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High pulse energy, high repetition picosecond chirped-multi-pulse regenerative amplifier laser

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ABSTRACT

We successfully presented a multi-pulse picosecond laser with passively mode-locking, grating-stretching, regenerative amplifier and grating compression technologies. Firstly, 8.5 ps pulses with a repetition rate of 143 MHz and a maximum average output power of 160 mW were obtained by a semiconductor saturable absorption mirror (SESAM). Secondly, we got the pulses width stretched to 99.9 ps with 90 mW and single grating. Thirdly, a pulse sequence with each of five pulses per group was obtained by using a multi-pulse regeneration amplifier system, from which output energy was about 28 mJ at the repetition rate of 1 kHz and 112.1 ps in single pulse width. Finally, using a grating compressor we acquired these pulses compressed to a pulse width of 28 ps and 14 mJ in each group at a repetition rate of 1 kHz.

1. Introduction

In recent years, the picosecond laser system has been widely used in the field of material processing, photonic device production, microscopy and biomedicine [1–6]. It is of great significance to carry out studies on the wavelength of 1064 nm which is the most commonly used fundamental frequency pulse. The suitable gain medium Nd:YVO_4 and SESAM are used directly to generate pulses around 10 ps; however, low damage threshold and low extraction efficiency are two main barriers to meet higher needs for the pulses with width of about 10 ps. Initially, we obtained hundreds of picosecond pulses output with high repetition rate and high pulse energy by combining the grating stretcher and multi-pulse regenerative amplifier together [7–10]. As for the laser with pulse width of about 10 ps at 1064 nm, we selected a grating as a pulse stretching and compressing device. Meanwhile, gratings are the only way to get pulses with high peak power compressed in a large range compared with the picosecond amplification system which does not employ stretchers and compressors [11,12]. This method can get higher single pulse energy, and extracting efficiency that has been greatly improved after passing through the stretcher which is conducive to the next multi-pass amplification; meanwhile, the output pulse obtained in our experiment has a narrower line-width than that of the sub-picosecond or femtosecond amplification system [13].

A high-repetition-frequency pulse train output provides both high peak power and the effect of heat accumulation of multi-pulse, which improves the efficiency of industrial processes. In the first step we obtained a pulse 112.1 ps in single pulse width at the repetition rate of 1 kHz and 28 mJ in average energy with a single grating-stretching and multi-pulse regeneration amplifier. Then, by using a grating compressor we got these pulses compressed to 28 ps and 14 mJ in each group at a repetition rate of 1 kHz.

2. Experimental setup

Fig. 1 illustrates the experimental setup, which consists of four parts: part 1 is a picosecond seed source, part 2 is a single grating pulse stretching system, part 3 is a multi-pulse regenerative amplifier system, and part 4 is a single grating pulse compressing system.

Part 1 is the passively mode-locking resonator by SESAM. As the upper level life-time of Nd:YVO_4 is much shorter than that of Nd:YAG, researchers used it to obtain mode locked pulses. The laser is end-pumped by an 888 nm laser diode with the gain medium is an Nd:YVO_4 crystal, and mode-locking is achieved with a SESAM. The gain material is Nd:YVO_4, 0.5% doped, with sizes of $3 \times 3 \times 5\ mm^3$, which is 1064 nm high-reflection coated on one end, 808 nm antireflection coated on the other end and is cut by 5° to avoid the etalon effect. M1 is a plano-concave total reflection mirror of $R = 300$ mm at 1064 nm and M2 is a 0° total reflection mirror at 1064 nm. M3 is an output mirror of 4% transmittance, out of which two output beams were obtained.

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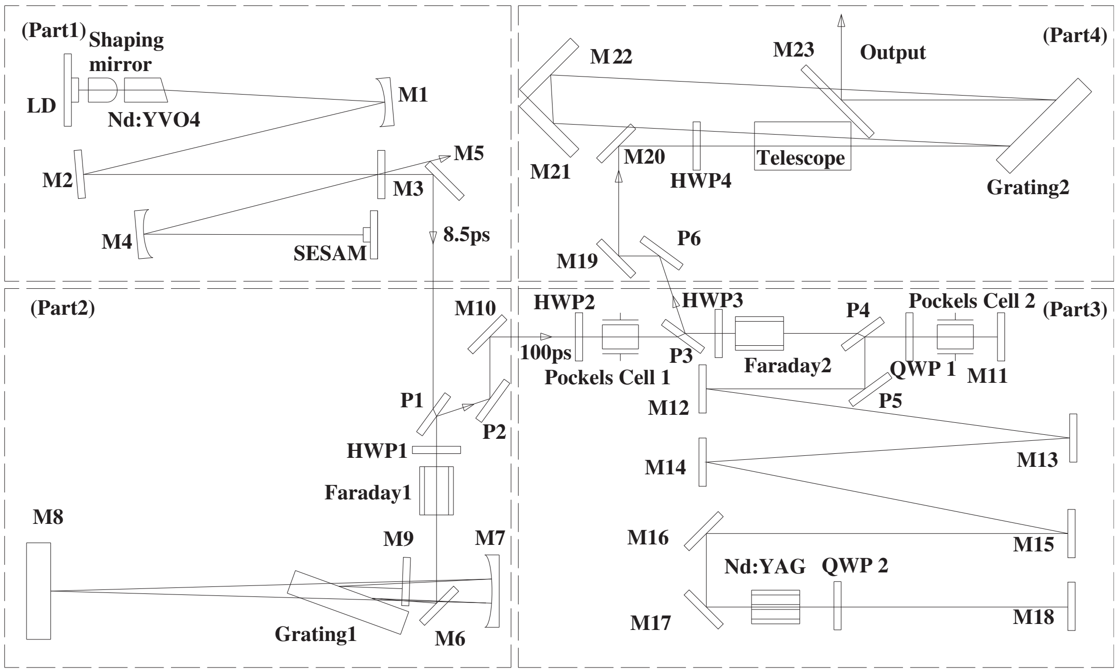

