*ISSN 1054-660X, Laser Physics, 2008, Vol. 18, No. 1, pp. 12–14.*
*© MAIK “Nauka/Interperiodica” (Russia), 2008.*
*Original Text © Astro, Ltd., 2008.*

# LD-Pumped Actively Q-Switched Yb:YAG Laser with an Acoustic–Optical Modulator

**T. Yubing**[a, b, *], **T. Huiming**[a], **P. Jiying**[a, b], **and L. HongYi**[a, b]

[a] *Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Jilin ,130033 China*
[b] *Graduate School of the Chinese Academy of Sciences, Beijing, 100080 China*
*e-mail: tianyb761@hotmail.com

Received July 14, 2007

**Abstract**—We have investigated an acoustic–optical Q-switched Yb:YAG laser end-pumped by a fiber-coupled laser diode. At room temperature, the 1030-nm wavelength pulsed output is realized. When the incident power was 11.3 W, a maximum average output power of 1.034 W is achieved at the repetition frequency of 20 kHz, and this corresponds to an optical conversion efficiency of 9.1%. The shortest laser pulse width of 37.4 ns was observed at the repetition frequency of 5 kHz, when the incident power was 11.3 W. The highest peak power 6.79 kW was achieved at the repetition frequency of 1.12 kHz, when the incident power was 8.7 W. The highest single-pulse energy of 319.67 μJ was achieved at the repetition frequency of 1.12 kHz, when the incident power was 10.14 W.

PACS numbers: 42.55.Xi, 42.55.Rz, 42.60.Bg, 42.60.Gd

**DOI:** 10.1134/S1054660X08010027

## 1. INTRODUCTION

Actively Q-switched solid-state lasers with high peak powers have potential use in optical communications, laser ranging, information storage, material processing and medical surgery, nonlinear frequency conversion, and so on. Recently, high-power laser-diode pumped Yb:YAG lasers have received great attention due to their robust properties. Yb:YAG has a very low quantum defect (8.6%) resulting in three times less heat generation than Nd-based laser systems [1]. The absorption bandwidth at 940 nm is 18 nm, which make it less sensitive to diode wavelength specifications. Moreover, Yb:YAG has a long storage lifetime (951 μs) [2] and a relatively large emission cross section, which make it highly suitable for Q-switching operation.

In the past decade, several researchers reported on Q-switched Yb:YAG lasers. T.Y. Fan reported the first actively Q-switched Yb:YAG laser with an electrooptic modulator [3]. A passively Q-switched Yb:YAG laser with $Cr^{4+}$:YAG was first demonstrated by Jun Dong [4]. They employed a Ti:sapphire laser as the pump source and achieved an average output power of 55 mW at 1.03 mm with pulse width 350 ns. The first Yb:YAG microchip laser that was passively Q-switched with a SESAM was reported by G.J. Spühler [5] and a 530-ps pulse width has been obtained. To our knowledge, there were few reports that were actively Q-switched with an acoustic–optical modulator end-pumped by a fiber-coupled laser diode.

In this paper, we report on the results of an actively Q-switched Yb:YAG laser. The dependence of the average output power, peak power, single-pulse energy, and pulse width on the Q-switching repetition frequency have been investigated.

## 2. EXPERIMENTAL SETUP

The acoustic–optical Q-switched experimental setup is shown schematically in Fig. 1. The pump source employed in the experiment was a fiber-coupled laser diode with a core diameter of 400 μm and a numerical aperture of 0.22 (made by LIMO Corporation, maximum output power 25 W), which works at the maximum absorption wavelength 940 nm of the Yb:YAG crystal. The coupling optics consists of two identical piano-convex lenses with focal lengths of 40 mm used to reimage the pump beam into the laser crystal at a ratio of 1 : 1. The coupling efficiency is 98%. The laser crystal, a 10 at %, ∅4 × 1 $mm^3$ Yb:YAG, was antireflection (AR) coated at 940 nm and

