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A dual-end-pumped Ho : YAG laser with a high energy output

X.M. Duan, Z. Cui, L.J. Li, T.Y. Dai, K.K. Yu, B.Q. Yao

Abstract. **We report a high energy output from a Ho : YAG oscillator resonantly double-end pumped by Tm : YLF lasers at room temperature. The maximum pulse energy of 52.5 mJ was achieved at a pulse repetition rate of 100Hz and a pulse duration of 35.2 ns, corresponding to a peak power of approximately 1.5 MW. The output wavelength was 2090.7 nm with beam quality factor M^2 ~ 1.2.**

Keywords: *2-μm laser, Ho : YAG oscillator, high energy.*

1. Introduction

Solid-state lasers operating in the nominally eye-safe 2-μm wavelength region are vital for applications in medicine, material processing, lidar systems and mid-IR generation via pumping optical parametric oscillators (OPOs) [1 – 5]. High energy Ho-based lasers are ideal pump sources for OPOs [6 – 8]. Due to the long upper laser level lifetime, Ho-doped solid-state lasers are particularly attractive for *Q*-switched operation. In addition, direct pumping of Ho ions offers several advantages such as low quantum defect between pump and laser, reduced up-conversion loss and reduced sensitivity of gain to temperature. These advantages indicate the possibility of fabricating a Ho-doped laser with a high energy output.

Recently, an output energy of 550 mJ has been achieved using a cryogenic Ho : YLF oscillator at a pulse repetition rate of 1 Hz [9]. A 125-mJ pulse energy at a pulse repetition rate of 100 Hz has been reported in a Ho : YAG master oscillator – power amplifier (MOPA) system [10]. Compared with a MOPA system, a single oscillator can be more compact and convenient for numerous applications. YAG and YLF are known to be the most widespread laser hosts for 2-μm generation. Compared with YLF, the YAG crystal has a higher thermal conductivity and better mechanical properties; in addition, good quality YAG crystals can be easily grown. Thus, there is a current need for a high energy Ho:YAG oscillator. A 50.6-mJ pulse energy at a pulse repetition rate of 60 Hz from a 2.09 μm Ho : YAG oscillator pumped by a pulsed Tm : YLF laser was reported by Budni et al. [11]. Operating at a pulse repetition rate of 100 Hz, pulse energies exceeding 30 mJ at a wavelength of 2.09 μm were obtained in a diode-pumped Ho : YAG laser [12].

In this paper, we demonstrate an output energy as high as 52.5 mJ at a pulse repetition rate of 100 Hz in a Ho : YAG oscillator resonantly double-end-pumped by two Tm : YLF lasers. The output at 2090.7 nm was observed at a pulse duration of 35.2 ns, corresponding to a peak power of approximately 1.5 MW. The beam quality factor was measured to be M^2 ~ 1.2.

X.M. Duan, Z. Cui, T.Y. Dai, K.K. Yu, B.Q. Yao National Key Laboratory of Tunable Laser Technology, Harbin Institute of Technology, Harbin 150001, China; e-mail: xmduan@hit.edu.cn;
L.J. Li Institute of Optoelectronic Technology, Heilongjiang Institute of Technology, Harbin 150001, China

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2. Experimental setup

The schematic diagram of the Ho : YAG oscillator is shown in Fig. 1. Two diode-pumped Tm : YLF lasers with an emission wavelength of 1908 nm were used as a pump source, both lasers having a maximum output power of 40 W. One of the lasers was s-polarised while the other was p-polarised. The pump beam radius in the Ho : YAG crystal was 450 μm. A thin-film polariser (TFP) had a high reflectance for the s-polarised pump and a high transmittance for the p-polarised pump. Two TFPs were employed in the oscillator to avoid the mutual influence between the Tm : YLF lasers. The Ho : YAG crystal used in this experiment was grown by the Czochralski technique. Both end faces of the crystal were AR-coated for the laser wavelength around 2.1 μm and the pump wavelength around 1.9 μm. The 0.8 at% Ho : YAG crystal was a 50-mm-long rod with a diameter of 5 mm. The

