High Order Hermit-Gaussian Mode Passively Q-Switched $Nd:YVO_4$ Microchip Laser

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Abstract: Versatile high order Hermit-Gaussian mode lasers with peak power of over 720 W have been generated in passively Q-switched $Nd:YVO_4$ microchip laser by applying tilted large pump beam diameter incident on $Nd:YVO_4$ crystal.
OCIS codes: (140.3295) Laser beam characterization; (140.3530) Laser, neodymium; (140.3480) Laser, diode-pumped; (140.3580) Laser, solid-state; (140.3540) Laser, Q-switched

1. Introduction

Generation of high order transverse mode in solid-state lasers has gain more attention in recent years because high order transverse mode lasers have potential application on manipulation of particles, optical trapping, optical guiding, formation of versatile vortex and so on [1, 2]. Hermit-Gaussian (HG) mode generated in resonator has definite characteristics for various applications compared to those obtained with optical methods [3]. HG mode beams generated in the laser-diode pumped solid-state lasers [4, 5] are more convenient and simpler than gas and semiconductor lasers for generation of HG modes with controllable transverse amplitude distribution and stability [6, 7]. However, these lasers work in continuous-wave and output power is limited to several mW. Very recently, a digital laser for on-demand laser modes was developed successfully by applying computer-controlled spatial light modulators [8], various HG mode lasers have been generated, however, the optical conversion efficiency is quite low and limits the applications. Pulsed HG mode lasers with high peak power and high repetition rate are favorable for manipulating micro-particles and increasing the resolutions of optical trapping and capacity of quantum computation. Therefore, passively Q-switched microchip lasers are worthy to be investigated for generating with various high order HG transverse modes.

Here, high order HG mode beams have been directly generated in Cr^{4+}:YAG passively Q-switched $Nd:YVO_4$ microchip laser. The $Nd:YVO_4$ crystal was pumped with tilted pump beam from laser-diode. Various high order HG mode lasers with nanosecond pulse width and hundreds watt peak power were obtained.

2. Experiments

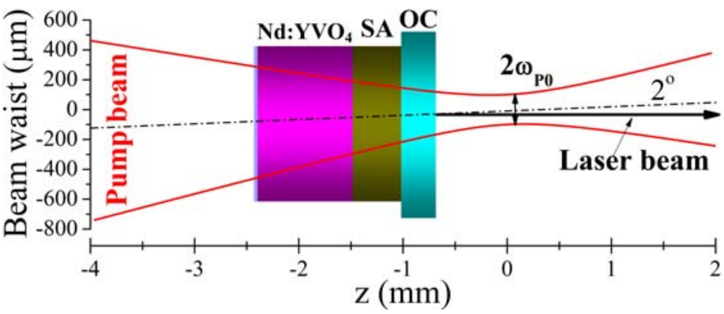

Fig. 1.Experimental setup of Cr^{4+}:YAG passively Q-switched $Nd:YVO_4$ microchip laser for generation of high order HG mode output, SA is the saturable absorber, OC is the output coupler, ω_{p0} is the focused pump beam waist, z is the $Nd:YVO_4$ crystal position along the pump beam direction.

The experimental setup of laser-diode pumped Cr^{4+}:YAG passively Q-switched $Nd:YVO_4$ microchip laser for generation high order HG modes is shown in Fig. 1. An 808 nm fiber-coupled LD with a numerical aperture (NA) of 0.22 and core diameter of 400 μm was used as the pump source. The output pump beam from laser-diode was collimated and focused by using two focusing lenses with 8 mm and 15 mm focal length, respectively. The diameter of the pump beam focus spot incident on the rear surface of $Nd:YVO_4$ crystal was measured to be 200 μm. A plane-parallel 1-mm-thick a-cut $Nd:YVO_4$ crystal doped with 1 at.% Nd^{3+} ions was used as the gain medium. One surface of the $Nd:YVO_4$ crystal was coated with anti-reflection at 808 nm and high-reflection at 1064 nm to act as the rear cavity mirror of the laser cavity. The other surface of $Nd:YVO_4$ crystal was coated with anti-reflection at 1064 nm to reduce the intracavity loss. A 0.5-mm-thick Cr^{4+}:YAG crystal attached to the Nd:YVO_4 crystal was acted as the saturable absorber, its initial transmission is 88.5%. A 2-mm-thick K9 plane-parallel output coupler with reflection of 90% at 1064 nm was attached to the saturable absorber. The total length of the laser cavity was 1.5 mm. The Nd:YVO_4 and Cr^{4+}:YAG crystals were tilted with 2 degrees away from the pump beam direction and positioned 2.4 mm away from the focus beam waist for generating high order HG transverse laser modes. The laser was operated at room temperature without any actively cooling. The average output power was measured with a Thorlabs power meter. The characteristics of laser pulse were recorded by using a fast InGaAs photodiode and a digital oscilloscope (Tektronix TDS6604, 6 GHz bandwidth, 20 GS/s). The output laser beam profile was monitored and recorded by using a laser beam quality analyzer (Thorlabs BC106-VIS).

