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LD end pumped mode locked and cavity dumped Nd:YAP laser at 1.34 μm

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ABSTRACT

We report a LD end pumped actively mode locked, passively Q switched and cavity dumped Nd:YAP laser at 1.34 μm. The dumped output pulse energy of 160 μJ is obtained at a repetition rate of 10 Hz. Passing through a LD end pumped, double-passed Nd:YAP amplifier the pulse energy is amplified to 1.44 mJ. The corresponding amplification factor is 9. Stimulated Raman scattering experiment is taken with a 9 mm long $PbWO_4$ Raman crystal. Maximum of 20% Raman conversion is reached.

1. Introduction

1.34 μm lasers have various applications. It can be used in the fields of spectroscopy, micro machining, optical fiber communication, remote sensing, and medical treatment [1–3]. Moreover, based on the 1.34 μm laser system, highly efficient radiation in the red wavelength range can be easily achieved by frequency doubling. In addition, its Raman conversion is in the 1.5–1.6 μm range [4,5]. The use of laser wavelength at 1.5 μm has merits of high eye safe threshold of 1 J/cm^2, no photochemistry damage and low sky radiance interference, which makes it attractive to detect CO_2 concentration in the atmosphere and the wind field [6]. In order to obtain Stimulated Raman scattering (SRS) at 1.5 μm laser, high intensity 1.3 μm laser is required. Therefore, pulsed laser operation at a wavelength of 1.34 μm has attracted much attention in the last few years. Many laser materials including Nd:KGW [7], Nd:YAG [8], Nd:YAP [9], Nd:$GdVO_4$ [10–14], Nd:$LuVO_4$ [15], and Nd:YVO_4 [16–20], have been successfully used for pulsed 1.34 μm radiation. Due to the large stimulated emission cross section (2.2×10^{-19} cm^2), broad emission bandwidth (690 GHz) and high thermal conductivity (11 $Wm^{-1} K^{-1}$), Nd:YAP is considered to be a promising laser crystal material for the pulsed radiation at 1.34 μm.

Mode locking is a method to obtain pico-second pulses with high peak power. Up to now, several saturable absorbers such as Co^{2+}-doped crystals [11,14,15,20], semiconductor saturable absorber mirrors (SESAMs) [17], nanotube saturable absorber [13] and V^{3+}-doped crystals [7,8,10,12,18] have been employed as passive Q switches. The reported experimental results show that pulse widths obtained by Co-doped crystals such as Co:LMA are usually large [14,15], while a SESAM introduces higher loss and results in a lower damage threshold, which limits its application [17]. Among the V^{3+}-doped crystals, V^{3+}:YAG crystals have attracted great interest due to their excellent physical and optical performance at 1.34 μm. In our previous work [9], with a V^{3+}:YAG of initial transmission 89%, maximum output pulse train energy of 0.82 mJ was obtained. The average output energy of a single mode locked pulse is 11 μJ, while the peak single pulse energy is 17 μJ. With a V^{3+}:YAG of initial transmission 60%, a maximum output pulse train energy of 3.2 mJ was obtained. The average output energy of a single mode locked pulse is 160 μJ, while the peak single pulse energy is 250 μJ. These results are much higher than the values reported before [3,10,19,21]. However, in all the previous works the laser output is a modulated mode-locked pulse train within a long Q switched envelop. It is difficult to be used in many applications.

In this paper, we report a LD end pumped actively mode locked, passively Q switched and cavity dumped Nd:YAP laser at 1.34 μm. It can generate single short pulse with 160 μJ energy and 680 ps duration. After the amplification of a double pass LD end pumped Nd:YAP amplifier, the maximum pulse energy is 1.44 mJ. The output pulse is focused into a 9 mm long Raman crystal $PbWO_4$ with a 200 mm focal lens. 20% Raman conversion is obtained with single pass.

