High-power continuous wave diode-pumped Nd:YAlO3 laser emitting on the low-gain 1378-nm and 1385-nm transitions

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High-power continuous-wave diode-pumped Nd:$YAlO_3$ laser that emits on low-gain 1378- and 1385-nm transitions

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Efficient operation of a diode-pumped Nd:$YAlO_3$ laser on low-gain 1378- and 1385-nm transitions is reported for the first time, to our knowledge. A three-mirror folded cavity with a prism yielded a cw laser output power of 800 mW for an absorbed pump power of 11 W. The laser beam was TEM_{00}. We managed to eliminate the instabilities in the output power by purging the cavity of water vapor with nitrogen. © 2001 Optical Society of America

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1. Introduction

Yttrium aluminium garnet ($Y_3Al_5O_{12}$ or YAG) and yttrium orthoaluminate ($YAlO_3$) are both known to be among the best laser host crystals to date. Many of the physical properties of these two materials are similar. One of their differences is that $YAlO_3$ is biaxial whereas YAG is optically isotropic.[1] Therefore the absorption and the emission spectra of neodymium in $YAlO_3$ are polarization dependent. This property represents an advantage of $YAlO_3$ compared with YAG for many laser applications in which polarized operation is required. The spectroscopic properties of Nd:$YAlO_3$ have been extensively investigated in the past. Several transitions of Nd:$YAlO_3$ are well known from prior studies, particularly the transitions around 1.08,[1–3] 1.34,[2–7] and 1.43 μm.[8,9] In this paper we investigate two lines in the $^4F_{3/2} \rightarrow {}^4I_{13/2}$ transition of neodymium at 1378 and 1385 nm that have never been studied, to our knowledge. The emission cross section for these lines is relatively low ($\sim 10^{-20}$ cm^2),[9] which is approximately 40 times smaller than for the 1.08-μm line and 20 times smaller than for the 1.34-μm line.[10] Consequently, an efficient diode-pumped laser at 1378 and 1385 nm presents a challenge because it requires a laser cavity in which laser oscillations on the above-mentioned higher gain lines have to be suppressed.

2. Crystal Orientation

Several pump systems at different wavelengths have been studied with Nd:$YAlO_3$ crystals. For example, these crystals have been diode pumped by a fiber-coupled diode,[8] a beam-shaped diode module,[8] or diode arrays,[2,6,7] usually around 804 or 808 nm, inasmuch as the absorption spectrum of neodymium in $YAlO_3$ crystal presents peaks at these wavelengths.[2] Nd:$YAlO_3$ crystals have also been pumped by a Ti:sapphire laser at 813 nm,[11,12] corresponding to the strongest absorption coefficient in the 800–820-nm range in Nd:$YAlO_3$. In each case attention has been paid to the orientation of the crystal to optimize the pump absorption, on the one hand, and the output power, on the other hand. Unfortunately the convention used to define the crystallographic axes is not always the same in the literature (Pnma or Pbnm convention), leading to confusion.[8,9]

The pump source used for all our experiments was a cw 16-W fiber-coupled AlGaAs laser diode manufactured by SDL, Inc. with a 400-μm-diameter core and a 0.2 numerical aperture, emitting a nonpolarized output beam. This diode had a broad emission spectrum centered at 808 nm with a full width at half-maximum of approximately 3 nm. We first used this diode for preliminary absorption tests to choose the crystal orientation. These tests were done on a Nd:$YAlO_3$ cube with its faces perpendicular to the crystallographic axes a, b, and c (here we used the Pnma convention). We found that absorption was at its maximum for a diode beam propagating along the a axis. Moreover, the crystal orientation should be defined to have the highest gain possible at

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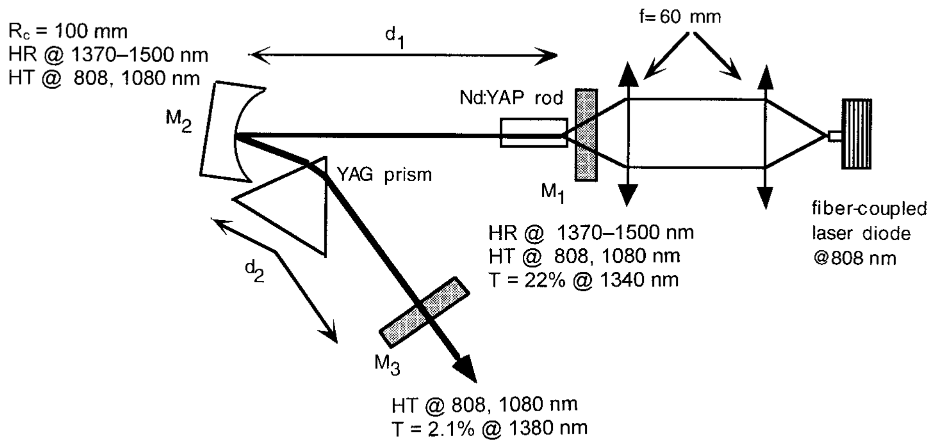

Fig. 1. Diode-pumped $Nd:YAlO_3$ laser operating on the 1378- and 1385-nm lines.

