High-power and high-efficiency operation of an all-solid-state, quasi-continuous-wave, titanium sapphire laser system

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High-power and high-efficiency operation of an all-solid-state, quasi-continuous-wave, titanium sapphire laser is obtained with a diode-laser-pumped frequency-doubled Nd:YAG laser as the pump source. A maximum output power of 2.5 W is obtained for 16-W power of 532-nm pump light. A much higher conversion efficiency of 15.7% is obtained when at the maximum output power.

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P. F. Moulton first realized quasi-continuous-wave Ti:sapphire laser in 1984, which was operated in room temperature[1]. Ti:sapphire laser, since its naissance, has been studying broadly because of its suitability for a number of applications, such as laser spectrum, laser chemistry, nonlinear optics and atmosphere monitor. Solid-state Ti:sapphire laser, which can be optically pumped by diode-laser-pumped solid-state lasers or directly pumped by diode lasers, can form the basis of compact, efficient, and long-lived laser systems. There are lots of optical pump sources which have been shown to be capable of pumping Ti:sapphire oscillators: argon-ion lasers, copper-vapor lasers, and flash-lamp-pumped frequency-doubled Nd:YAG and Nd:YLF lasers, as well as flash lamps for direct pumping. These pump sources present problems for many applications.

Advances in the development of high-power laser diodes have resulted in great interest in the development of high-power, high-efficiency all-solid-state laser systems. Most diode laser pumped systems have been primarily based on Nd-doped materials due to their high efficiency. Such systems now offer the opportunities of great frequency agility in all-solid-state laser systems through frequency conversion techniques and further pumping of other laser gain media, such as Ti: sapphire crystal.

There is little of study in Ti:sapphire lasers pumped by all-solid-state, quasi-continuous-wave, frequency-doubled Nd:YAG laser. The recent research in this area was reported by Zhang and Feng, in which the output power was only 660 mW and the efficiency was 9.4%[2]. That preliminary research demonstrated the feasibility of an all-solid-state Ti:sapphire laser system.

In this work we employ higher output power and higher efficiency operation of a Q-switched Nd:YAG laser pumped by continuous-wave laser diode arrays to achieve high-efficiency frequency doubling in a crystal of KTP and pumping of the Ti:sapphire laser than reported earlier. The system described in this paper is based on the 400-W continuous-wave laser diode array as the initial pump source and resulted in all-solid-state pumping of Ti:sapphire, to achieve a maximum output power of 2.5 W which is almost forth times as before, and a much higher efficiency of 15.7%.

As we know, Ti:sapphire has a broad absorption band between 400 – 600 nm, with a peak at 490 nm. The 532-nm output of the frequency-doubled Nd:YAG laser matches very well to the absorption peak of Ti:sapphire. The schematic diagram of the Ti:sapphire laser pumped by the diode-laser-pumped, frequency-doubled, A-O Q-switched Nd:YAG laser is shown in Fig. 1.

The laser uses a $\phi 5 \times 130$ mm^2 0.6% Nd:YAG rod, which is side pumped by continuous-wave diode-laser arrays. The acousto-optical Q-switch is an $8 \times 10 \times 50$ mm^3 fused silica, which is offered by NEOS Company from the United Kingdom. The laser cavity is 500 mm long and utilizes a 3000-mm curvature, 1064-nm high-reflection (HR) mirror and a 1064-nm HR, 532-nm high-transmission flat mirror as the cavity coupler. The acousto-optical Q-switch, the Nd:YAG rod, a harmonious mirror, and a KTP frequency-doubling crystal are put in the laser cavity, correspondingly. This Ti:sapphire pumping system yields 2 – 10 k repeat frequency, 20-W maximum average power, 532-nm green light with a pulse width of about 280 ns.

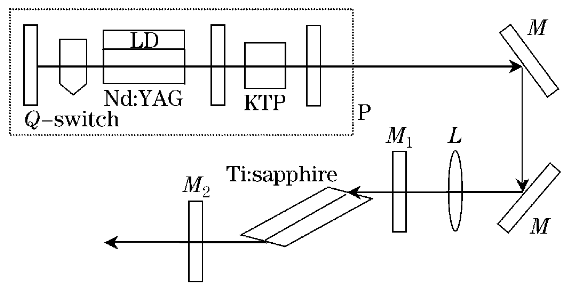

Fig. 1. Schematic diagram of the all-solid-state, quasi-continuous-wave, Ti:sapphire laser system. LD: diode array; P: Ti:sapphire laser pump source; M: HR 532-nm flat mirror; L: focal lens; M_1, M_2: Ti:sapphire cavity mirrors.

In this experiment, we use two flat mirrors to form the lasing cavity for the Ti:sapphire system. A 50-mm focal length lens focused the pump beam into the laser cavity. The laser crystal is placed at the pumping laser beam focus.