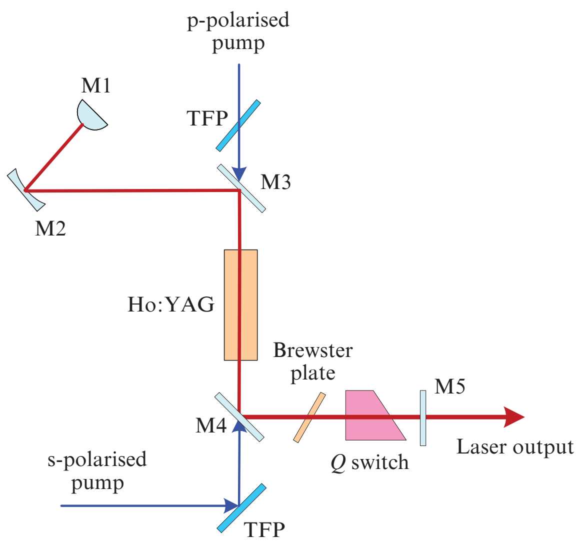

Figure 1. Schematic diagram of the experimental setup.

absorption coefficient of Ho:YAG in the oscillator at λ_p = 1.91 μm was about 0.56 cm^{-1}, providing nearly 96% pump absorption by the crystal. The crystal was wrapped in indium foil and clamped in a copper heatsink held at a temperature of 18 °C with a thermoelectric cooler. The folded resonator was about 670 mm long and had a convex highly reflecting mirror (M1) with a radius of curvature of 200 mm, a concave highly reflecting mirror (M2) with a radius of curvature of 500 mm, two 45° dichroic mirrors (M3, M4) and a flat output coupler (M5) with a transmittance $T = 40\%$. The dichroic mirrors (M3 and M4) provided both high reflection at 2.09 μm and high transmittance at 1.91 μm. A YAG etalon was utilised as a Brewster plate to achieve the linear polarised output. A 50-mm-long acousto-optic modulator (AOM) was used for *Q*-switch operation. The AOM had a maximum RF power of 100 W.

3. Experimental results

The output energy of the Ho:YAG laser was measured at pulse repetition rates of 100, 500 and 1000 Hz (Fig. 2). At a pulse repetition rate of 100 Hz, the maximum output energy was 52.5 mJ with the incident pump power of 75.6 W. At pulse repetition rates of 500 and 1000 Hz, the maximum output energy was 19.4 and 10.0 mJ, respectively. The temporal behaviour of *Q*-switched laser pulses was recorded by a digital Wavesurfer 64 Xs oscilloscope (Lecroy) equipped with an InGaAs detector. The measured dependence of the laser pulse duration on the incident pump power at a fixed repetition rate of 100 Hz is shown in Fig.3. The pulse duration sharply decreased with increasing incident pump power. As a result, the minimum pulse duration was 35.2 ns when the incident pump power was 75.6 W (Fig .4), corresponding to a peak power of approximately 1.5 MW.

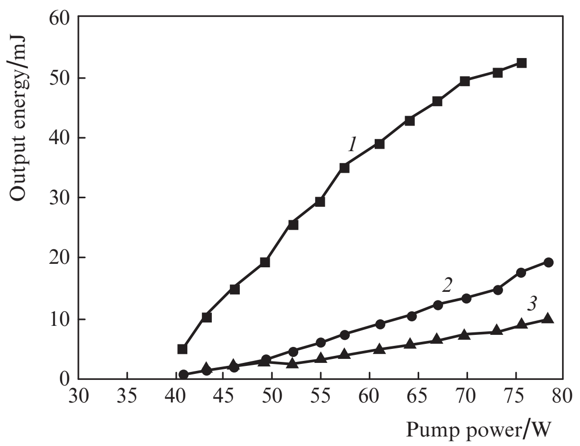

Figure 2. Output energy of the Ho:YAG laser vs. pump power at a pulse repetition rate of (*1*) 100, (*2*) 500 and (*3*) 1000 Hz.

The output wavelength of the Ho:YAG oscillator was recorded with a grating monochromator. At a pulse energy of 52.5 mJ, the wavelength is centred at 2090.7 nm (Fig. 5). The output beam radius of the oscillator was measured by a 90/10 knife edge technique at several positions through a waist formed by a lens ($f = 150$ mm). By fitting the Gaussian beam standard expression to these data, the beam quality factor was estimated to be $M^2 \sim 1.2$ (Fig. 6).