1378 and 1385 nm. According to Heine *et al.*,[9] the strongest emission cross sections for these transition lines are obtained for a beam polarization parallel to the *b* axis. For all these reasons, the crystal was oriented with the *a* axis along the rod axis, and the laser polarization was along the *b* axis as we considered longitudinal pumping.

3. Experimental Setup

For the experiments described below, we used a 1% $Nd:YAlO_3$ laser rod with a 3-mm diameter and a 7-mm length. The ends of the rod were flat, parallel, and antireflection coated at 808 and 1380 nm. The rod was also antireflection coated at 1080 nm to avoid any parasitic laser oscillation at this wavelength. The $Nd:YAlO_3$ rod was wrapped in indium foil and placed in a copper mounting with its *b* axis horizontal. A Peltier element drained off the heat to a water-cooled copper plate.

As shown in Fig. 1, the output beam of the pump diode was collimated and focused into the crystal by two doublets of 60-mm focal length. The pump optics had a magnification of 1, so that the diameter of the pump beam at the focus was 400 μm. The maximum pump power available at the focus was approximately 13.8 W, corresponding to a total transmission for the pump optics of 90%. The absorption of the pump in the crystal was constant from approximately 806 to 810 nm. Therefore accurate control of the diode temperature was not necessary. For all our experiments the temperature of the diode was approximately 14 °C. For an incident power of 13.8 W, 80% of the pump power was absorbed.

The resonator design was similar to that used by Moore *et al.*[13] It was a folded cavity, consisting of a plane input mirror, M_1, with high reflectivity (99.5%) at 1380 nm and high transmission (93%) at the pump wavelength (808 nm); the crystal described above; a concave folded mirror, M_2, with a 100-mm radius of curvature; a Brewster's angle YAG prism; and a plane output coupler, M_3 (Fig. 1). All the mirrors were highly transmission coated around 1080 nm to prevent lasing of the 1080-nm line. The input mirror, M_1, had a 22% transmission at 1340 nm to prevent laser oscillation on this line. Mirrors M_1 and M_2 were also highly reflective between 1370 and 1500 nm. We tried several transmissions at 1380 nm for the output mirror: 1.2%, 2.1%, and 5.8%.

Laser oscillations were apt to occur on several transition lines around 1.3 μm: the 1340-nm line ($\sigma \cong 20 \times 10^{-20}$ cm^2) and the 1378- and 1385-nm lines ($\sigma \cong 10^{-20}$ cm^2) were all *b* polarized, whereas the 1430-nm line ($\sigma \cong 10^{-20}$ cm^2) was *c* polarized.[9] We inserted the prism—made of undoped YAG, inasmuch as this material has the advantage of no absorption around 1.3 μm—into the cavity to select the 1378- and 1385-nm lines. In this way we benefited from two different effects induced by the prism. On the one hand, the Brewster's angle prism transmitted without loss only the polarization that was on the incidence plane, i.e., along the *b* axis. The *b*-axis polarized lines were the 1340-, 1378-, and 1385-nm wavelengths.[9] The prism forced the laser oscillation along the *b* axis and then suppressed the 1430-nm oscillation that was *c* polarized. On the other hand, the dispersion of the prism enabled selection of both the 1378- and 1385-nm lines (but was not strong enough to separate them).

The small pump beam in the laser rod resulted in strong thermal lensing, and for a 12-W incident pump power (i.e., 9.6 W absorbed) the measured focal length was approximately 80 mm. As described by Moore *et al.*[13] and Kern *et al.*,[14] a three-mirror resonator can prevent significant degradation in beam quality. In our experiments the criteria for TEM_{00} operation were satisfied by setting the arm lengths, $d_1 = 109$ mm and $d_2 = 80$ mm, resulting in a TEM_{00} radius of 130 μm in the rod.

