Journal of Russian Laser Research, Volume 33, Number 1, January, 2012

EXPERIMENTAL INVESTIGATION OF THE PULSE WIDTH OF A DIODE-PUMPED ACOUSTO-OPTICALLY Q-SWITCHED Tm:YAG LASER

Chunting Wu,[1,3*] Fei Chen,[2] Rui Wang,[2] and Youlun Ju[3]

[1]*School of Science, Changchun University of Science and Technology*
Changchun, 130022, China

[2]*State Key Laboratory of Laser Interaction with Matter*
Changchun Institute of Optics, Fine Mechanics and Physics
Chinese Academy of Sciences
Changchun, 130033, China

[3]*National Key Laboratory of Tunable Laser Technology*
Harbin Institute of Technology
Harbin 150080, China

*Corresponding author e-mail: bigsnow1@126.com

Abstract

We study a pulsed laser-diode-pumped acousto-optically (AO) Q-switched Tm:YAG laser. To satisfy the requirements of a wind measurement lidar, we investigate experimentally the factors influencing the output-pulse width in a thermal compensating linear laser cavity. We show that the laser-pulse width is not only influenced by the pumping intensity of the diode lasers, the laser-cavity length, and the transmissivity of the output coupler, but also depends on the stimulated emission cross-section of the laser media.

Keywords: diode-pumped lasers, acousto-optically Q-switched Tm:YAG laser.

1. Introduction

Single-doped Tm^{3+} lasers operating at 2 μm have attracted much attention for numerous applications ranging from remote sensing and medicine to laser radars [1–7]. Many Tm^{3+}-doped laser media have been used for obtaining high-power 2 μm laser output in a diode-end-pumped configuration. As one of them, the Tm:YAG laser has been employed extensively for its merits, such as good thermomechanical property, high doping concentration, long fluorescence lifetime, and so on [8]. However, Tm:YAG lasers operating at room temperatures are quasi-three-level laser systems, and the thermal population of the lower laser level affects the laser characteristics. To improve the laser performance, many operating conditions should be optimized, such as the diode pumping intensity and spatial distribution, laser cavity length, transmissivity of the output coupler, the parameters of the laser media, and so on.

In recent years, some results on the continuous-wave (cw) laser characteristics of Tm:YAG laser have been reported [9–12]. In 2002, a cw Tm:YAG laser with 150 W output was achieved in [13] where a

---

Manuscript submitted by the authors in English first on December 2011 and in final form on January 24, 2012.

1071-2836/12/3301-0098

compound parabolic concentrator was used. It is difficult to realize high power output for lower gain and higher saturable reabsorption losses in a Tm:YAG Q-switched laser system. With a RTP Pockels cell, such as the Q-switch generator, a pulsed Tm:YAG laser was realized with a maximum output of 2.4 mJ and a pulse width of 57 ns [14]. In 2008, a Q-switched 2.013 μm Tm:YAG laser with a pulse energy of 4 mJ and a pulse width of 80 ns at a repetition frequency of 100 Hz was reported in [15], and it was used as the pump source of a ZGP-OPO to generate mid-IR 3-5 μm radiation. For accurate wind-velocity measurements, commercial aircraft safety, or global wind monitoring, a Tm:YAG laser with a long pulse width is required to achieve the narrow transform-limited bandwidths, which is needed to measure wind velocities within ± 1 m/s [16].

In this paper, we demonstrate a pulsed LD pumped and AO Q-switched Tm:YAG laser. Using a thermal compensating linear laser cavity, we investigate experimentally the factors influencing the output-pulse width. We show that the laser pulse width is influenced mainly by the pumping intensity of the diode lasers, the laser cavity length, the transmissivity of the output coupler, and the laser media characteristics.