2. Experiments

2.1. Oscillation resonator

The dashed box in Fig. 1 shows the experimental setup of an actively mode locked, passively Q switched and cavity dumped Nd:YAP laser. The pump laser diode (LASERLINE^{TM}) can offer a maximum peak power of 1000 W at 803 nm wavelength. The pump frequency is 10 Hz. The pump power is delivered by a fiber system (HIGHYAG^{TM}) with 1 mm

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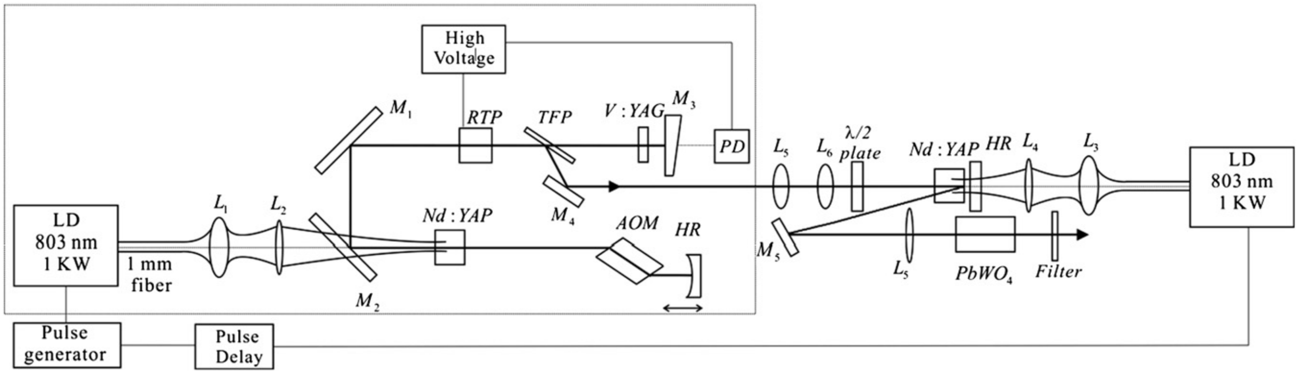

Fig. 1. Experimental setup.

core diameter and NA = 0.2. A telescope system with convex lenses L_1 ($f = 100$ mm) and L_2 ($f = 150$ mm) is used to focus the diode pump laser beam into the Nd:YAP crystal. All the components in laser cavity are anti-reflection (AR) coated for 1080 nm in order to prevent laser running at this wavelength. The output laser is detected by Optical Spectrum Analyzer (OSA), only laser emission at 1.34 μm is showed. The active medium is a 1.34 μm AR coated Nd:YAP crystal with 8 mm length, 9.5 mm diameter and with the b-axis in the laser beam direction. The doping concentration of Nd in Nd:YAP laser crystal is 0.8%. M_1 and M_2 are 45° mirrors which are s-polarized high reflection (HR) at 1.34 μm. Because the emission cross section of b-cut Nd:YAP crystal at c-axis is larger than that at the a-axis at 1.34 μm [22], the laser emission is c-axis polarized. The laser crystal is rotated in order to get the c-axis as s-polarization for mirrors M_1 and M_2. HR mirror is a concave mirror with 2 m focal length. M_3 is a wedged mirror used with 98.5% reflectivity at 1.34 μm. M_4 is a mirror HR coated at 1.34 μm at Brewster Angle. The AOM, which is made of quartz as acousto-optic medium and of $LiNbO_3$ as transducer, is working at 65 MHz. This leads to an optical cavity length of 1153.8 mm. The AOM has an aperture of 2.0 mm, and length of 2.5 mm. HR is moved to adjust the cavity length in order to satisfy the cavity length requirement. V^{3+}:YAG is used as a passive Q switch. The V^{3+}:YAG has an aperture of 10 mm, a length of 3 mm, and the initial transmission is 89%. An opto-electronic RTP crystal (rubidium titanyl phosphate — $RbTiOPO_4$) and a thin film polarizer (TFP) together are used as cavity dumper. The TFP has a reflectivity of s-polarized laser larger than 99%, and the transmission of p-polarized laser larger than 95%. The RTP Pockels cell is constructed with two RTP crystals, which are thermal compensated. Each RTP crystal has a cross section of 3 mm 3 mm and a length of 10 mm. At first, the half-wave voltage is applied on the RTP crystal. So s-polarized laser changes to p-polarized after the RTP crystal, and is free to go through the TFP. The loss inside the cavity is low, the laser begins to oscillate. An InGaAs photodiode is used to detect the output pulse train from M_3. When the largest signal of the output pulse train is detected, the half-wave voltage applied on the RTP crystal is shut down within 6 ns. The s-polarized of the laser oscillation does not change the polarization direction after RTP crystal, and it is dumped outside the cavity by the TFP. Then the voltage increased slowly to the half-wave voltage after around 100 ns. Fig. 2 displays the voltage jump at the Pockels cell.