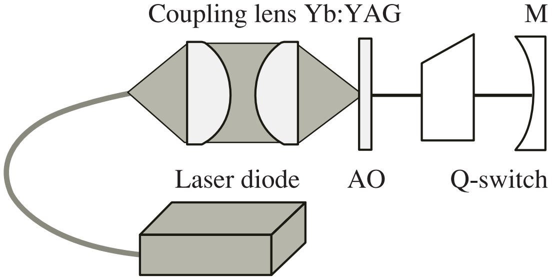

**Fig. 1.** Schematic diagram of the acoustic–optical Q-switched experimental setup.

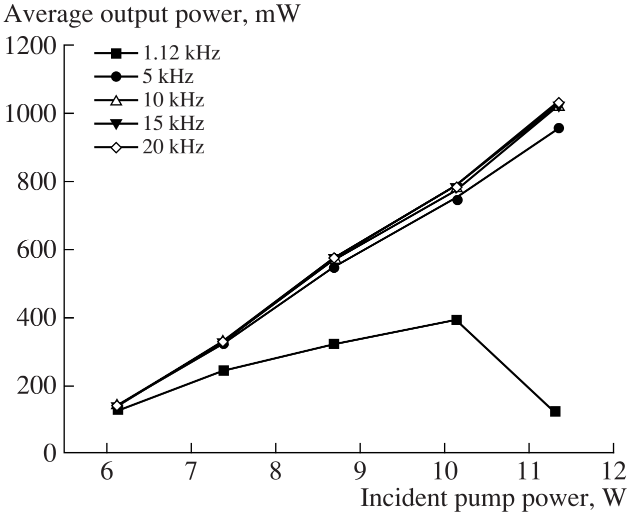

**Fig. 2.** Average output power versus pumping power for different pulse repetition frequencies.

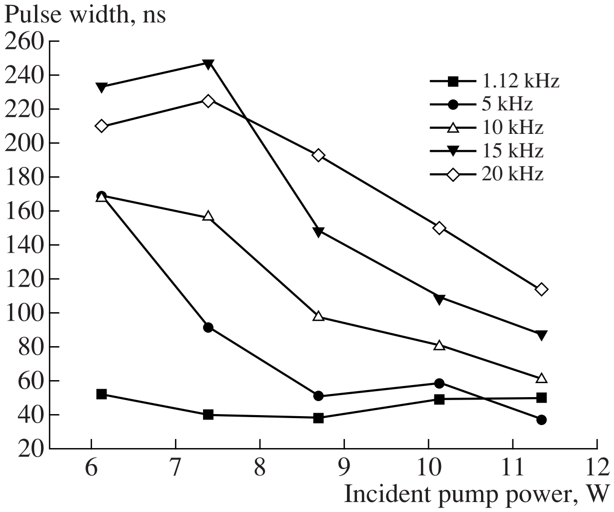

**Fig. 3.** Pulse width versus pumping power for different pulse repletion frequencies.

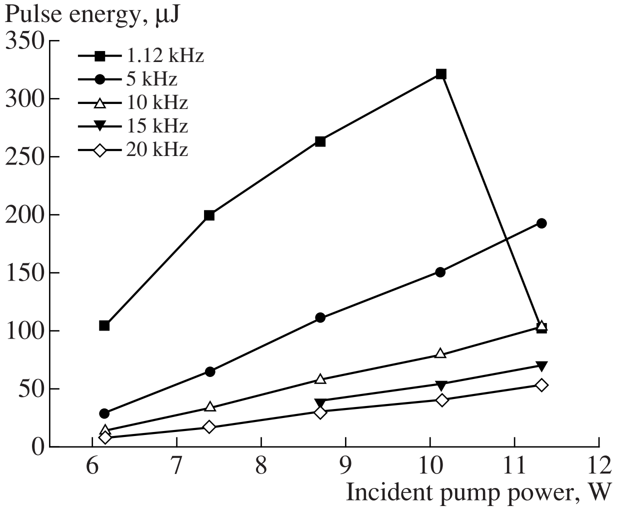

**Fig. 4.** Single-pulse energy versus pumping power for different pulse repletion frequencies.

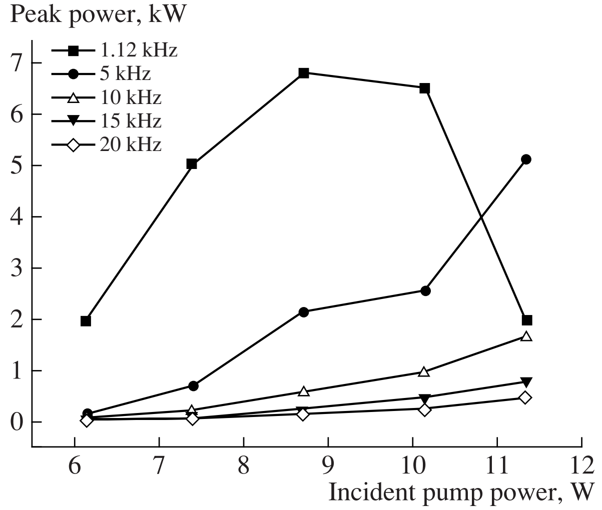

**Fig. 5.** Pulse peak power versus pumping power for different pulse repetition frequencies.

high reflection (HR) at 1030 nm on the pump face; the other face was antireflection (AR) coated at 1030 nm. It was set close to the focus of the coupling optics. The Yb:YAG crystal was wrapped by a thin indium foil and then attached to the copper block to obtain a good thermal contact and stress relief. The copper block was cooled by thermoelectric coolers. The surface temperature was controlled at 20°C during the experiment. The radius of curvature of the output mirror M is 100 mm. It was coated high reflection (HR) at 1030 nm ($R$ = 89%), the plane face was coated AR at 1030 nm ($T >$ 98%). The cavity length was approximately 50 mm.

The QSGSU-10/Q acoustic–optical modulator (The 26th Electronics Institute, Chinese Ministry of Information Industry), the effective length of which is 24 mm, was placed near the Yb:YAG crystal, it was cooled in the same way as in the case of the Yb:YAG crystal, and its surface temperature was controlled at 20°C.

## 3. RESULTS AND DISCUSSION

In conventional Q-switching, pulsed-laser operation can be obtained with the repetition frequency $f$ smaller than the inverse fluorescence lifetime $\tau^{-1}$. For Yb:YAG, stable pulsing cannot be achieved with a higher repetition frequency. Because the inverse fluorescence lifetime $\tau = 951$ μs. For a higher repetition frequency, only