2. Experimental Setup

A schematic of the experimental setup is shown in Fig. 1. A fiber-coupled pulsed LD with a maximum peak power of 30 W is used as a pump source. The central output wavelength of the LD is 785 nm, which coincides with an absorption peak of Tm^{3+}. The fiber core has a diameter of 400 μm and a numerical aperture of 0.22. The diode-laser beam is shaped and focused by a series of convex lenses. The mode matching between the pumping laser and the oscillating laser is optimized by changing the pump-beam waist radius and location. The pulse repetition rate and the pulse width of the pump laser can be changed to achieve high-efficiency laser output. A Tm:YAG rod with a doping concentration of 3.5 at.% was employed as a gain medium. The rod was 4 mm in diameter and 10 mm in length. The faces are polished plane, parallel, and have antireflection coating near 785 nm and 2.01 μm. The operation temperature of the crystal is 288.7 K. A convex input mirror is selected with a radius of curvature of -300 mm to provide partial compensation of the thermal lens in the laser rod. The input mirror is highly reflective at a wavelength near 2.01 μm ($R > 99.5\%$) and highly antireflective at a wavelength about 790 nm ($R < 0.5\%$). A concave output coupler is used with a radius of curvature of 300 mm. A 46 mm long fused-silica AO Q-switch with low insertion losses is used to produce a Q-switched operation. The wavelength of the Tm:YAG laser is measured with a monochrometer (300 mm focal length, 300 lines/mm grating blazed at 2000 nm). The pulsed laser is detected by an InGaAs detector connected with a Tektronix TDS3032B digital oscilloscope.

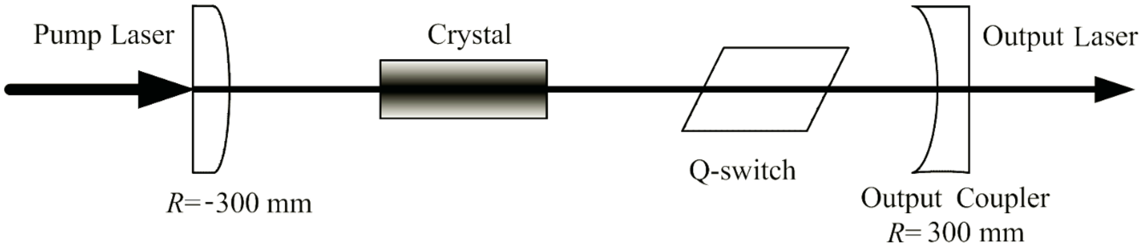

Fig. 1. Schematic of the experimental setup.

3. Experimental Results and Discussion

3.1. Pump Intensity

First, we studied the dependence of the pulse width of the output laser on the pump intensity. When the incident pump power is not saturated, the pulse width decreases with increase in the pump intensity. This is due to the increase in the population inversion and decrease in the pulse build-time of Q-switching. The pump intensity is directly impacted by the incident pump power and the size of the pump beam waist. Enlarging the pump beam waist is helpful for reducing the pump intensity and increasing the output-pulse width. The experimental results are shown in Fig. 2, where the Tm:YAG laser performance at 100 Hz is investigated when the radius of the pump-beam waist $\omega_p = 400$ μm and 600 μm. With the increase in the incident pump energy, the pulse width decreases exponentially and the output energy increases linearly. At $\omega_p = 400$ μm, the laser output saturates when the energy is beyond 1.85 mJ. At the same output energy, the pulse width at $\omega_p = 600$ μm is wider than that at $\omega_p = 400$ μm.

