All-solid-state quasi-continuous-wave high power dispersion cavity tunable Ti:sapphire laser

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An all-solid-state quasi-continuous-wave dispersion cavity tunable Ti:sapphire laser pumped by a laser diode pumped frequency-doubled Nd:YAG laser is reported. Using a dense flint glass prism as the dispersion element, a tuning range from 730 to 880 nm with the linewidth of 3 nm and the pulse width of 17.2 ns was obtained. The maximum output power of this laser system was 5.6 W at 786.3 nm corresponding to an optical-to-optical conversion efficiency of 25.5% under the pump power of 22 W.

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Ti:sapphire laser is called a vibronic laser due to the close blending of the electronic and vibrational frequencies. Besides the common advantages of the solid lasers, such as compact structure, stability, long life, room temperature operating, and high gain, Ti:sapphire laser has a output range from about 660 to 1180 nm, which is the broadest tuning range for any single solid state, gas, or liquid laser media (almost the summation of the wavebands covered by dye lasers). So Ti:sapphire laser has been popularly used in laser spectrum, laser chemistry, laser remote sensing, atmosphere optics, and so on[1,2]. Using nonlinear optical frequency conversion technology, the tuning range can be expanded to infrared, blue, ultraviolet or deep ultraviolet wavebands[3]. That is a very important tunable light source used in pollution monitoring, ultraviolet dynamic spectroscopy, and nano-(micro-)mechanical process[4].

This letter demonstrates an all-solid-state tunable Ti:sapphire laser pumped by a laser diode (LD) pumped Q-switched intra-cavity frequency-doubled Nd:YAG laser. Using a dense flint glass prism as dispersion element, a tunable laser with tuning range from 730 to 880 nm was achieved. The linewidth of output was 3 nm and the pulse width was 17.2 ns. The maximum output power was 5.6 W with 25.5% optical-to-optical conversion efficiency at 786.3 nm.

The experimental setup is depicted schematically in Fig. 1, which is consisted of Q-switched LD pumped intra-cavity frequency-doubled Nd:YAG laser, lens, and Ti:sapphire resonator. The laser head used in Nd:YAG laser system was a diode-side-pumped module with three 4 × 20 W LD arrays mounted side by side to a 3-mm-diameter rod of 1% Nd^{3+}-doped YAG of 68-mm length in a close-coupled configuration. M_1 was coated for high reflection at 1064 nm. M_2 was the backmirror of KTP frequency-doubled resonator with high reflection (HR) coating at 532 nm and antireflection (AR) at 1064 nm. The output coupler M_3 was coated for high reflection at 1064 nm and high transmission at 532 nm. The plano-concave lens L with focal length of 150 mm used to enhance the density of pump power makes the coupling of pump beam and oscillating beam better. The diameter of 532-nm pump beam in the Ti:sapphire crystal was about 400 μm. Ti:sapphire resonator was consisted of M_4, M_5, prism, and Ti:sapphire crystal. M_4 was coated for HR at 750—850 nm. M_5 was the output coupler for 750—850 nm, with a transmission of 20% around the center wavelength of 800 nm. The transmission curve of M_5 was shown in Fig. 2. Ti:sapphire crystal was provided by Shanghai Institute of Optics and Fine Mechanics with the dimension of $7 \times 7 \times 16$ (mm), FOM = 150. The crystal was cut with Brewster's angle at both ends for better coupling of the pump source and low loss of Ti:sapphire laser. To extract the deposited heat, the crystal was wrapped with indium foil and tightly mounted in a water-cooled copper holder. A dense flint glass prism was placed symmetrically in the resonator, which was used as the dispersion element to narrow the linewidth of output. The distance between the vertex of prism and the end of the crystal was 40 mm. The incident and the emergent angles are Brewster's angle to reduce the insertion loss, the point angle of the prism was about 60°, at center wavelength of 800 nm ($n = 1.74$, $\theta_B = 60.1°$). The Brewster's angle facing Ti:sapphire crystal and the prism would import astigmatism inevitably. But placing the prism symmetrically in the resonator could reduce the astigmatism[5].

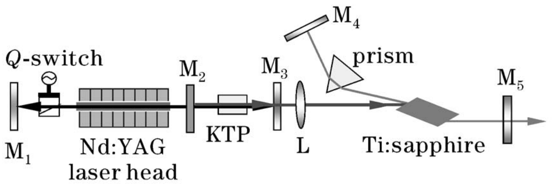

Fig. 1. All-solid-state quasi-continuous-wave dispersion cavity Ti:sapphire laser system.

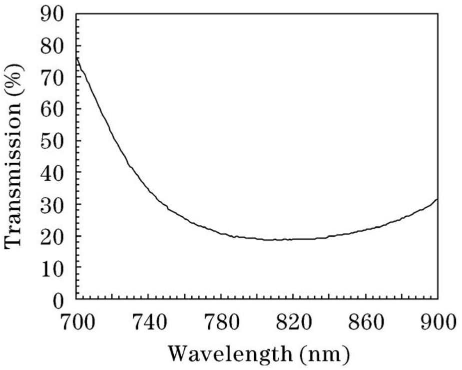

Fig. 2. Transmission of mirror M_5.

