THE PULSED-DIODE END-PUMPED PASSIVELY Q-SWITCHED SOLID-STATE Nd^{3+}: YAG LASER

Nguyen Van Hao[1*], Nguyen Thi Xiem[1], Nguyen Thi Nhu Hai[1], Nguyen Trong Nghia[2]
[1] College of Science, Thai Nguyen University, Vietnam
[2] Center for Quantum Electronics, Institute of Physics, VAST, Vietnam

ABSTRACT

The pulsed diode end-pumped passively Q-switched solid-state Nd:YAG lasers are investigated experimentally. A high power laser diode (pulse repetition rate adjustable from 1 Hz to 10 kHz, pulse duration of 600 μs) is used as a pumping laser. The obtained results show that the pulsed diode end-pumped passively Q-switched solid state Nd- doped lasers have the advantages in controlling pulse repetition rate, improving nanosecond solid-state laser pulse power and stability (low jitter) in comparison with the use of CW diode end-pumping.

Keywords: *Nd: YAG crystal, diode-pumped laser, passive Q-switching, controlled repetition rate*

INTRODUCTION

High energy laser pulses of short durations may be obtained by Q-switching techniques of laser cavity. Compared with active Q-switching, passive Q-switching is more economical and practical because of the modest requirement of optical elements inside the laser cavity. Therefore, these techniques have attracted much research and development both in experiment and theory [1-17]. In the passively Q-switched Nd^{3+} doped solid-state lasers, Cr^{4+}: YAG crystal is widely used. It has been allowed to create all-solid-state compact, simple, and pulsed lasers, providing laser pulses ranging from several to tens of nanoseconds. Pulse repetition rate of solid-state laser can reach a few hundred kHz [5-7], however, a fix characteristic of CW pumped passively Q-switched solid-state laser is low time stability (high jitter). Thus, it has prevented many applications of these lasers.

In this paper, we report the experimental results in research and development of pulsed-diode end-pumped Nd^{3+}: YAG laser at 1064 nm in passive Q-switching laser operations using two-mirror folded resonator configurations of different output couplers. The obtained results show that the pulsed diode end-pumped passively Q-switched solid state Nd^{3+}-doped lasers have the advantage in controlling pulse repetition rate, improving nanosecond solid-state laser pulse power and time stability (low jitter) in comparison with the use of CW diode end-pumping.

EXPERIMENTAL

We consider a stable two-mirror cavity configuration (Fig. 1) consisting of a flat mirror M_2 (output coupler) and a concave mirror M_1. As previously discussed [5, 6], it is a semi-concentric laser resonator; its intra-cavity beam waist is nearly located on the output mirror plane (M_2) and its beam diameter is smallest and approximately some tens micrometer.

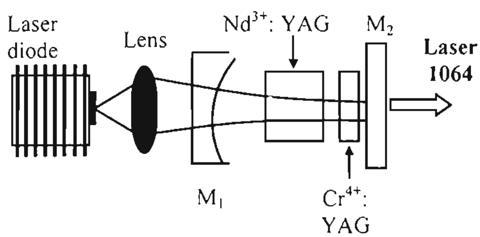

Fig. 1. Experimental setup for the two-mirror cavity passively Q-switched Nd^{3+}: YAG laser

Laser diode (ATC-Semiconductor Devices) emitted at the wavelength of around 808 nm with a maximal CW laser power of 2 W. Its active cooling and temperature stabilization at a suitable temperature were provided by a built-in Peltier cooling device (LDD-10, ATC-Semiconductor Devices) maintaining its

* *E-mail: haonv08@gmail.com*

output laser diode wavelength matched to the absorption peak of the Nd^{3+}:YAG laser crystal. The polarization of the laser diode emission is horizontal. The diode has a built-in cylindrical micro-lens for its fast axis collimation. This allows us to use simple pump optics as a single lens of 25 mm focus length to couple and focus the laser diode light into the laser crystal. The two-mirror laser folded resonator consisted of the concave mirror M_1 with high reflection coating at 1064 nm and anti-reflection coating at 808 nm at both sides, its focal length is 20 mm and the output flat mirror M_2 of 6 % transmission. The laser crystal were used to be a 1% doped Nd^{3+}:YAG crystal (3 mm - diameter, 3 mm - long) that were AR coated on both sides at 1064 nm and mounted on suitable passive copper heat sinks. The Nd^{3+}: YAG laser crystal was oriented for the maximum absorption at 808 nm. All optical component and crystal were provided from Casix [19].

