Diode-pumped actively *Q*-switched Nd:YAG laser at 946 nm*

YANG Ji-min, LIU Jie **, and JE Jing-liang
College of Physics and Electronics, Shandong Normal University, Jinan 250014, China

(Received 4 March 2005)

A diode-pumped Nd:YAG acousto-optically (A-O) *Q*-switched laser at wavelength 946 nm formed with a simple plane-plane cavity has been demonstrated. The maximum average output power was 850 mW. The highest peak power was 531 W with the pulse repetition rate of 20 kHz and pulse width of 80 ns at the incident pump power of 19.5 W.

CLC number: TN248.1 **Document code**: A **Article ID**: 1005-0086(2005)01-0044-02

Compact, solid-state lasers emitting nanosecond pulses wavelength near 946 nm are of a particular interest because of several important practical applications. The need for an efficient and simple solid-state laser source in the blue has been the most motivating reason for investigating the 946 nm laser emission in Nd:YAG, as it allows generation of blue light by direct frequency doubling or sum frequency mixing of diode lasers. A high energy pulsed laser operating on this transition would be useful to the remote-sensing scientific community in view of the presence of strong atmospheric water-vapor absorption lines near 946 nm. However, cras section. Researchers have reported diode pumped all-solid-state cw and passive *Q*-switched laser operation at wavelength 946 nm by use of the line $^4F_{3/2} \rightarrow {}^4I_{9/2}$ transion in Nd:YAG[1-8]. Previously, a high-energy *Q*-switched operation on this transition of Nd:YAG has been demonstrated, employing a folded laser resonator[9]. Its devices were complicated. In this letter, we report efficient operation of a compact diode-pumped acousto-optical *Q*-switched Nd:YAG laser at wavelength 946 nm formed with a simple plane-plane cavity.

Efficient lasing on the 946 nm transition ($^4F_{3/2} \rightarrow {}^4I_{9/2}$) is considerably more difficult to achieve than on the more familiar 1 064 nm transition. This is partly due to its quasi-three-level nature which results in a significant reabsorption loss at room temperature, and a very small stimulated emission cross section. It exhibits a significant thermal population of the lower laser levels. For a low laser threshold, the short gain elements and a high pump power should be required. This was achieved by using an end-pumped configuration (see Fig. 1). In our experiment, we built a laser with a simple plane-plane cavity. the pump source was a 30 W laser diode with a center wavelength of 808 nm, the numerical aperture (N. A.) is 0.2. The pump beam focused into the laser crystal with a spot radius of about 320 μm. The plane-plane cavity lengths that were experimentally used are 72 mm and 96 mm, respectively. The Nd:YAG crystal (0.5 at. %) was 3 mm×3 mm×3mm in size. The left side of the Nd:YAG crystal was coated to be highly reflecting (HR) at 946 nm, and anti-reflecting (AR) at 808 nm pumping wavelength. It also acted as the input mirror M1. The other side of the crystal was coated for AR at 946 nm and 808 nm. The output couplers (M2) used in the experiments was a flat mirror with transmittance at 946 nm of 3.2%. The A-O *Q*-switching crystal was inserted into the cavity at the position possibly close to the output coupler as where the laser beam spot size was at the minimum. The pulse temporal behavior was recorded by a fast photodiode detector and oscilloscope.

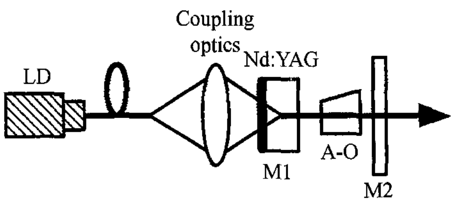

Fig. 1 Schematic for A-O *Q*-switched Nd:YAG laser

Under high-power end-pumping conditions, the thermal lensing in the laser crystal will be strong enough to drive the stable state of plane-plane resonators deep into the stable region. The effective focal length for the entire crystal is given by[10]

$$f = \frac{\pi K_c \omega_p^2}{p_{ph}(dn/dT)}\left(\frac{1}{1-\exp(-\alpha l)}\right) \qquad (1)$$

where p_{ph} is the fraction of pump power that results in heating, $p_{th} = [1-(\lambda_p/\lambda)]p_{in} = [1-(808/946)] = 0.15\ p_{in}$ (p_{in} is the pump power), α is the absorption coefficient of the crystal which depends on the Nd^{3+} doped. K_c is the thermal conductivity. dn/dT is the temperature coefficient of the refractive index. From Eq. (1) it can be

* Supported by Key National Science Foundation of Shandong Province(Z2003A01)
** E-mail: jieliu@sdnu.edu.cn

seen that the effective focal length depends on the square of the pump beam radius ω_p, and is independent of the crystal length l. Thus in order to minimize the thermal focal length and maximize the performance at a given pump power, one should utilize the largest possible pump radius that maintains an acceptable pump beam to laser beam mode match. In our experiments, an effective thermal focal length is calculated in Nd:YAG. Employing Eq. (1), the focal length of thermal lens is approximately 8 cm under the maximal incident pump power of 19.5 W. It should be noted that this focal length is comparable to the resonator length. The thermal lensing effect crucially influences the resonator stability and the mode spot size leading to the fall of output power.

