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Self-starting mode-locked picosecond Ti:sapphire laser by using of a fast SESAM*

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A stable continuous wave mode-locked picosecond Ti:sapphire laser by using a fast semiconductor saturable absorber mirror (SESAM) is demonstrated. The laser delivers pulse width of 20 ps at a central wavelength of 813 nm and a repetition rate of 100 MHz. The maximum output power is 1.34 W with pump power of 7 W which corresponds to an optical–optical conversion efficiency of 19.1%.

Keywords: self-starting, picosecond, SESAM
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1. Introduction

In recent years, the semiconductor saturable absorber mirror (SESAM) has received considerable interest due to its saturable absorbability characteristics in self-starting mode-locked lasers. Many passively mode-locked all-solid state lasers with SESAMs have been achieved successfully, and the pulse widths range from picoseconds to several femtoseconds depending on the performance of laser gain media and the parameters of the SESAMs. For example, a novel high-power self-starting mode-locked Ti:sapphire femtosecond laser with a SESAM as self-starting element was demonstrated.[1] Its slope efficiency was 22% and pulse width was shorter than 16 fs. Even shorter pulse duration was achieved by Keller's group,[2] they realized self-starting 6.5 fs pulses from a Kerr-lens mode-locked Ti:sapphire laser with a broadband SESAM. Moreover, the self-starting dynamics of the Kerr-lens mode-locking (KLM) in a Ti:sapphire laser using an intracavity broadband SESAM was investigated experimentally.[3] Other types of passively mode-locked lasers with SESAMs based on different laser gain media also were reported such as Yb:YAG,[4] Nd:YAG,[5] Cr:forsterite,[6] and Nd:YVO4.[7,8]

Unlike KLM, passively mode-locking with SESAMs is a type of soliton-like mode-locking in which the mechanism of short pulse formation is completely of the balance of self phase modulation (SPM) and group velocity dispersion (GVD). The starting and maintenance of soliton-like mode-locking is realized by SESAMs and has nothing to do with the nonlinearity of the laser gain media，so one can release the critical adjustment difficulties of the KLM ultrashort pulsed lasers. By using a SESAM, the mode-locking operation can be achieved in nearly all the stable region of the laser cavity, leading to a promising future of manufacturing compact, economical, easily operated mode-locked lasers.

In this paper we present the results of a passively mode-locked picosecond Ti:sapphire laser with a fast SESAM, and by using an unfocusing configuration, we obtain a stable continuous wave (CW) mode-locked operation.

2. Experiment and results

The experimental set-up is shown in Fig.1.

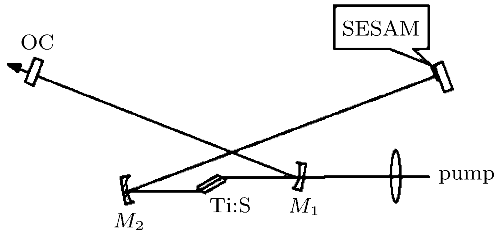

Fig.1. Schematic diagram of the experimental set-up of the Ti:sapphire laser. M1, M2 are dichroic concave mirrors with radius of curvature (ROC) of 100mm. Ti:S stands for Ti:sapphire laser crystal; OC, output coupler.

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It is a commonly used X-type configuration like other Ti:sapphire mode-locked lasers. The laser is pumped by a commercial 10 W frequency–doubled 532 nm Nd:YVO_4 pump source (Millennia-X Spectra-Physics). The pump beam is coupled into the laser crystal through a 100-mm focal-length highly antireflecting lens. The Brewster-angle-cut Ti:sapphire crystal has a length of 10 mm, and is mounted on a copper heat sink which is cooled by circulating water to keep a stable temperature of 11°C. The cavity consists of two dichroic plane–concave mirrors (M_1, M_2), a SESAM and a plane output coupler (OC). The dichroic mirrors have high transmission at 532 nm and high reflection at a centre wavelength of about 800 nm. The radius of curvature is 100 mm. The total cavity length is 150 cm which corresponds to a repetition rate of 100 MHz. In our experiment, we do not focus the laser mode with another concave mirror to the SESAM, whereas it is very common in other experiments. We find that it is easy to achieve mode-locking under specifically designed cavity configuration. At the same time, the beam quality is much better than that by using a focusing configuration due to the astigmatism of the concave mirror.

To investigate the output power characteristics of the laser, two different transmissions of the output coupler (OC) are used, one is 10%, and the other is 20%. As seen in Fig.2, the relationship between the output power and the pump power of the two different OCs is very similar, the slope efficiencies of the 10% and 20% OCs are 23.6% and 27.9%, respectively. The pump power threshold of the 10% OC is 1.54 W, whereas it is 2.2 W for the 20% OC, which is much higher than its counterpart. The maximum output power is 1.34 W with pump power of 7 W for the 20% OC, which corresponding to an optical – optical conversion efficiency of 19.1%.