A longitudinal and end-pumping configuration was used, as shown in Fig. 1. The pump source is a diode laser (ATC-Semiconductor Devices) emitted at the wavelength of around 808 nm with a maximum CW power of 2 W. The diode laser is supplied by the LDD-10 driver (ATC-SD) designed for the diode laser operation in continuous wave and pulse modes with stabilized and controlled current. In the mode pulse, .the adjustable range of diode laser duration is from 0.1 ms to 0.998 s, the adjustable range of diode laser pulse repetition rate is from 1 Hz to 10 kHz. This driver stabilizes and controls the laser diode temperature [18]. Nd:YAG laser crystal cooling and temperature stabilization at 25 °C is provided by a built-in Peltier cooling device (LDD-10) in order to maintain its output laser wavelength exactly matched the absorption peak of Nd: YAG crystal.

Laser wavelength and spectra were measured with a grating spectrometer (DFS-8, 3 Å/mm, Russia) equipped with a linear diode array (BP-2048, USA). A fast photodiode (rise time < 0.3 ns) connected with a digital oscilloscope (TD 7154B; 1.5 GHz, Tektronix, USA) was used to record the duration of laser pulses. The laser energy was measured by the Joule meter (13 PME 001, Melles Griot, USA).

The Cr^{4+}: YAG crystal (Casix) having the initial small-signal transmissions of 80 % at 1064 nm was used as an intra-cavity saturable absorber. We used the stable two-mirror resonator configuration (Fig. 1), as previously discussed, it is a semi concentric laser resonator. Its beam waist is nearly located on the output mirror plane (M_2) and therefore, the Cr^{4+}: YAG crystal used as an intra-cavity saturable absorber is put as adjacent as possible to the output mirror plane M_2.

RESULTS AND DISCUSSION

Figures 2 and 3 shows the pulse peak power of passively Q-switched Nd^{3+}: YAG laser operations (with the Cr^{4+}: YAG of T_0 = 80%) versus pump power where Fig. 2 corresponds to the laser pulse pump (600 μs, 20 Hz) and Fig. 3 corresponds to the continuously wave (CW) pump by diode laser. The results showed that the pumping by the stability diode laser pulse has the capacity to achieve higher pulse peak power (nearly 2 times) compared with CW pump method using laser diode (Fig. 3). This is achieved due to two reasons: reduced the thermal effects of solid-state gain medium due to pump by diode pulses with low pulse repetitive rate and pulse-width of Q-switched solid-state laser is shorter.

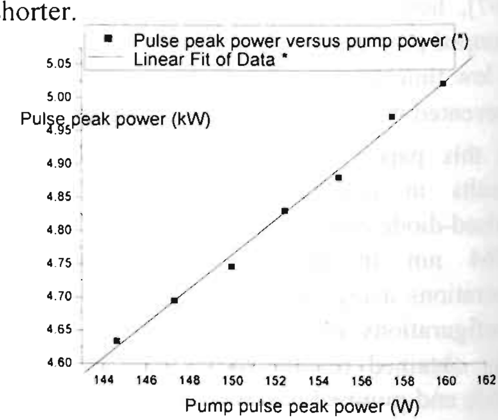

Fig. 2. Pulse peak power versus pump power of pulsed diode pumped Nd: YAG laser.

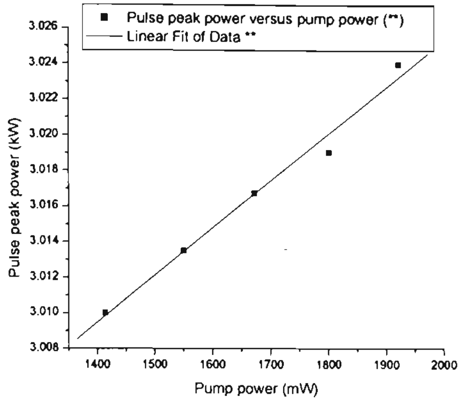

Fig. 3. Pulse peak power versus pump power of CW diode pumped Nd: YAG laser

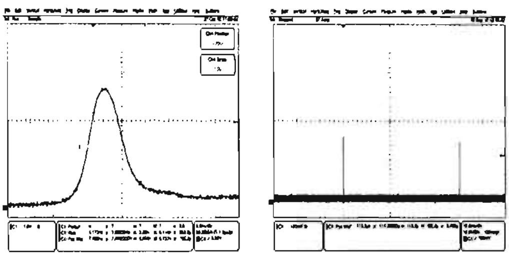

Fig. 4. Pulse width of 7.5 ns passively Q-switched Nd: YAG laser pumped by pulses of 600 μs and pulse repetition rate of 20 Hz with output coupling of 6 %