Fig. 1. Schematic of experimental setup.

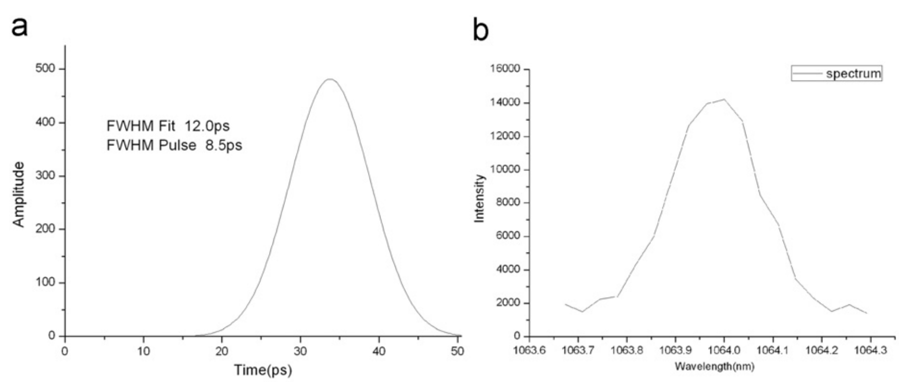

Fig. 2. Schematic of the mode-locking optical parameter. (a) The autocorrelation curve of mode-locking pulses and (b) The spectrum of mode-locking pulses.

One beam was sent to the high voltage supply of regenerative amplification as a trigger signal, and the other as a seed pulse. qM4 is a plano-concave total reflection mirror of $R=200$ mm at 1064 nm. We used a SESAM as the mode-locking device with absorption coefficient of 2% and the saturation fluence of $F_{sat}=50$ μJ/cm^2. The response time of SESAM is about 10 ps which is placed at the end of the cavity as an end mirror mounted on a brass heat sink.

Pump power is 3.8 W to assure the stability of SESAM, to obtain a seed pulse with 160 mW in average power. Fig. 2(a) is the autocorrelation curve of mold-locked seed pulse measured by a autocorrelation function analyzer from co. APE (Type No. Pulse Check-SM), showing us an FWHM of 8.5 ps. We measured the spectral width with spectrometer produced by ANDOR (type No. SR-500I-D1) and the spectral width is 0.3 nm as shown in Fig. 2(b). According to the Fourier transform limited pulse, time bandwidth product must be equal to or greater than the constant k ($\Delta\nu\Delta t \geq \kappa$). As for the Gauss pulse$\kappa=2\ln 2/\pi=0.414$; at this moment the time bandwidth product is slightly larger thanκ, so it has a bit of a chirp.

Part 2 is a single grating pulse stretching system. Reflected by M5, the seed pulse passes through the isolator which consists of Faraday1 and HWP1 and then leads its way to part2. P1 is a quartz Brewster plate, Faraday1 is a faraday rotator, and HWP1 is a half-wave plate. We selected the martinez grating stretcher which consists of a spherical mirror and a grating due to its low cost and easy adjustability [14]. The stretcher is made up of M6, M7, M9 and Grating1. M6 is a 45° total reflection mirror at 1064 nm and Grating 1 has gold coating with 1800 lines/mm. M7 is a total reflection mirror whose radius of curvature is designed according to the stretch requirement. M8 and M9 are two 0° total reflection mirrors at 1064 nm. The seed pulse reaches the grating after reflection on the M6 surface, and the included angle between seed pulse and the normal of grating surface was slightly greater than 73.3° (Littrow angle). The Littrow angle is the optimal incident angle for its minimum spot deformation; however, in order to separate the incident beam and diffracted beam we let the incident angle be slightly greater than the Littrow angle. After diffraction, the pulses are reflected from M7 (little angle of elevation) to M8 (in the focus of M7) and then reflex back to M8. Meanwhile, the pulses have a slight angle between incident light and reflected light on M4. The diffracted pulses arrive at M9 after they have diffraction on the grating, and by adjusting M9 we let the pulses in accordance with the original path and return to the optical isolator after going through the grating the fourth time. The pulses are exported from P1 after stretching.