conclusion

The first high-power Ho:YAG laser wavelength-stabilized by a volume Bragg grating is reported. A maximum output power of 15 W and a slope-efficiency of 37 % were achieved using in-band diode pumping. The Ho:YAG laser was wavelength-stabilized to 2096 nm and the linewidth was 0.35 nm FWHM.

In free-running mode, a maximum output power of 46 W, which is also the highest value reported up to now, was achieved. The corresponding slope efficiency was 62 %. In this case, the emission wavelength was 2118 nm with a linewidth of 3 nm FWHM. In addition, the potential of the developed Ho:YAG laser system for pulsed operation was investigated. In q-switched operation up to 6.2 mJ of pulse energy limited only by possible damage of the optical surfaces were achieved. The repetition rate was 250 Hz. The output coupler had a transmission of 30 % and the pulse length was about 180 ns.

In further experiments, it is planned to demonstrate the enormous potential of this simple and compact Ho:YAG laser system. VBGs with higher outcoupling rates will be tested in order to reduce the intracavity photon density and thus the stress on the surfaces of the optical components. This will allow wavelength-stabilized and Q-switched operation of the demonstrated system in the future.

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