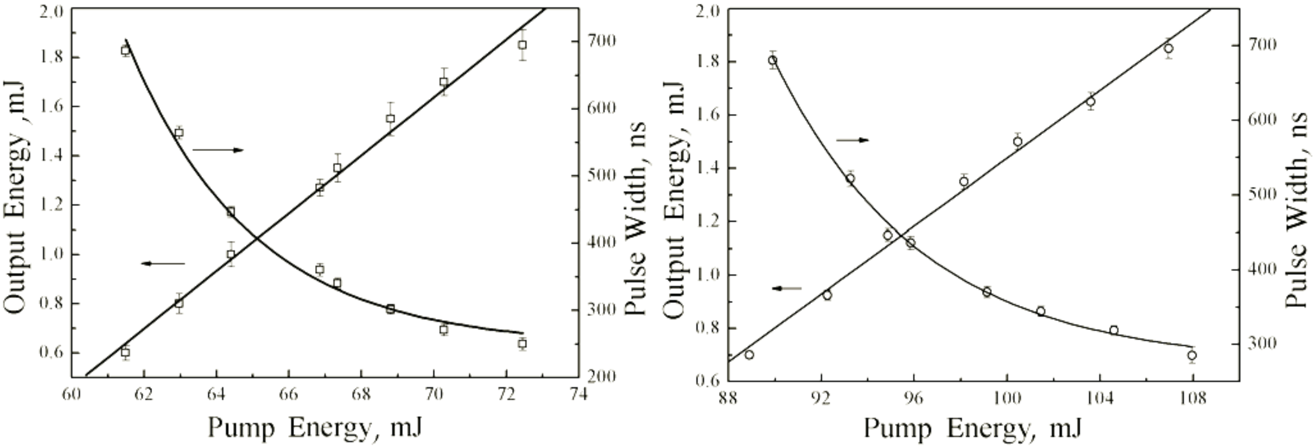

Fig. 2. Pulse width and output energy of a Tm:YAG laser versus the pump energy. Experimental data are shown by squares, circles, and triangles, and the fitting curve by the solid line. Coupling ratio 1:2 and $\omega_p = 400$ μm (left) and coupling ratio 1:3 and $\omega_p = 600$ μm (right).

3.2. Laser Cavity

Then we studied how the output laser performance was influenced by the laser cavity.

On the one hand, we studied the pulse width and output energy of the Tm:YAG laser at 30 Hz at different cavity lengths. In Fig. 3 one can see that the pulse width increases with increase in the length of the laser cavity. When the cavity length does not exceed 275 mm, the output energy is almost constant at the same incident energy. On the other hand, the laser pulse at 100 Hz was recorded and compared by using three kinds of output couplers with different transmissivities. As shown in Fig. 4, at the same output energy, the pulse width obviously increases with increase in transmissivity.

3.3. Laser Medium

The pulse width of the output laser is influenced by the parameters of the laser media. We carried out comparative experiments employing Tm,Ho:YVO$_4$ and Tm:YAG lasers at 30 Hz. As shown in Fig. 5,

