

Diode-pumped, Cr:YAG passively Q -switched and mode-locked Nd:YVO₄/KTP green laser

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The phenomena of simultaneous Q -switching and mode-locking in a diode-pumped Nd:YVO₄/Cr:YAG/KTP green laser are reported and discussed in this paper. With 5.3-W pump power, by using a nearly hemispherical cavity (the cavity length is only 97 mm), the results of modulation depth of 70% and the period of 0.6 ns are obtained, the output power and the repetitive frequency of Q -switched pulse are 90 mW and 12 kHz, respectively.

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As we know, generally, the laser crystal used to emit passive Q -switching with Cr:YAG is not Nd:YVO₄ but Nd:YAG^[1] because the lifetime of the upper laser level of Nd:YAG is longer than Nd:YVO₄ and the short lifetime of upper laser level is adverse for passive Q -switching. However, the number of longitudinal modes is great in a Nd:YVO₄ laser, which is favorable for mode-locking, so Nd:YVO₄ crystal was often used in a diode-pumped mode-locked laser.

There are already some papers^[2-4] on diode-pumped Cr:YAG passively Q -switched and mode-locked infrared Nd:YVO₄ (or Nd:YAG) lasers. In those papers, the length of cavity and the modulation depth are about 1 m and 60%–100% respectively. However, to our knowledge, it is the first time that KTP crystal is inserted into the cavity to obtain passively Q -switched and mode-locked green laser. In this paper, moreover, the resonator is a nearly hemispherical cavity, its length (about 97 mm) is the shortest to date^[2-4], so the equipment is more practical.

The experimental setup is shown in Fig. 1. An 8-W fiber-coupled laser diode array is used to pump Nd:YVO₄ crystal ($3 \times 3 \times 5$ mm³, 0.7 at.-% doped). The left side of Nd:YVO₄ is coated with 808 nm anti-reflection (AR) and 1064 nm high reflection (HR) coatings as a reflective mirror of the laser resonator, and the right side with 1064 nm AR. Both facets of Cr:YAG ($\phi 6 \times 1.5$ mm², initial transmission rate of 80% for small signal in 1064 nm) are coated with 1064 nm AR. A piece of Type-II critical phase-matching KTP crystal ($2 \times 2 \times 9$ mm³, both facets coated with 1064 nm AR and 532 nm AR) is used as the frequency doubler. The concave surface of the output mirror, with radius of curvature of 100 mm, is coated with 1064 nm HR and 532 nm AR, and the facet with 532 nm AR. The laser resonator (about 97 mm long) is a nearly hemispherical cavity.

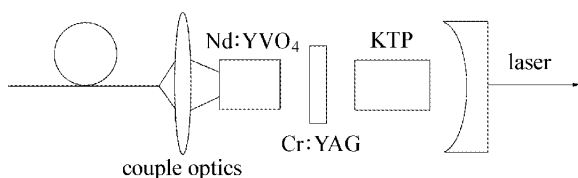


Fig. 1. The setup of passively Q -switched and mode-locked green laser.

The output pulse is measured by an oscilloscope (Lecroy, model 9361C, 300-MHz bandwidth) and an instant photonic diode. With 5.3-W pump power, passively Q -switched and mode-locked green laser pulses are obtained, with the modulation depth of the mode-locked pulse of 70% and the mode-locked pulse period of about 0.6 ns ($\tau = 2 \times \sum(n_i l_i)/c$, $n_{\text{YVO}_4} = 2.06$, $n_{\text{Cr:YAG}} = 1.82$, $n_{\text{KTP}} = 1.81$, $c = 3 \times 10^8$ m/s, $n_{\text{air}} = 1$, l_i is the length of the i th medium), the output power and the repetitive frequency of Q -switched pulse are 90 mW and 12 kHz, respectively. Oscilloscope traces of Q -switched pulse are shown in Fig. 2, and those of Q -switched and mode-locked pulse are shown in Fig. 3.

That fiber-coupled LD-pumped Nd:YVO₄/Cr:YAG/KTP laser emitting passive Q -switching and mode-locking is decided by the characteristic of energy level of Cr:YAG^[5]. The four-level model of Cr:YAG is shown in Fig. 4.