Considering the multi-mode operating and large angle of divergence of the pump beam, the diameter of the pump beam focused into Ti:sapphire crystal was still large (about 400 μm), so was the pump mode volume. Although a four mirror folded resonator is very popular, the configuration is miscellaneous and the mode volume of oscillating beam is usually small (the diameter is usually less than 100 μm). However, in a two-mirror linear cavity, the mode volume of oscillating beam is larger and can make use of the whole pump region[6,7]. So a simpler flat-flat resonator configuration was chosen to improve the coupling of pump beam with oscillating beam and enhance conversion efficiency. Moreover, as shown in Fig. 1, this configuration had another obvious advantage: the pump beams enter Ti:sapphire crystal directly avoiding the reflection loss and damage of HR mirror. In the experiment, the resonator was optically symmetrical and the cavity length was 150 mm. The pump beam was focused to a waist diameter of about 400 μm in the crystal. The focal length of pump-induced thermal lens of Ti:sapphire crystal was 195 mm when the pump power was 22 W. The diameter of oscillating beam at 800 nm in the crystal was 434 μm. It could be seen that the oscillating mode volume matched the pump beam's well and the laser operated on the power-stable point.

In this work, the output power at 532 nm was 22 W with the repetition rate of 5 kHz and pulse width of 61.2 ns when the current was 21 A. A spectrum analyzer (Agilent Technologie, 6842B) and a power meter (Molectron, EMP1000) were used to measure the output wavelength and the output power of Ti:sapphire laser, respectively.

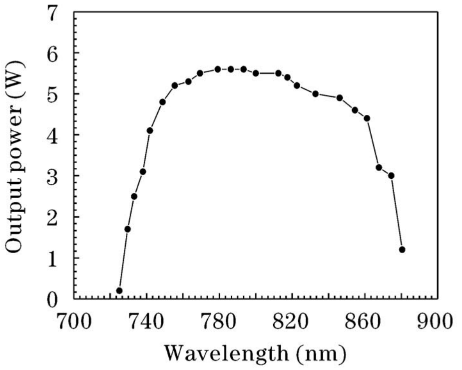

Fig. 3. Output power as a function of output wavelength at $T = 20\%$.

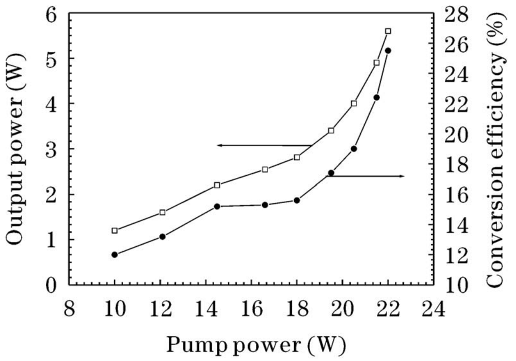

Fig. 4. Output power and conversion efficiency as functions of pump power at 786.3 nm.

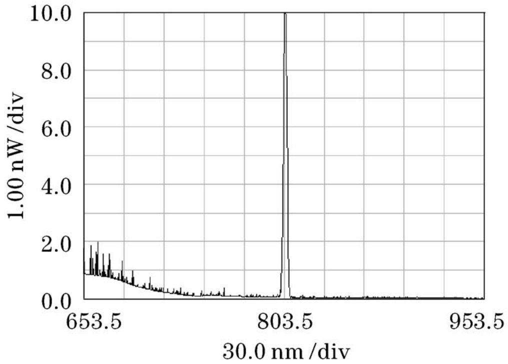

Fig. 5. Linewidth of output at 803.5 nm.

By turning M_4, we got a tunable output from 730 to 880 nm. The output power of Ti:sapphire laser as a function of output wavelength is shown in Fig. 3. The maximum output power was obtained at 786.3 nm.

Figure 4 shows the output power of 786.3 nm as a function of pump power at 532 nm. The maximum output power was 5.6 W and optical-to-optical conversion efficiency was 25.5%. As can be seen, the conversion efficiency increased with the pump power increasing without any decline. This means that the Ti:sapphire laser exhibited long-term amplitude stability and robust operation without the onset of thermal lensing effects.

Figure 5 shows the spectrum at 803.5 nm. The linewidth of output (FMHW) was about 3 nm. Figure 6 shows a narrow pulse width of output. Compared with the pulse width of 61.2 ns pump light, the output pulse

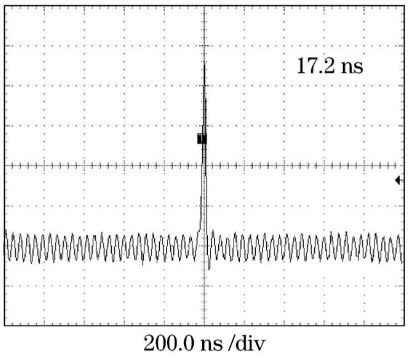

Fig. 6. Pulse width of output.

width of Ti:sapphire laser came to be 17.2 ns (measured by the oscilloscope of Tektronix TDS620B) due to the gain-switched effects[8].

As shown in Fig. 3, it was found that the output power of tuning range around center wavelength did not vary much from 770 to 820 nm, which did not agree with the fluorescent spectrum of Ti:sapphire well. It results from the transmission of broadband film of output mirror M_5. The transmission of 770—850 nm ($T \approx 20\%$) is almost the same as in Fig. 2 and is lower than the optimal transmission of center wavelength. Though the gain at center wavelength is the maximum, the transmission is not optimal. On the other hand, other wavelengths around it do not have the maximum gain, but may have a better transmission. This result is adapted to the practical application, such as a requirement for a wide tuning range of the similar output.

In summary, we have demonstrated an all-solid-state Ti:sapphire laser in which a dense flint glass prism is used as the dispersion element. A tuning range from 730 to 880 nm was achieved. The linewidth of output was 3 nm and pulse width was 17.2 ns. Configured in a simple cavity design, the Ti:sapphire laser exhibited robust operation without the onset of thermal lensing effects. The conversion efficiency from 532 nm pump laser to Ti:sapphire laser at 786.3 nm was 25.5%, with the maximum output power of 5.6 W. Continuing research is currently underway.

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