High-Average-Power Diode-End-Pumped Intracavity-Doubled Nd:YAG Laser

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HIGH-AVERAGE-POWER DIODE-END-PUMPED INTRACAVITY-DOUBLED Nd:YAG LASER

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Abstract

A compact diode-pumped Nd:YAG laser was frequency-doubled to 0.532 μm with an intracavity KTP or LBO crystal using a "V" cavity configuration. Two acousto-optic Q-switches were employed at repetition rates of 10-30 kHz. Dichroic fold and end mirrors were used to output two beams with up to 140 W of 0.532 μm power using KTP and 116 W using LBO as the frequency doubling crystal. This corresponds to 66% of the maximum output power at 1.064 μm obtained with an optimized output coupler reflectivity. The minimum output pulse duration varied with repetition rate from 90 to 130 ns. The multimode output beam had a smooth profile and a beam quality of $M^2 = 51$.

Introduction

High average power lasers operating at 0.53 μm have a number of applications in medicine and materials processing as well as serving as useful pump sources for other systems such as Ti:sapphire lasers. Recent work using repetitively Q-switched intracavity-doubled Nd:YAG lasers has demonstrated that output powers of 75 to over 100 W is possible using KTiOPO_4 (KTP) or LiB_3O_5 (LBO) as the nonlinear frequency conversion element.^{1,2,3,4} Furthermore, work at LLNL based on a side-pumped architecture has resulted in >150 Watts of reliable power.⁵ Here we describe a compact diode-end-pumped Nd:YAG system capable of generating up to 140 W of power at 532 nm operating at repetition rates of 10-30 kHz using KTP. In addition, output powers up to 116 W were obtained using LBO as the frequency-doubling element.

Layout and Design

The layout of the laser system is shown in Figure 1. The pump array consists of 38 laser diode bars mounted on microchannel cooler packages.⁶ The 1.5 cm bars produce up to 30 W per package at 807 nm, yielding a maximum pump power of 1.14 kW. Cylindrical microlenses collimate the light from each package,⁷ which is then focussed into the end of the laser rod using a fused silica lens duct.⁸ The measured delivery efficiency of the lens duct was 71%. The 5 mm diameter by 100 mm long composite laser rod utilizes 5 mm long undoped end caps for thermal management.⁹ The Nd doping level of $1.4 \times 10^{19} \text{ cm}^{-3}$ was chosen to reduce the stress fracture to a manageable level while still resulting in over 95% of the pump light being absorbed.

The laser resonator is arranged in a "V" configuration¹⁰ with highly reflective elements at the 1064 nm laser wavelength located at the pump end of the rod (which is also highly transmitting at the 807 nm pump wavelength), the 250 mm radius of curvature fold mirror and the 250 mm radius of curvature end mirror. The 250 mm radius of curvature mirrors are highly transmitting for 532 nm light, resulting in two output beams when a frequency conversion crystal is inserted in the

cavity. Tests were also performed with a flat cavity end mirror which was highly reflecting for both the 1064 nm fundamental and the 532 nm second harmonic, resulting in a single output beam from the fold mirror of up to 130 W. The fold angle was kept below 25 degrees to minimize astigmatism in the output beams. In order to obtain sufficient gain hold-off at the repetition rates of interest, two acousto-optic Q-switches are located near the laser rod. Alignment of the two Q-switches was found to be critical for operation at the highest powers.

The frequency doubling element, either a 5 x 5 x 5 mm KTP crystal¹¹ or a 5 x 5 x 18 mm LBO crystal¹² is located near the cavity end mirror. This location was found to minimize the effect of thermal lensing in the frequency doubling crystal itself. The cavity lengths and mirror curvatures were chosen such that the multimode intracavity beam is approximately 3 mm in diameter on the doubling crystal in order to minimize the possibility of optical damage and degradation. The “V” cavity configuration results in a beam diameter on the crystal which increases with increasing pump power (i.e. thermal lens). Initial tests with an “L” cavity indicated that the beam diameter on the crystal is significantly smaller, due to the cavity length necessary to insert two Q-switches. In addition, this resonator layout results in a decreasing beam diameter on the crystal with increasing diode pump power.

Figure 1: Schematic of diode-end-pumped system. The major components are: a) 38 bar diode array, b) lens duct, c) composite Nd:YAG laser rod with undoped end caps and 1064 nm, d) acousto-optic Q-switches (2), e) dichroic mirror (high reflectance @ 1064 nm, high transmittance @ 532 nm, 250 mm radius of curvature), f) KTP or LBO nonlinear optical crystal, g) dichroic mirror (high reflectance @ 1064 nm, high transmittance @ 532 nm, 250 mm radius of curvature).

Laser Performance

The output power at 532 nm vs pump power for several repetition rates is shown in Figure 2 using a KTP crystal. The maximum output power of 140 W was observed at 15 kHz repetition rate with output powers ≥ 130 W obtained for higher repetition rates up to 30 kHz. In general, Q-switch hold-off becomes more difficult at the highest pump powers as the repetition rate is lowered. The Figure shows that the maximum output power observed at 10 kHz occurs slightly below the maximum pump power, presumably due to losses inadvertently introduced during alignment in order to obtain sufficient gain holdoff. More limited tests were performed using an LBO crystal, yielding a maximum of 116 W output power at 20 kHz.

Output pulses were recorded using a fast storage oscilloscope. At the maximum pump power of 1.1 kW, the 0.532 μm pulse width decreases with decreasing repetition rate from 150 ns

FWHM at 30 kHz to 90 ns FWHM at 10 kHz. Analysis of scattered light from the 1.064 μm intracavity beam indicated that the infrared pulse intensity was generally proportional to the square root of the green output pulse, indicating the frequency doubling conversion efficiency was not saturated.

Beam quality measurements on the output beam were obtained by measuring the second moment of the intensity distribution at various distances from a focusing lens. These measurements yielded an M^2 value of 51, reflecting the multimode nature of the nearly gaussian beam profile.

Figure 2: Output power at 532 nm vs diode pump power for various repetition rates using a 5 x 5 mm KTP crystal.

Summary

In summary, we have described a compact end-pumped intracavity-doubled Nd:YAG laser capable of producing up to 140 W at 0.532 μm using KTP and 116 W using LBO as the frequency doubling crystal. The maximum optical (diode)-optical (green) efficiency obtained was 11%. Operation is possible from 10 - 30 kHz corresponding to output pulse widths of 90 to 150 ns FWHM. The beam quality is characterized by an M^2 value of 51.

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 - ¹¹ KTP crystals were obtained from Crystal Associates, Waldwick, NJ, USA and Cristal Laser, Chaligny, France.
 - ¹² LBO crystals were obtained from EKSMA, Vilnius, Lithuania and Fujian Castech, China.

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