4. Results

We carried out our first experiments without purging the laser cavity. By means of a photodiode, we observed that the laser typically operated in a pulsed regime. The pulses were of 20-μs duration with a peak power of approximately 2 W, which is thought to be a self-*Q*-switching effect caused by the water vapor

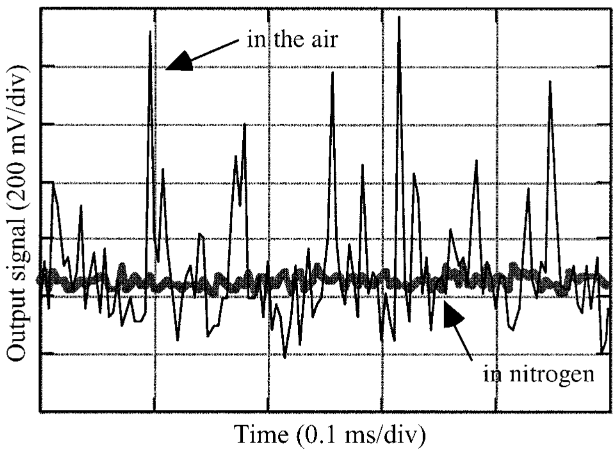

Fig. 2. Output signals for a Nd:$YAlO_3$ laser on the 1378- and 1385-nm lines operating in the air (thin curve) and in an atmosphere purged of water vapor (thick curve).

in the cavity acting as a saturable absorber. Indeed water-vapor absorption presents several peaks around 1380 nm. Added to the weak emission cross section at 1378 and 1385 nm, these absorption lines explain the difficulty in obtaining stable high-power operation around 1380 nm. Thus, to ensure cw operation it was necessary for us to purge water vapor from the cavity by using nitrogen. Figure 2 also shows the efficiency of this purge (thick curve). The intensity of the peaks slowly decreased until the peaks were suppressed. The remaining fluctuations might arise from residual water absorption. Note that a similar self-Q-switching effect induced by water absorption had already been observed with a Nd: YAG laser at 1123 nm.[13]

The results for laser output power versus absorbed pump power are shown in Fig. 3. We obtained these results by using nitrogen to purge the cavity of water vapor. The best performance was obtained with the 2.1% transmission coupler; the laser reached threshold at an absorbed pump power of 3 W and produced a maximum cw output of 800 mW on the 1378- and 1385-nm lines in a linearly polarized TEM_{00} beam.

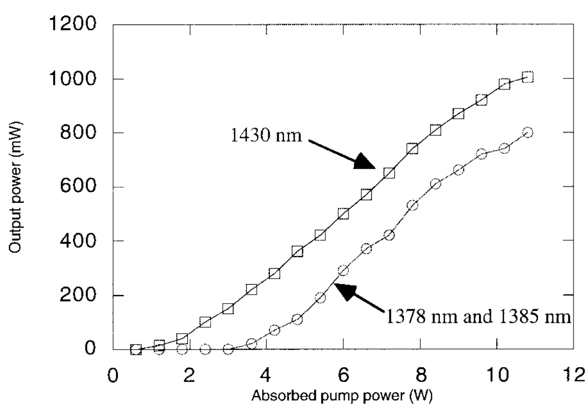

Fig. 3. Output power versus absorbed pump power for a Nd: $YAlO_3$ laser: comparison between the 1378- and 1385-nm lines (circles) and the 1430-nm line (squares).

5. Comparison with the 1430-nm Line

To illustrate the effect of water absorption, we compared the output powers at 1430-nm wavelength; the results are shown in Fig. 3. Indeed the 1430-nm line corresponds to a region where no water vapor is absorbed and the emission cross section at 1430 nm is the same order of magnitude as the 1378- and 1385-nm lines. This 1430-nm line was far enough away from the strong 1340-nm line that the mirrors were sufficient for selecting the wavelength (i.e., prism unnecessary). High-power operation at 1430 nm was much easier than at 1378 and 1385 nm, and we achieved 1 W at this wavelength for an absorbed pump power of 11 W, whereas we obtained 800 mW at 1378 and 1385 nm for the same absorbed pump power. This result at 1430 nm is comparable with those obtained at the same wavelength by Kretschmann *et al.*,[8] i.e., output power of 590 mW with a 10-W fiber diode and output power of 2.2 W with a 27-W beam-shaped diode module, but in addition our laser beam was of TEM_{00}.

6. Conclusion and Applications

We have demonstrated high-power operation of a diode-pumped Nd:$YAlO_3$ laser on low-gain 1378- and 1385-nm lines for the first time to our knowledge. In a compact setup consisting of a folded nitrogen-purged cavity, we achieved 800 mW of TEM_{00} output for 11 W of absorbed pump power. The selection of the emission wavelengths was obtained by choosing convenient treatments for the mirrors and by inserting a prism into the cavity.

Such a laser could prove suitable for application in telecommunications. The Raman effect in a silica optic fiber generates a shift of approximately 90 nm at pump wavelengths of 1378 and 1385 nm. Using this effect with our high-power laser could enable the S band to be reached (that is, between approximately 1460 and 1500 nm) and then a signal to be amplified in this spectral bandwidth. Another advantage of this laser emitting on a doublet of lines is the possibility of its broadening the Raman gain.

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