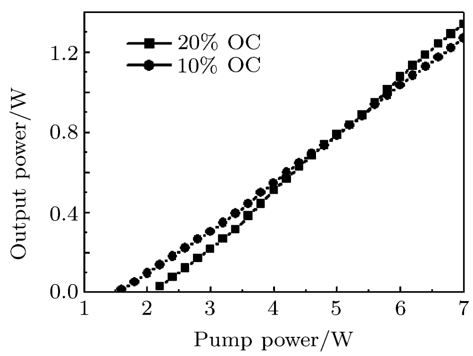

Fig.2. Dependence of the output power on the pump power measured for different transmissions of the OC.

When operating at low pump power below 4 W, it is easy to work at Q-switched mode-locking state,[9] which is mainly due to the low gain saturation flux. With an increase of the pump power and careful alignment, the laser turns to work at CW mode-locking state. Figure 3 shows the typical waveform of the CW mode-locking of the laser, which is collected by a digital real-time oscilloscope (Agilent 54642A, with 500 MHz bandwidth and 2-Gs/s sampling rate) and a fast photodiode with rise time less than 0.1 ns.

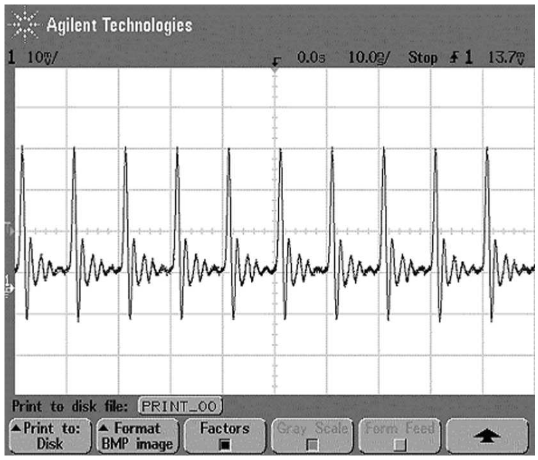

Fig.3. CW mode-locked pulse trains of the laser with the SESAM.

The measured spectrum and the intensity autocorrelation trace are depicted in Fig.4.

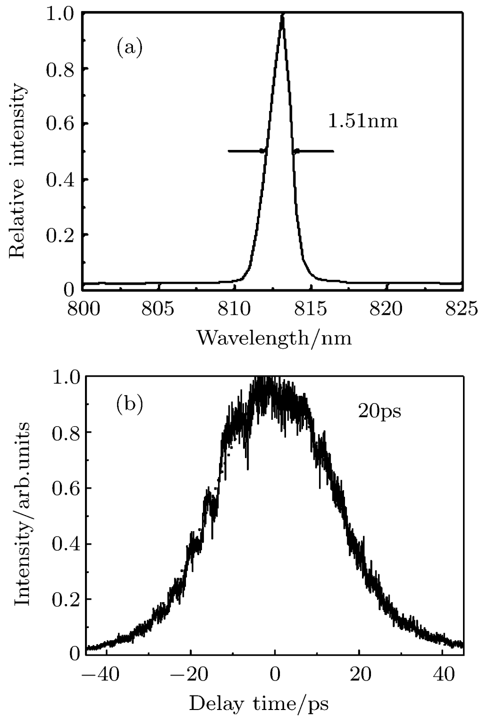

Fig.4. Spectrum (a) and intensity autocorrelation trace (b) of the CW mode-locked laser.

The full width at half maximum (FWHM) of the spectrum is 1.51 nm at the central wavelength of 813 nm, and the autocorrelation trace suggests a pulse width of 20 ps, assuming a sech^2 pulse waveform. The time bandwidth product is 12.2, which is far bigger than that of the transform limited pulse. We attribute it to the dispersion of the Ti:sapphire laser crystal because the crystal is very long and no measures are taken for dispersion compensation. Intracavity compensation with prism pairs or chirped mirrors may lead to near transform limited several tens of fs pulses.

In our experiment we utilize different SESAMs for mode-locking. Three kinds of SESAMs are tested, of which one is produced by Institute of Semiconductor, Chinese Academy of Sciences, another one is from AIST (Japan), and the last one is a product of Batop corporation (Germany). Performance of the first two pieces of SESAM are almost the same, CW mode-locking can be achieved at a pump power of about 4 W, while it is 8 W when using the one made by Batop corporation. This is mainly due to the different saturable absorbability coefficient of these SESAMs. The bigger the saturable absorbability coefficient, the larger the mode-locking power density required.

We also have investigated the pulse characteristics after tightly focusing on the SESAM by a concave mirror with ROC of 100mm, to our disappointment, the spectrum and power stabilities are extraordinarily bad, not mention to measure the pulse width. We believe this is induced by the thermal noise and over saturation of the SESAM. At the same time, the average power reduced considerably due to the great change of the laser cavity mode.

3. Conclusion

In conclusion, we have developed a passively mode-locked Ti:sapphire laser with a fast SESAM, CW mode-locking with 20 ps pulse trains is achieved, the maximum output power is 1.34 W with slope efficiency of 27.9%. Further progress to directly amplify these picosecond pulses is undergoing, which may lead to a reliable multiple hertz high–energy light source.

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