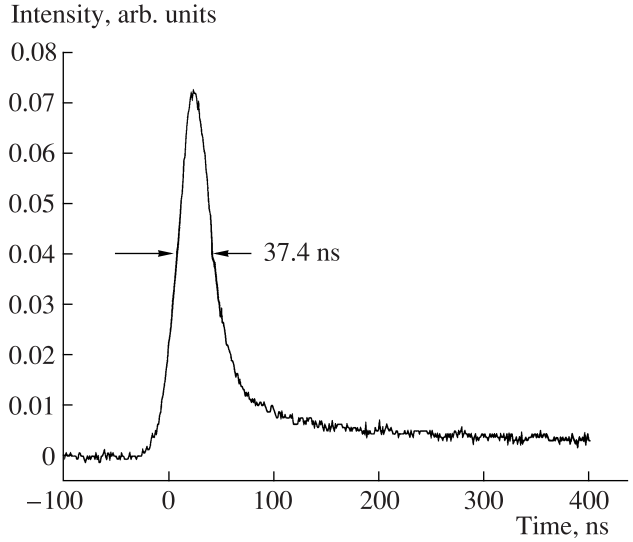

**Fig. 6.** The profile of a single pulse at the pulse repetition frequency of 5 kHz.

a small fraction of the stored energy can be extracted by a pulse. The inversion stays at a high level after a pulse is extinguished. Due to small perturbations during the pulse-buildup time, the energy extracted from the laser crystal can differ from pulse to pulse. These small perturbations can increase, since the remaining inversion left by a "small" pulse results in a subsequent "large" pulse. Finally, this "inversion coupling" can lead to instabilities. So, we investigated the average output power at the Q-switching repetition frequencies of 1.12, 5, 10, 15, and 20 kHz, respectively. Figure 2 shows the output characteristic, which is represented in the form of the average output power versus incident pump power on the laser crystal for different repetition frequencies. The maximum average output power of 1034 mW was obtained when the incident pump power was 11.3 W, with the corresponding optical conversion efficiency of 9.1%. From Fig. 2, we can see that the average output power increased with an increasing incident pump power at the repetition frequency of 5, 10, 15, and 20 kHz, and there was no pump saturation, so the output power can be scaled with a high pump power. This is coincident in the theory [6]. At the repetition frequency of 1.12 kHz, the laser performance was degraded due to the occurrence of coating damage at the Yb:YAG surface when the incident pump power was 11.3 W. The coating damage was caused by the high intracavity intensity and low damage threshold of the coating, which can be avoided by improving the coating quality.

We also investigated the dependence of the peak power, single-pulse energy, and pulse width on the Q-switching repetition frequency. The laser-pulse signal was detected by using a fast photodiode detector. A 300-MHz digital storage oscilloscope (LeCroy model 9361c) was used to observe and measure the laser-pulse signal. The results are shown in Figs. 3–5. From Figs. 3 and 4, we can see that the shortest pulse width was 37.4 ns at the repetition frequency of 5 kHz, when the incident power was 11.3 W. The highest single-pulse energy of 319.67 μJ was achieved at the repetition frequency of 1.12 kHz, when the incident power was 10.14 W. If the coating wasn't damaged, the shortest pulse width and the highest single-pulse energy should be observed at the 1.12 kHz when the incident power was 11.3 W. In Fig. 5, the highest peak power of 6.79 kW was achieved when the pump power was 8.7 W. In fact, the peak power for the incident power of 10.14 W should be higher than that for 8.7 W at the same repetition frequency. This phenomenon could be the error that exists in the experiment for which the actual cause is unknown.

Figure 6 shows a typical single Q-switched laser pulse with 191-μJ energy and 37.4-ns pulse width at a pulse repetition frequency of 5 kHz for the incident power of 11.3 W. The corresponding peak power is approximately 5.10 kW.

## 4. CONCLUSIONS

The operation of a fiber-coupled LD-pumped Yb:YAG actively Q-switched laser has been demonstrated at room temperature. The maximum average power of 1034 mW was obtained with 9.1% optical–optical efficiency. The shortest laser pulse width of 37.4 ns, the highest single-pulse energy of 319.67 μJ, and the highest peak power of 6.79 kW have been achieved. The laser performance can be improved by improving the crystal coating quality.

## REFERENCES

1. T. Y. Fan, "Heat Ieneration in Nd:YAG and Yb:YAG," IEEE J. Quantum Electron. **29**, 1457–1459 (1993).
2. D. S. Sumida and T. Y. Fan, "Effect of Radiation Trapping on Fluorescence Lifetime and Emission Cross Section Measurements in Solid State Laser Media," Opt. Lett. **19**, 1343–1345 (1994).
3. T. Y. Fan, Diode-Pumped Q-switched Yb:YAG Laser, Opt. Lett. **18**, 423–425 (1993).
4. Jun Dong, Peizhen Deng, and Yupu Liu, "Passively Q-Switched Yb:YAG Laser with $Cr^{4+}$:YAG as the Saturable Absorber," Appl. Opt. **40**, 4303–4307 (2001).
5. G. J. Spühler, R. Paschottal, and M. P. Kullberg, "A Passively Q-Switched Yb:YAG Microchip Laser," Appl. Phys. B **72**, 285–287 (2001).
6. Kejian Yang, Shengzhi Zhao, and Guiqiu Li, "Theoretical and Experimental Study of a Laser-Diode-Pumped Actively Q-Switched Nd:YVO4 Laser with Acoustic-Optic Modulator," Opt. Laser Technol. **37**, 381–386 (2005).
7. Junhai Liu, Changqing Wang, and Chenlin Du, "High-Power Actively Q-Switched Nd:GdVO4 Laser End-Pumped by a Fiber-Coupled Diode-Laser Array," Opt. Commun. **188**, 155–162 (2001).