3. Results and discussion

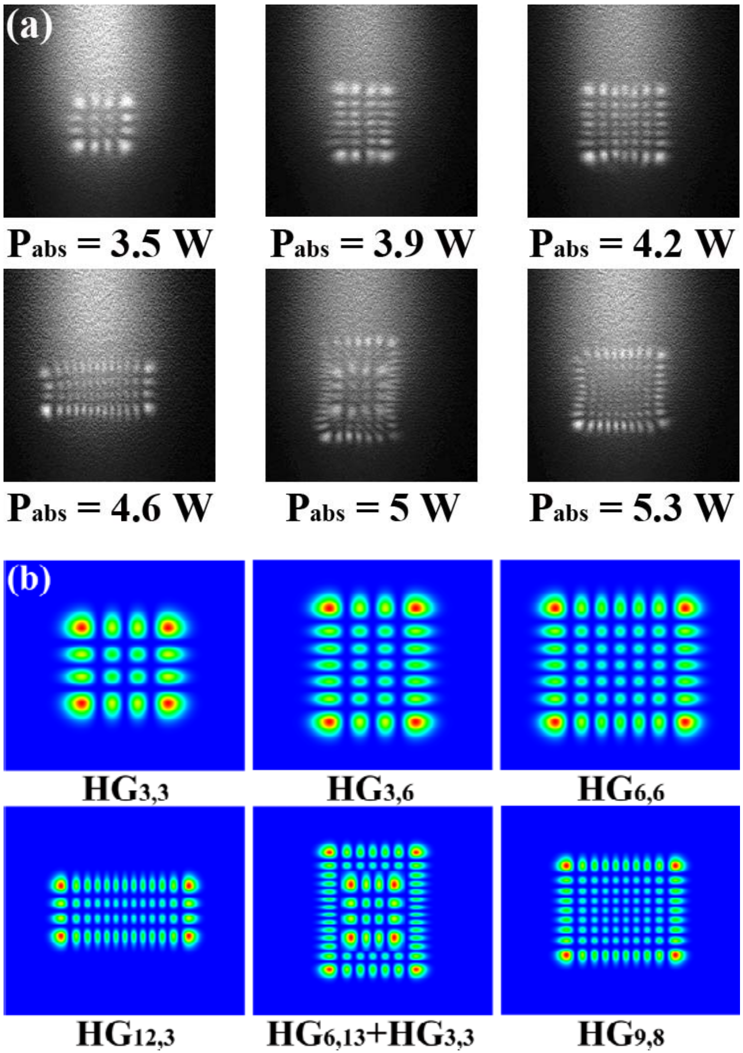

Fig. 2. (a) HG mode transverse distribution obtained in passively Q-switched Nd:YVO_4 microchip laser at different absorbed pump power levels; (b) the numerical simulated results corresponding to the observed HG mode transverse distribution in Fig. 2 (a).