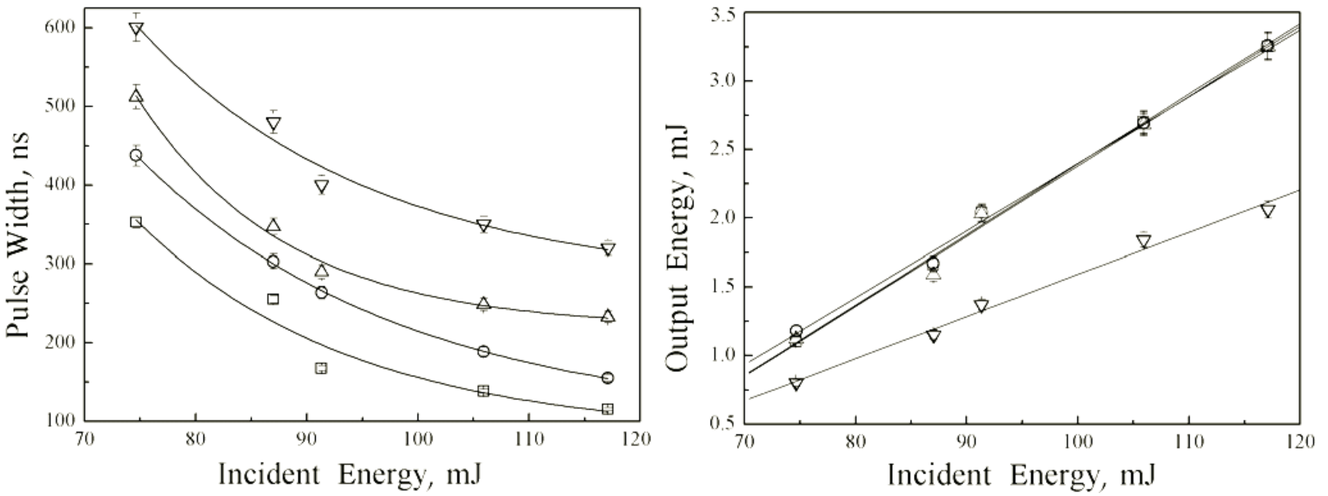

Fig. 3. Pulse width (left) and output energy (right) versus the incident pump energy at $L = 120$ mm $(\square)$, 220 mm $(\diamond)$, 275 mm $(\triangle)$, and 330 mm $(\triangledown)$.

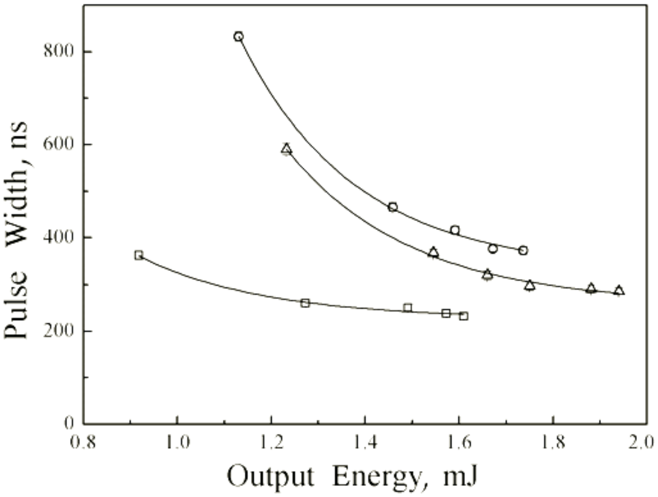

Fig. 4. Pulse width versus the output energy for different output couplers with $T = 2.0\%$ $(\square)$, 3.5% $(\triangle)$ and 4.4% $(\diamond)$.

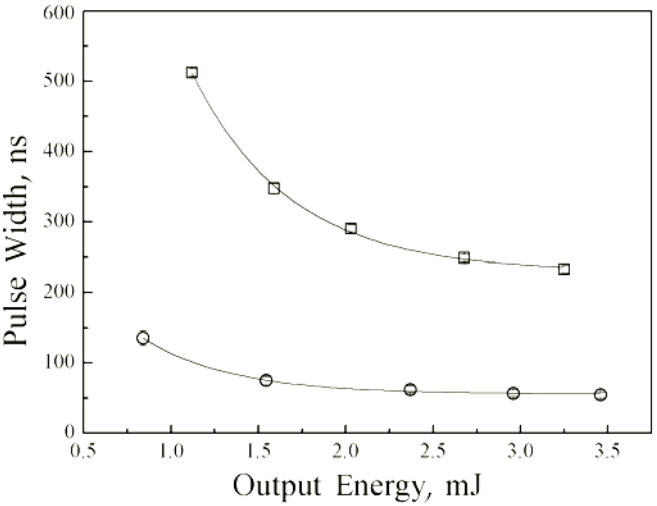

Fig. 5. Pulse width versus the output energy of a Tm:YAG laser with $L = 275$ mm and $T = 5.8\%$ $(\square)$ and a Tm,Ho:YVO$_4$ laser with $L = 1$ m and T=20% $(\circ)$.

