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Diode-laser pumped passively Q-switched green laser by intracavity frequency-doubling with periodically poled LiNbO$_3$

Shaojun Zhang[a,*], Qingpu Wang[b], Xiangang Xu[a], Chunming Dong[a], Xingyu Zhang[b], Ping Li[b]

[a] *Institute of Crystal Materials, State Key Laboratory of Crystal Materials, Shandong University, 27 Shan Nan Road, Jinan 250100, China*
[b] *Department of Optics of Shandong University, Jinan 250100, China*

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Abstract

A continuous-wave (CW) laser-diode (LD) pumped passively Q-switched intra-cavity frequency-doubling green laser is reported in this paper. We used 3% at Nd doped YVO$_4$ as gain medium, Cr^{4+}: YAG as a saturable absorber for passively Q-switch and periodically poled LiNbO$_3$ (PPLN) as a frequency doubler. The output energy of the green laser is 1.96 µJ with the pulse-width of 15.6 ns. No green-noise problem exists in the green laser. Some theoretical results on the passive Q-switching and intra-cavity frequency-doubling are also discussed.

Keywords: Laser-diode pump; Passively Q-switching; Cr^{4+}: YAG; Green laser; PPLN

1. Introduction

In recent years, developments of solid-state lasers pumped by diode laser have attracted much attention because of their wide potential for various applications of compact, long-lived, and efficient sources of coherent radiation. Optical disk systems require green light sources to realize high-density recording. Frequency conversion of laser-diode pumped all solid-state lasers with periodically poled non-linear crystals (such as LiNbO$_3$ [1], LiTaO$_3$ [2], KTiOPO$_4$ [3], KTiOAsO$_4$ [4] and RbTiOAsO$_4$ [5]) into the visible and UV spectral regions is a widely investigated research field. The quasi-phase-matching frequency-doubler of periodically poled crystals permits access to the highest nonlinear coefficient, which is the d_{33} coefficient in the crystals mentioned above, and avoids any walk-off problems because parallel polarizations along the main crystal-axis are used.

2. Experimental results and discussion

The experimental set-up of a continuous-wave (CW) laser-diode (LD) pumped passively Q-switched intra-cavity frequency-doubling green laser is shown in Fig. 1. We used 3% at Nd doped YVO$_4$ with a size of $3 \times 3 \times 2$ mm^3 as gain medium, Cr^{4+}: YAG as a saturable absorber with small-signal transmission $T_0 = 94\%$ for passive Q-switch and periodically poled LiNbO$_3$ (PPLN) with the grating period $\Lambda = 6.1$ µm as a frequency doubler. The Cr^{4+}: YAG crystal was placed at Brewster's angle to compensate for the astigmatism due to the laser beam to be folded by M1.

The V-type laser cavity consisted of one face of the Nd: YVO$_4$ crystal with high-reflectance (HR) coating at 1.06 µm and high transmittance (HT) at 0.808 µm and a 500 mm radius of curvature mirror (M2) with HR coating at 1.06 µm and 0.53 µm. A 100 mm radius of curvature mirror (M1) with HR coating at 1.06 µm and HT coating at 0.53 µm was used for folding the fundamental laser beam and for the second harmonic output. A CW-1W-LD and a focus system were used for the end-pumping. The temperature of the PPLN was controlled at 87°C. A photodiode (MRD500) and oscilloscope (TEK TDS620B) were used for receiving and recording the laser pulse series. The results were shown in Figs. 2 and 3.

The output energy of the green laser is 1.96 µJ with the pulse-width of 15.4 ns with 600 mW pumping laser input. No green-noise problem exists in the green laser, because both the polarizations of the fundamental and second harmonic waves are the same. To our knowledge, this is the

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[*] Corresponding author.
E-mail address: sjzhang@icm.sdu.edu.cn (S. Zhang).

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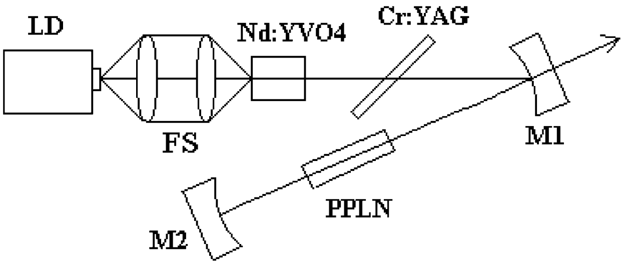

Fig. 1. Experimental set-up. LD: laser diode; FS: focus system; M1& M2: concave mirror.

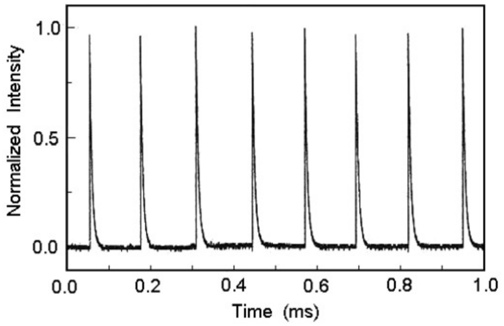

Fig. 2. The pulse series of laser output.

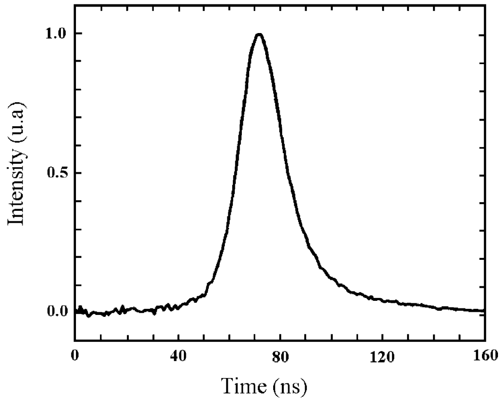

Fig. 3. The single pulse of laser output.

first time that Cr^{4+}: YAG as a saturable absorber and also as Brewster plate was used in a passively Q-switched intracavity frequency-doubling green laser with PPLN.