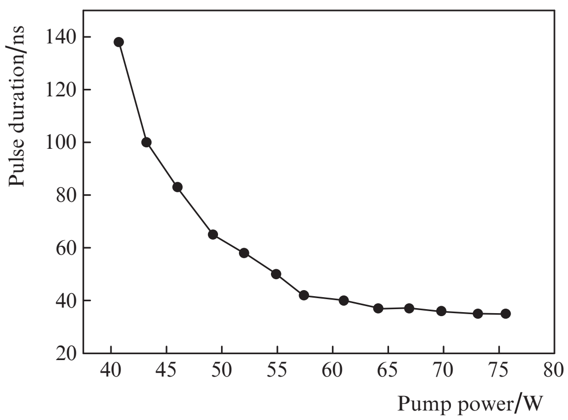

Figure 3. Pulse duration vs. incident pump power at a pulse repetition rate of 100 Hz.

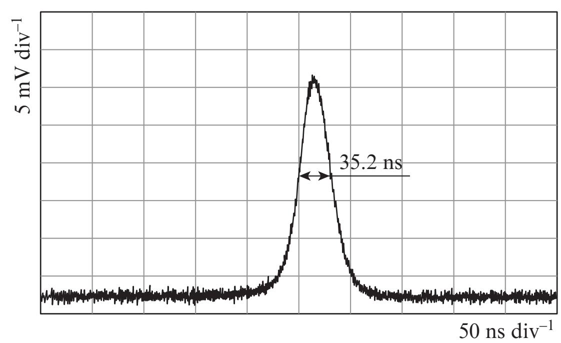

Figure 4. Profile of the Ho:YAG laser pulse at a pulse repetition rate of 100 Hz.

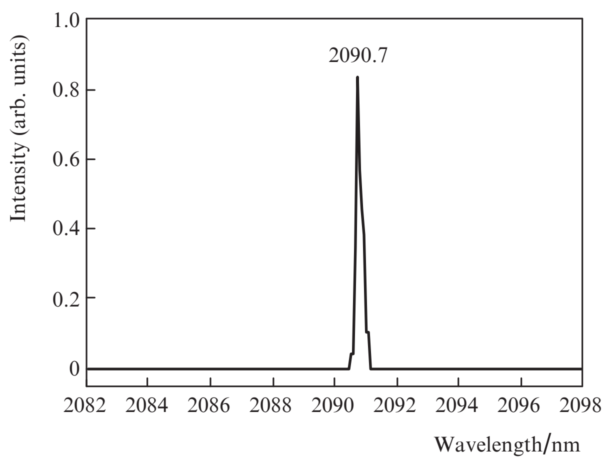

Figure 5. Emission spectrum of the Ho:YAG oscillator.

4. Conclusions

We have demonstrated a high energy Ho:YAG oscillator resonantly double-end-pumped by two Tm:YLF lasers at room temperature. In the regime of *Q*-switched operation, the maximum output energy of 52.5 mJ was achieved at a pulse repetition rate of 100 Hz. The output wavelength is 2090.7 nm with a pulse duration of 35.2 ns, corresponding to a peak power of approximately 1.5 MW. The laser operated

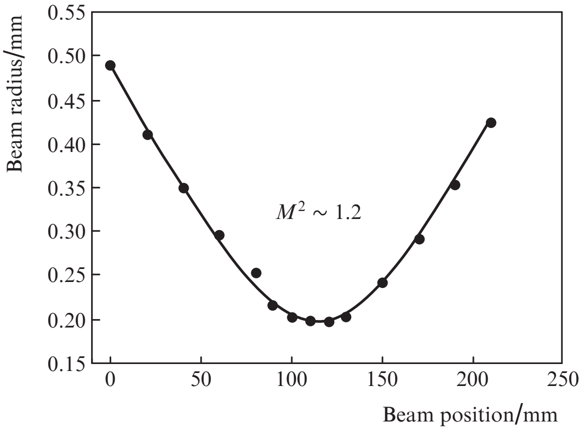

Figure 6. Beam quality factor of the Ho : YAG oscillator.

with a beam quality factor of $M^2 \sim 1.2$, which was measured by a 90/10 knife-edge method.

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