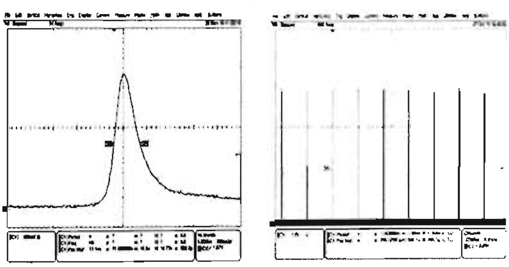

Fig. 5. Pulse width of 11 ns and pulse repetition rate of 4.83 kHz of CW diode pumped passively Q-switched Nd: YAG laser with output coupling of 6 %

Figure 4 shows the pulse width of diode end-pumped passively Q-switched solid state Nd^{3+}:YAG laser. The result also showed that, pulse width of pulsed-diode end-pumped passively Q-switched solid state Nd^{3+}: YAG laser achieve shorter when it is pumped by the diode laser pulse (~ 7.5 ns) compared to when it is CW pumped by diode laser (~ 11 ns) as shown in figure 5.

Figure 6 shows the time stability of diode pumped Nd: YAG laser passively Q-switched with a Cr^{4+}: YAG crystal. The results also showed that, for time stability (jitter) of pulsed-diode pumped Nd: YAG laser is 4 times better than when it was pumped by CW diode laser (Fig. 7 - at the same scale). This is achieved also by two reasons: greatly reduced the thermal effects of solid-state gain medium due to pumped by diode pulses with low pulse repetition rate and very high stability of the intensity and duration of the pump pulse of laser diode.

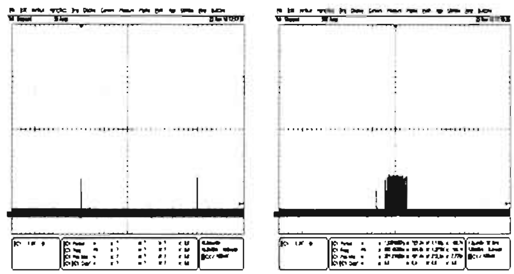

Fig. 6. Jitter on time of pulsed diode pumped Nd: YAG laser passively Q-switched by a Cr^{4+}: YAG crystal with output coupling of 6 %

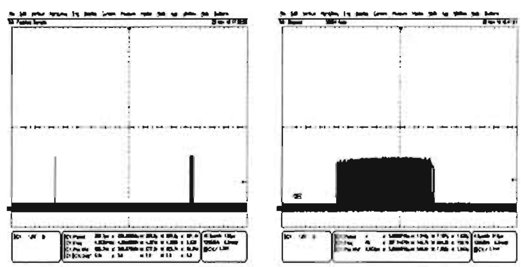

Fig. 7. Jitter on time of CW diode end-pumped Nd: YAG laser passively Q-switched by a Cr^{4+}:YAG crystal with output coupling of 6 %

CONCLUSION

We have investigated the output laser characteristics at 1064 nm of pulsed diode - pumped Nd^{3+}: YAG laser in passively Q-switched operations with the Cr^{4+}: YAG crystal as a saturable absorber intra cavity. This study is based on the comparison of operational characteristics in two pulse and CW pumping regimes. Thank to avoid thermal effects for solid-state laser medium, pulsed diode - pumped passively Q-switched solid-state Nd^{3+}: YAG laser not only has advantages in controlling the pulse repetition rate, but also to improve its capacity pulse peak power (pulse peak power can be achieved 5 kW - higher than 1.7 times compare to CW pumping method), shorter pulse-width (~ 7.5 ns - 1.4 times shorter compared to CW pumping method), concurrently having a better time stability (jitter less than 4 times). Therefore, pulsed-diode end-pumped passively Q-switched solid-state Nd^{3+}: YAG crystal laser may be a coherent light source capable of using widely available.

Acknowledgments. The authors would like to thank for the financial supports from Vietnam NAFOSTED (Physics, Project N^0. 103.06.89.09) and the Laser Program of Vietnam Academy of Science and Technology.