According to Zhang [6,7], the normalized differential equation of photon density $\Phi(0,\tau)$ on the cavity axis of a passively Q-switched intracavity frequency-doubling green laser is

$$\frac{d\Phi(0,\tau)}{d\tau} = \Phi(0,\tau)\int_0^1 \exp\{-A(\tau)y^{\beta}\}\,dy - \left(1-\frac{1}{N}\right)\Phi(0,\tau)\frac{1-\exp[-\alpha A(\tau)]}{\alpha A(\tau)} - \frac{\Phi(0,\tau)}{N} - \eta_{SHG}\Phi^2(0,\tau), \tag{1}$$

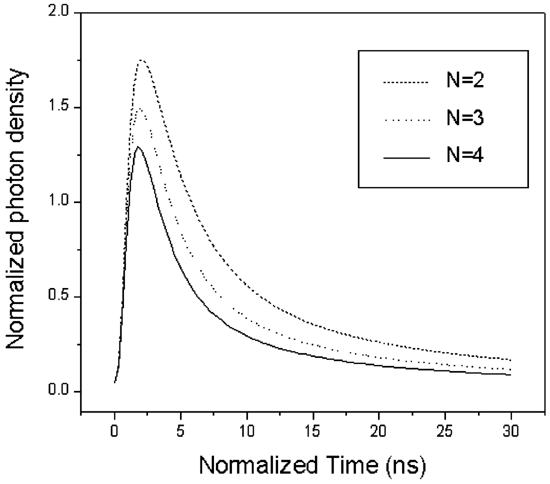

Fig. 4. The curves of $\Phi(0,\tau)$ versus τ.

where, τ is normalized time and other parameter expressions are:

$$\tau = \frac{t}{t_r}\left[\ln\left(\frac{1}{R}\right) + \ln\left(\frac{1}{T_0^2}\right) + \delta\right], \tag{2}$$

$$\Phi(0,\tau) = \phi(0,\tau)\frac{2\gamma\sigma l}{\ln\left(\frac{1}{R}\right) + \ln\left(\frac{1}{T_0^2}\right) + \delta}, \tag{3}$$

$$A(\tau) = \int_0^{\tau} \Phi(0,\tau)\,d\tau, \tag{4}$$

$$\beta = \frac{1}{1+(\omega_L+\omega_P)^2}, \tag{5}$$

$$N = \frac{\ln\left(\frac{1}{R}\right) + \ln\left(\frac{1}{T_0^2}\right) + \delta}{\ln\left(\frac{1}{R}\right) + \left(\frac{\sigma_{esa}}{\sigma_{gsa}}\right)\ln\left(\frac{1}{T_0^2}\right) + \delta}, \tag{6}$$

$$\eta_{SHG} = \frac{h\nu\eta}{2\sigma\gamma t_r}. \tag{7}$$

In expressions (2)–(7), $\phi(0,\tau)$ is photon density of the cavity axis, l is the optical length of the cavity, t_r is round-trip time in the cavity, R is the reflection-index of the output mirror, T_0 is the small-signal transmission of Cr^{4+}: YAG, δ is the loss of the cavity, ω_L and ω_P are the radii of laser and pumping laser, σ is the stimulated emission cross section of Nd: YVO_4. σ_{esa} and σ_{gsa} are the excited-state and ground-state absorption cross-sections, γ is the reversal factor, η is a factor that shows the ability of a nonlinear crystal to double the laser frequency, α is a factor that shows the level of the saturable absorber to be blanched.

With different values of N, α, β, η_{SHG}, we can numerical solve Eq. (1) to make the curves of $\Phi(0,\tau)$ as Fig. 4 and $\Phi^2(0,\tau)$ versus τ.

By analyzing the curves, we can obtain the output energy E_{SHG} and the pulse-width W_{SHG} of the laser.

$$E_{\mathrm{SHG}} = \frac{\pi\omega_{\mathrm{L}}^2 hv}{4\sigma\gamma}\left[\ln\left(\frac{1}{R}\right) + \left(\frac{1}{T_0^2}\right) + \delta\right] \times \eta_{\mathrm{SHG}} \int_0^{\infty} \Phi^2(0,\tau), \tag{8}$$

$$W_{\mathrm{SHG}} = \frac{t_{\mathrm{r}}\varDelta}{\ln\left(\frac{1}{R}\right) + \left(\frac{1}{T_0^2}\right) + \delta}. \tag{9}$$

In expression (9), $\varDelta$ is the FWHM of $\Phi^2(0,\tau)$.

Substitution of $\sigma = 2.5 \times 10^{-18}$ cm^2, $t_{\mathrm{r}} = 0.33$ ns, $\alpha = 2.6$, $hv = 1.87 \times 10^{-19}$ J, $\sigma_{\mathrm{esa}} = 8.2 \times 10^{-19}$ cm^2, $\sigma_{\mathrm{gsa}} = 4.3 \times 10^{-18}$ cm^2, $R = 99.8\%$, $\eta = 17\%$, $\delta = 0.03$, $\gamma = 0.7$, $\omega_{\mathrm{p}} = 0.5$ mm, $\omega_{\mathrm{L}} = 0.5$ mm, $l = 100$ mm, we obtained the output energy 2.13 μJ and the pulse-width 14.9 ns, these are in basic agreement with the experimental values.

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