The V^{3+}:YAG with 89% initial transmission is used for passive Q switching. Fig. 3 shows the temporal shape of the output pulse, which is measured by an InGaAs photodiode with oscilloscope Tektronix TDS 680B (1 GHz, 5Gs/s). The FWHM of the single pulse shown from the oscilloscope is about 680 ps. The output pulse energy of 160 μJ is obtained with 110 mJ pump energy. The negative curve in this picture might be caused by the electric effect from the photodiode and oscilloscope. The laser beam diameter of the oscillation output is measured with InGaAs linear image sensor. It is around 1.2 mm. We should note that due to the non-100% p-polarization transmission of the TFP and the thermal induced depolarization of the RTP crystal, there exits pre-pulses before the main output pulse. The peak power ratio of the pre-pulse to the main pulse is measured to be less than 3%.

The V^{3+}:YAG with 60% initial transmission is also tested in our experiments. Unfortunately about half minute after laser running, the coating of RTP crystal is damaged, and the laser is ceasing.

2.2. Amplifier

The dumped output laser is focused with lens L_5 ($f = 75$ mm) and L_6 ($f = 50$ mm) into the amplifier Nd:YAP crystal with 8 mm length, 9.5 mm diameter and with the b-axis in the laser beam direction. The laser beam diameter inside the crystal is measured with InGaAs linear image sensor as around 0.7 mm. The amplifier pump laser diode is working at 10 Hz at 803 nm wavelength. The pump pulse duration is 300 μs. It is triggered with the oscillation pumping diode with a delay box. The pump power is delivered by a fiber system with 1 mm core

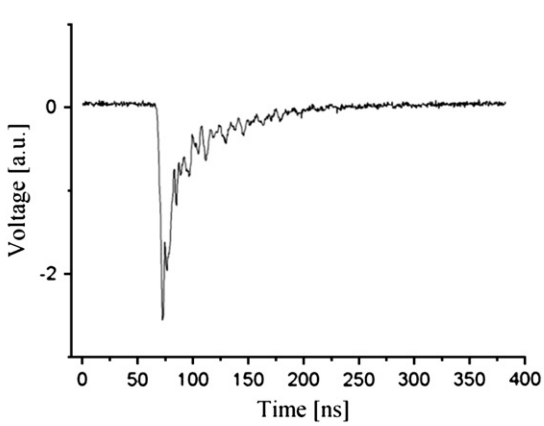

Fig. 2. Voltage step applied to Pockels cell for cavity dumping.

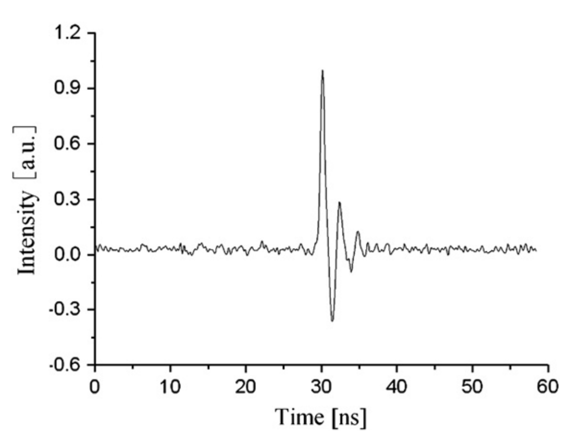

Fig. 3. Temporal pulse shape of actively mode locked, passively Q switched and cavity dumped Nd:YAP laser.