The A-O *Q*-switch was laid into the cavity, which generated pulses with repetition rate of 20 kHz, the shortest pulse width of ~80 ns. Using two different length of the plane-plane cavity, the A-O *Q*-switched at room temperature was measured. The short cavity is more suitable for high-power pumping. The output power was linear with the incident pump power. Fig. 2 shows the output characteristics of *Q*-switching operation at different incident pump power. For $L=7.2$ cm, at the incident pump power of 19.5 W, the 946 nm operation average output power of 850 mW was achieved, corresponding to an optical conversion efficiency of 4.4%,

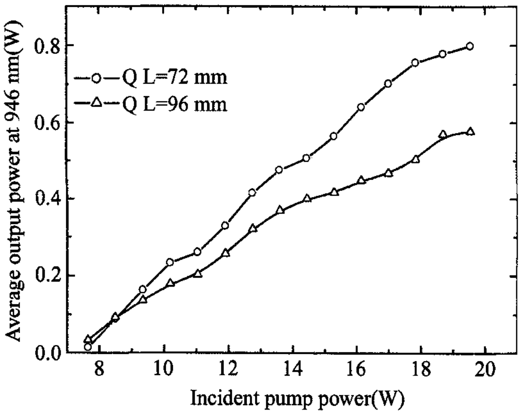

Fig. 2 The A-O *Q*-switch averaged output power of Nd:YAG laser as a function of incident pump power

peak power of 531 W. For $L=9.6$ cm, the output power was lower than that obtained for $L=7.2$ cm in the whole range of pump power.

When the incident pump power was 19.5 W, the output power tended to saturate, and the maximum output power of 580 mW was obtained, corresponding to an optical conversion efficiency of 3%, peak power of 363 W. These results were related to the higher diffractional loss, narrower thermal stability range and worse mode match between the pump and oscillating beams compared with the case of $L=7.2$ cm. This simple optical system has good output mode and high stability, and it is convenient for extra-cavity frequency doubling to extend the wavelength to blue range.

In conclusion, we have demonstrated efficient room-temperature operation of a compact diode-pumped acousto-optical *Q*-switched Nd:YAG laser at 946 nm, using a simple plane-plane cavity. In our experiment, the maximum *Q*-switched output power at 946 nm were 850 mW, corresponding to an optical conversion efficiency of 4.4%, peak power of 531 W. Our result proves that this scheme is of practical value for the construction of a infrared all-solid-state laser.

References

[1] W. A. Clarkson, R. Koch, and D. C. Hanna, *Opt. Lett.*, **21** (1996), 737.

[2] Tim Kellner, Frank Heine, Günter Huber, and Stefan Kück, *Appl. Opt.*, **37**(1998), 7076.

[3] G. J. Spühler, T. Südmeyer, R. Paschotta, M. Moser, K. J. Weingarten, and U. Keller, *Appl. Phys. B.*, **71**(2000), 19.

[4] Lanbin LU, Ling Wang, Panming Fu, Xiaobo Chen, and Zhiguo Zhang. *Opt. Lett.*, **26**(2001), 72 .

[5] Pingxue Li, Dehua Li, Zhiguo Zhang, and Shiwen Zhang, *Opt. Commun*. **215**(2003), 159.

[6] V. Pruneri, R. Koch P. G., Kazansky W. A., Clarkson P. St. J. Russell, and D. C. Hanna, *Opt. Lett.*, **20**(1995), 2375.

[7] LIU Wei-ren, HUO Yu-jing, and HE Shu-fang, *J. of Optoelectronics • Laser* **13**(2002), 247. (in Chinese)

[8] ZHENG Quan, ZHAO Ling, SHAO Yong-hong, TAN Hui-ming, and QIAN Long-sheng. *Chinese J. of Lasers*, **30** (2003), 673. (in Chinese)

[9] Theresa J. Axenson. *Opt. Soc. Am. B.*, **19**(2002), 1535.

[10] M. E. Innocenzi, H. T. Yura, C. L. Fincher, and R. A. Fields, *Appl. Phys. Lett.*, **56**(1990), 1831.