at the same output energy, the pulse width of the Tm,Ho:YVO$_4$ laser is much narrower than that of the Tm:YAG laser. It should be noted that the cavity length for the Tm,Ho:YVO$_4$ and Tm:YAG lasers was 1 m and 275 mm, respectively, and the output coupler transmissivity was 20% and 5.8%. This can be attributed to the larger stimulated emission cross-section of Tm,Ho:YVO$_4$ ($\sigma_e = 7.7 \sim 8.0 \times 10^{-20}$ cm^2), which is much higher than that of Tm:YAG ($\sigma_e = 2.5 \times 10^{-21}$ cm^2). Under the same pumping conditions, the pulse width is mainly influenced by the stimulated emission cross-section of the laser medium. To satisfy the requirements of a lidar, a wider laser pulse is required, so a Tm^{3+}-doped crystal with smaller stimulated emission cross-section is favored.

4. Conclusions

In conclusion, we have studied a diode-pumped AO Q-switched Tm:YAG laser. Using a thermal compensating linear laser cavity, we investigated experimentally the factors influencing the output pulse width. Our results showed that the laser pulse width is influenced mainly by the LD pumping intensity, the laser cavity length, the transmissivity of the output coupler, and the laser medium characteristics. Increasing the pump beam waist, cavity length, and transmissivity of the output coupler along with using Tm^{3+}-doped crystals with smaller stimulated emission cross-section are helpful to achieve a long-pulse-width laser output.

References

1. P. A. Budni, M. L. Lemons, J. R. Mosto, and E. P. Chicklis, *IEEE J. Select. Top. Quantum Electron.*, **6**, 629 (2000).
2. O. A. Buryy, D. Y. Sugak, S. B. Ubizskii, et al., *Appl Phys B.*, **88**, 433 (2007).
3. J. K. Jabczynski, W. Zendzian, J. Kwiatkowski, et al., *Laser Phys. Lett.*, **4**, 863 (2007).
4. N. Berner, A. Diening, E. Heumann, et al., *OSA Trends in Optics and Photonics (TOPS) Conference on Advanced Solid-State Lasers*, Optical Society of America, Boston, MA (1999), Vol. **26**, p. 463.
5. Z. G. Wang, C. W. Song, Y. F. Li, et al., *Laser Phys. Lett.*, **6**, 105 (2009).
6. B. Q. Yao, L. L. Zheng, X. M. Duan, et al., *Laser Phys. Lett.*, **5**, 714 (2008).
7. C. T. Wu, Y. L. Ju, Q. Wang, et al., *Laser Phys. Lett.*, **6**, 707 (2009).
8. C. Bollig, W. A. Clarkson, R. A. Hayward, and D. C. Hanna, *Opt. Commun.*, **154**, 35 (1998)
9. C. T. Wu, Y. L. Ju, Y. F. Li, et al., *Chinese Opt. Lett.*, **6**, 594 (2008).
10. M. Tsunekane, N. Taguchi, and H. Inaba, *Appl. Opt.*, **38**, 1788 (1999).
11. E. C. Honea, R. J. Beach, S. B. Sutton, et al., *IEEE J. Quantum Electron.*, **QE-33**, 1592 (1997).
12. C. T. Wu, Y. L. Ju, Z. G. Wang, et al., *Laser Phys. Lett.*, **5**, 793 (2008).
13. K. S. Lai, W. J. Xie, R. F. Wu, et al., *OSA Trends in Optics and Photonics (TOPS) Conference on Advanced Solid-State Lasers*, Optical Society of America, Québec, Canada (2002), Vol. **68**, p. 535.
14. Sharone Golding, Eyal Lebiush, and Raphael Lavi, *Proc. SPIE*, **4630**, 13 (2002).
15. Marc Eichhorn, and Antoine Hirth, *OSA Trends in Optics and Photonics (TOPS) Conference on Lasers and Electro-Optics*, Optical Society of America, Washington, D.C. (2008), paper CTuII3.
16. Mahendra G. Jani, Norman P. Barnes, Keith E. Murray, and George E. Lockard, *Opt. Lett.*, **18**, 1636 (1993).