Diode-pumped solid-state green lasers with short pulse duration, high pulse energy, and high repetition rate are attractive for a wide range of applications, e.g., high-density optical storage, surgery, angioplasty, and optical testing. Two crystals are very important for those green lasers. One is the Nd:YVO₄ crystal, due to its high absorption coefficient, short lifetime of the upper level, density optical storage, surgery, angioplasty, and optical testing. Another is the KTP crystal, due to its high second harmonic conversion coefficient. So it is easy for Nd:YVO₄/KTP green lasers to obtain high second harmonic conversion efficiency[4–6].

There are already some reports on diode-pumped mode-locked Nd:YVO₄ green lasers[7–10]. In those papers, the mode-locked Nd:YVO₄ laser of 532 nm were based on the cascaded second-order nonlinearity mode-locking (CSM) and nonlinear mirror mode-locking (NLM). The CSM and NLM mode-locking mechanisms were similar in using an artificial fast saturable absorber. Recently, the development of mode-locked laser technology has been made with the application of real saturable absorbers. For example, semiconductor saturable absorber mirror (SESAM) has been recognized as a practical way to obtain stable picosecond pulses. Li et al. reported a continuous-wave (CW) mode-locked green laser with SESAM, which used YVO₄/Nd:YVO₄ as the gain medium[11]. However, as far as we know, the CW mode-locked Nd:YVO₄/KTP green laser by employing SESAM as saturable absorber has not been reported.

In this letter, we demonstrate the experiment of a passively CW mode-locked Nd:YVO₄/KTP green laser with SESAM as saturable absorber and using an intracavity frequency doubling KTP crystal. The maximum output power of 552 mW at 532 nm with a repetition rate of 87 MHz is obtained at the incident pump power of 7.25 W. The mode-locked pulse duration of green laser is about 8.4 ps, corresponding to the peak power of about 709 W.

The schematic setup of the passively CW mode-locked green laser is depicted in Fig. 1. The pump source used in our experiment was a 30-W fiber-coupled diode laser (LYPE30-SG-WL808-F400) with the output wavelength ranging from 806 to 809.5 nm at 27.5 °C and the numerical aperture of 0.22. The spot size inside the crystal was about 200 μm. The laser crystal was a-cut Nd:YVO₄ crystal with high nonlinear conversion coefficient. So it is easy for Nd:YVO₄/KTP green lasers to obtain high second harmonic conversion efficiency[4–6].

A diode-pumped continuous-wave (CW) mode-locked Nd:YVO₄/KTP green laser with semiconductor saturable absorber mirror (SESAM) is demonstrated. The maximum output power of CW mode-locked green laser is obtained to be 552 mW at the incident pump power of 7.25 W, corresponding to an optical-optical conversion efficiency of about 7.6%. The 532-nm CW mode-locked pulse duration is estimated to be about 8.4 ps with the repetition rate of 87 MHz.

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To examine mode matching, we substituted M1 and the KTP crystal with a flat mirror of 10% transmittance at 1064 nm. With the above laser cavity configuration, the average output of 3.55 W at 1064 nm was achieved at an incident pump power of 9.59 W, corresponding to an optical-optical efficiency of 37.0%, which proves that a good mode matching is achieved with the current cavity design.

The relationship between the 532-nm output power and the incident pump power is shown in Fig. 2. The threshold for generation of CW green light was about 0.11 W. Within the range of the incident power from 1.8 to 3 W, the laser had a Q-switching mode-locked operation regime. When the incident pump power increased to 3 W, the laser pulse switched to CW mode-locked regime. The green laser exhibited stable and clean CW mode-locked pulse train, which was detected by a fast photodiode detector (NEW FOCUS 1623) with a rising time of 2 ns. The maximum average output power of 552 mW was obtained at the incident pump power of 7.25 W. Further increasing the incident power, the KTP reached saturated gain and the output power could not increase any more. The output power fluctuation $\Delta P$ of the green laser was tested when the incident pump power was 7.25 W. The green laser power was measured at a time interval of 5 min in 1 h. If the output laser power fluctuation $\Delta P$ is calculated by

$$\Delta P = \sqrt{\frac{\sum_{i=1}^{n} (P_i - \bar{P})^2}{n}},$$

the instability $\Delta P/\bar{P}$ of the green laser is 0.61%.

The CW mode-locked pulse trains at 200- and 10-ns scales were investigated, as depicted in Fig. 3. The repetition rate of 87 MHz was in agreement with the theoretical result which was calculated by $f = c/2l$ (c is the speed of light in vacuum, l is the total length of the cavity). As KTP has mode-locking mechanism, the CW mode-locking pulse of 532 nm is cleaner and more stable than the CW mode-locked pulse of 1064 nm.

Due to the limitation of the instrument, the pulse duration of the 532-nm CW mode-locked pulse cannot be measured. However, the mode-locked pulse duration of 532 nm can be estimated from the mode-locked pulse duration of 1064 nm as $\tau_{532} = \tau_{1064}/\sqrt{2}$. The pulse duration of 1064 nm at the CW mode locked operation was measured by an autocorrelator (FR-103XL). A typical autocorrelation trace of the pulse is shown in Fig. 4. The train width (full-width at half-maximum FWHM) of the trace is about 560 μs. Taking a Gaussian profile, we estimated that the fundamental pulse duration was about 11.9 ps. Thus the pulse width of 532 nm was assumed to be approximately 8.4 ps.

In conclusion, we have successfully demonstrated a passively CW mode-locked intracavity frequency doubled Nd:YVO$_4$/KTP green laser with a SESAM.
Nd:YVO$_4$/KTP green laser with SESAM. By using a five-mirror cavity, the 87-MHz CW mode-locked pulse was obtained with the pulse width estimated to be 8.4 ps. The average output power of 552 mW was achieved at the incident pump power of 7.25 W, corresponding to the optical-optical efficiency of 7.6%. The instability of the green laser at the pump power of 7.25 W was 0.61%.

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References