The laser crystal is grown at Shanghai Institute of Optics and Fine Mechanics. The ends of the 16-mm-long rod are at Brewster angle; the polarization of light transmitted at the Brewster angle face is in the direction of the c axis. Polarization of the light along the c axis provides the highest absorption in the pumping green light, highest emission in the infrared, and the lowest residual absorption at the laser wavelengths. The laser crystal absorbed 85% of the incident 532-nm laser beam; it is in contact with a water-cooled copper plate, which extracts the deposited heat.

The laser crystal is symmetrically placed between two flat mirrors which are placed 60 mm apart. One mirror is highly transmitting 532-nm light and highly reflecting light between 700 − 900 nm, used as the input mirror. The other is 11.7% transmitting between 700 − 900 nm, used as the output coupler.

Alignment of the green and red laser beams to approximately 1 mrad is required to maintain a good overlap of the two beams over the 16-mm crystal length. The dispersion of Ti:sapphire causes approximately 15-mrad angular dispersion between the green and infrared beams. Thus, the pump light and laser light become separated by approximately the beam diameter outside the crystal.

The pump laser operates multimodelly and the emanative angle is big, so we cannot focus it very tightly. On the other hand, it will damage the Ti:sapphire crystal and cavity mirror because of the too higher peak power density by tighter focusing the pump light. In order to match the resonant light and the pump light, obtaining the optimal pump effect, the light radius of the resonant light in the crystal is not too small. Here, the light radius we got is about 200 μm. So we use two-flat-mirror cavity to attain higher laser conversion efficiency, not collapse cavity or ring cavity.

The threshold of this Ti:sapphire laser system is 4 W. A maximum output power of 2.5 W is obtained for 16-W pump power incident upon the Ti:sapphire rod. At this pump power the output pulse width is 80 ns. The optical-to-optical conversion efficiency of the Ti:sapphire laser is 15.7%. Output power of the Ti:sapphire laser versus the pump power of the 532-nm laser is shown in Fig. 2.

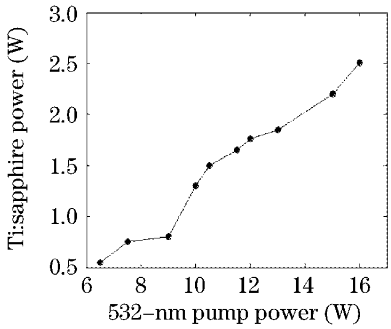

Fig. 2. The output of the Ti:sapphire laser as a function of the 532-nm pump power transmitted through the 700 − 900 nm HR mirror for a 60-mm-long cavity with an output mirror with 11.7% transmission.

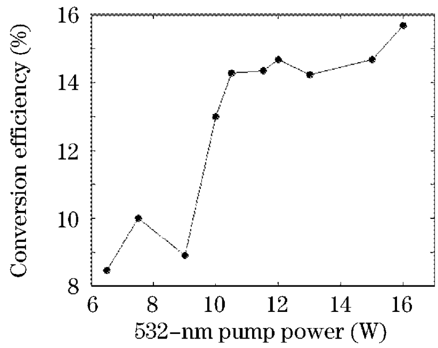

Fig. 3. Variation of optical-to-optical conversion efficiency of the Ti:sapphire laser with pump power.

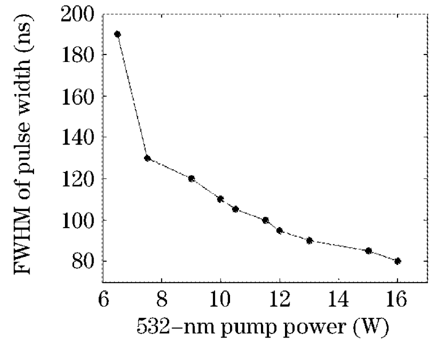

Fig. 4. Variation of FWHM of pulse width of the Ti:sapphire laser with pump power.

We describe the optical-to-optical conversion efficiency of the Ti:sapphire laser versus the pump power in Fig. 3. Through Fig. 3, we can find that the conversion efficiency is increased with the pump power increasing.

We also observe that the pulse width of the output laser is declined from 190 to 80 ns with the pump power increasing. The FWHM of pulse width versus pump power is shown in Fig. 4. The change of Ti:sapphire laser pulse width had been observed in many experiments. The main reason is the gain switch pulse generated by Ti:sapphire[3].

In this work we employ higher output power and higher efficiency operation of a Q-switched Nd:YAG laser pumped by continuous-wave laser diode arrays to achieve high-efficiency frequency doubling in a crystal of KTP and pumping of the Ti:sapphire laser. Using the 400-W continuous-wave laser diode array as the initial pump source, we result in all-solid-state pumping of Ti:sapphire, achieving a maximum output power of 2.5 W which is almost forth times as before, and a much higher efficiency of 15.7%.

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