The absorbed pump power threshold was 2.3 W owing to the large pump beam diameter applied. The fundamental mode laser oscillated when the absorbed pump power was lower than 3 W. The HG mode laser was obtained when the absorbed pump power was higher than 3 W. The $HG_{3,0}$ mode laser beam was obtained when the absorbed pump power was 3.1 W. Fig. 2 shows the typical HG mode transverse distribution of Cr^{4+}:YAG passively Q-switched Nd:YVO_4 microchip laser at different absorbed pump power levels and the corresponding numerical simulation of the observed transverse distribution of HG modes. The indices of the HG mode obtained in passively Q-switched $Nd:YVO_4$ microchip laser increase with the absorbed pump power. The $HG_{3,3}$ mode was generated when the absorbed pump power was 3.5 W. The $HG_{3,6}$ mode was generated when the absorbed pump power was 3.9 W. The $HG_{6,6}$ mode was generated when the absorbed pump power was 4.2 W. The $HG_{12,3}$ mode was generated when the absorbed pump power was 4.6 W. The $HG_{6,13}$ and $HG_{3,3}$ modes oscillated simultaneously when the absorbed pump power was 5 W. The $HG_{9,8}$ mode was generated when the absorbed pump power was 5.3 W. The formation of high order HG mode laser in Cr^{4+}:YAG passively Q-switched $Nd:YVO_4$ microchip laser was attributed to the asymmetry pump power distribution inside the $Nd:YVO_4$ crystal by applying tilted large pump beam diameter incident on the gain medium. The asymmetry inversion population distribution induced by the asymmetry pump power distribution inside the $Nd:YVO_4$ crystal governs the possible laser beam area and then determines the various HG modes oscillations in passively Q-switched $Nd:YVO_4$ microchip laser.

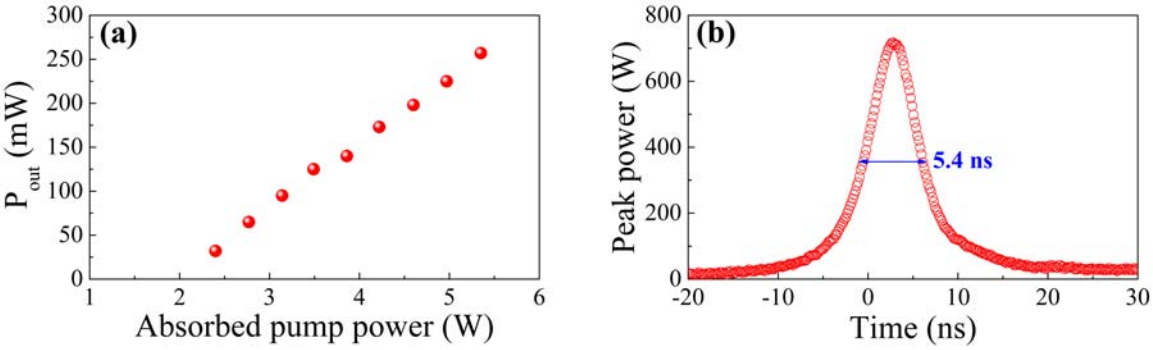

Fig. 3. (a) Average output power of high order HG mode passively Q-switched $Nd:YVO_4$ microchip laser as a function of the absorbed pump power; (b) the $HG_{9,8}$ mode laser pulse profile with pulse width of 5.4 ns and peak power of over 720 W.

Fig. 3(a) shows the average output power of HG mode passively Q-switched $Nd:YVO_4$ microchip laser with Cr^{4+}:YAG crystal as saturable absorber as a function of the absorbed pump power. The average output power increases linearly with the absorbed pump power, and there is no saturation of the average output power with the absorbed pump power. The slope efficiency is 7.4%. The maximum average output power of 257 mW was obtained when the absorbed pump power was 5.35 W. The corresponding optical-to-optical efficiency is 4.8%. Fig. 3(b) shows the obtained laser pulse of $HG_{9,8}$ mode laser with pulse width of 5.4 ns and peak power of 720 W. $HG_{9,8}$ mode laser oscillated at repetition rate of 67 kHz.

4. Conclusions

High order HG mode laser beams have been directly generated in Cr^{4+}:YAG passively Q-switched $Nd:YVO_4$ microchip laser by applying tilted pump beam incident on the $Nd:YVO_4$ crystal. The formation of high order HG modes in passively Q-switched $Nd:YVO_4$ microchip laser was attributed to the asymmetry inversion population distribution inside the $Nd:YVO_4$ crystal by applying tilted lager pump beam diameter incident on the gain medium. $HG_{9,8}$ mode laser with average output power of 257 mW has been obtained, and laser pulses with pulse width of 5.4 ns, peak power of over 720 W working at 67 kHz have been generated in passively Q-switched $Nd:YVO_4$ microchip laser, which have potential applications on optical trapping, quantum computation and so on.

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