REFERENCES

[1].J. Miller, A. J. Alcock, J. E. Bernard, Advanced Solid State Lasers, *OSA Proc, Wash DC* **13**, (1992), p. 322

[2].K. Spariosu, W. Chen, R. Stultz, M. Birnbaum, A.Shestakov, Dual Q switching and laser action at 1.06 and 1.44 μm in a Nd^{3+}:YAG-Cr^{4+}:YAG oscillator at 300 K, *Opt. Lett.* **18**, (1993), p. 814

[3].H. Eilers, W. Dennis, W. Yen, S. Kuck, K. Peterman, G. Huber. *IEEE J. Q-E 29*. (1993), p. 2508.

[4].S. H. Yim, D.R. Lee, B.K. Rhee, D. Kim, *Appl. Phys. Lett. 30*, (1998), p. 3193

[5].N. T. Nghia, L. T. Nga et al. *Advances in Natural Sciences (VAST)* **7**, No. 3-4 (2006), p. 181.

[6].N. T. Nghia, Do Q. Khanh, T. D. Huy et al., *ASEAN Journal of Science and Technology for Development*, **24**, 1-2 (2007), p.139.

[7].N. T. Nghia, Do Q. Khanh et al. *Comm. in Phys. (VAST)*, **19**, SI (2009), p.145.

[8].Zagumennyi, V. G. Ostroumov, I. A. Shcherbakov, T. Jensen, J. P. Meyen, G. Huber, *Sov. J. Q- E 22* (1992), p. 1071

[9].Wyss, W. Luthy, H. Weber, V. Vlasov, et al., *Appl. Phys.* B **68**, (1999), p. 659

[10]. J. Liu, Z. Shao, X. Meng, H. Zhang, L. Zhu, M. Jiang, *Opt. Commun.* **164**, (1999), p. 199

[11]. J. Liu, C. Wang, C. Du, L. Zhu, H. Zhang et al., *Opt. Commun.* **188**, (2001), 155.

[12]. H. Zhang, J. Liu, J. Wang, C. Wang, L. Zhu et al., *J. Opt. Soc. Am.* B **19**, (2002), 18.

[13]. Li, J. Song, D. Shen, N. Kim, J. Lu, K. Ueda, *Appl. Phys.* B **70**, (2000), p. 471

[14]. J. Liu, B. Ozygus, S.Yang, J. Erhard, U. Seelig et al., *J. Opt. Soc. Am.* B **20**, (2003), p. 652.

[15]. S. P. Ng, D. Y. Tang, L. J. Qin, X. L. Meng, *Opt. Commun.* **229** (2004), p. 331.

[16]. G. D. Boldwin, *IEEE J. Q-E* **7**, (1971), p. 220.

[17]. H. T. Powell, G. J. Wolga, *IEEE. J. Q-E* **7**, (1971), p.213.

[18]. http://www.atcsd.ru/faq.php

[19]. http://www.CASIX.com

TÓM TẮT

LASER RẮN Nd^{3+}: YAG BIẾN ĐIỆU THỤ ĐỘNG ĐƯỢC BƠM DỌC BẰNG CÁC XUNG LASER DIODE

Nguyễn Văn Hào[1*], Nguyễn Thị Xiêm[1], Nguyễn Thị Như Hải[1], Nguyễn Trọng Nghĩa[2]

[1] *Trường Đại học Khoa học - ĐH Thái Nguyên*

[2] *Trung tâm Điện tử học Lượng tử, Viện Vật lý, Viện KH và CN Việt Nam*

Các laser rắn Nd: YAG được bơm dọc bằng các xung laser diode và được biến điệu thụ động độ phẩm chất buồng cộng hưởng đã được nghiên cứu thực nghiệm. Một laser diode công suất cao (tần số xung có thể điều khiển từ 1 Hz đến 10 kHz, độ rộng xung 600 μs ở bước sóng 808 nm) đã được sử dụng như một nguồn bơm quang học cho laser rắn. Các kết quả thu được đã chứng tỏ các laser rắn này có những ưu điểm trong việc điều khiển tần số xung, cải thiện công suất đỉnh xung và ổn định thời gian (jitter thấp hơn) so với khi được bơm liên tục bằng laser diode.

Từ khóa: *Tinh thể Nd:YAG, laser bơm bằng laser diode, biến điệu độ phẩm chất thụ động, điều khiển tần số lặp lại.*

* *E-mail: haonv08@gmail.com*