There are four parameters concerning passive Q -switching of Cr:YAG, they are: the absorption cross-section for the ground state and the first excited state ($\sigma_{\text{gs}} = 1.1 \times 10^{-18}$ cm², $\sigma_{\text{es}} = 1.2 \times 10^{-19}$ cm²), the lifetime for the first excited state and the second excited state. Because the lifetime for the first excited state is relatively long (3–4 μ s), Cr:YAG is ranked as the slow saturable absorber and only used to emit passively Q -switched pulse usually (the saturable light intensity

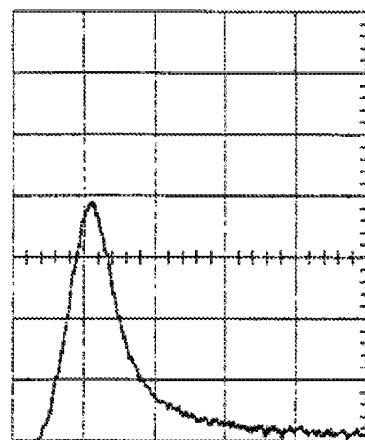


Fig. 2. Oscilloscope traces of Q -switched pulse (0.2 μ s/div).

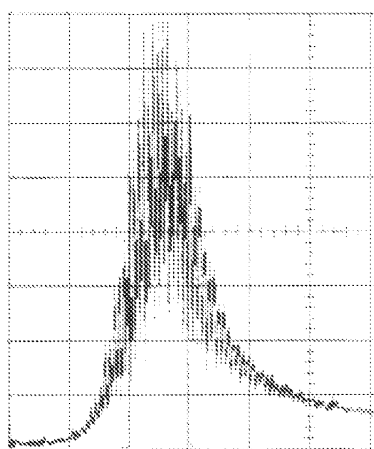


Fig. 3. Oscilloscope traces of Q -switched and mode-locked pulse ($0.2 \mu\text{s}/\text{div}$).

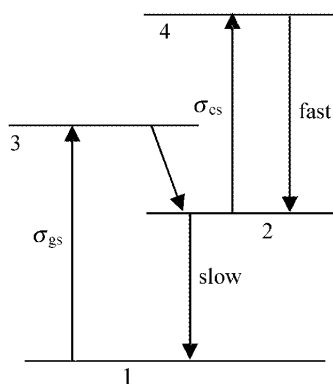


Fig. 4. The four-level model of Cr:YAG.

for the first excited state is about $6.3 \times 10^4 \text{ W}/\text{cm}^2$). However, recent research shows that the resonator is also able to make the second excited state be saturable and emit passively Q -switched and mode-locked laser when the incident light intensity is strong enough (the saturable intensity for the second excited state is about $7.5 \times 10^9 \text{ W}/\text{cm}^2$). The other reason why Cr:YAG can be used to emit mode-locking pulse is that the lifetime for the second excited state is very short (only 50 ps). The feasibility has been testified in above experiment.

Based on the above analysis, the aim of using nearly hemispherical cavity is to obtain small enough radius of the beam waist and strong enough power density that exceeds the saturable light intensity for the second excited state in Cr:YAG.

In the experiment, we found that there was not passively Q -switching and mode-locking when pump power is too weak or too strong. The reason is that the inverted population in upper laser level in laser crystal is not enough when the pump power is too weak, consequently, the peak power density of laser pulse is less than the saturable light intensity for the second excited state in Cr:YAG. Similarly, with too strong pump power, the build-up time and the peak power of the Q -switched pulse are decreased, so the passive Q -switching and mode-locking could not be obtained. As a result, to obtain the passive Q -switching and mode-locking, the peak power density of passive Q -switched pulse must be greater than the saturable light intensity for the first excited state in Cr:YAG.

By using Nd:YVO₄/Cr:YAG/KTP nearly hemispherical cavity, with 5.3-W pump power, the passively Q -switched and mode-locked green laser pulses are obtained, with the modulation depth of the mode-locked pulse of 70% and the mode-locked pulse period of 0.6 ns. Moreover, to our knowledge, the resonator length is the shortest to date, which is more practical. If the design is optimized sequentially, the mode-locked effect will be improved further.

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