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Advanced 20 TW Ti:S laser system for X-ray laser and coherent XUV generation irradiated by ultra-high intensities*

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Abstract

In order to develop a high repetition rate X-ray lasers, the longitudinal-pumped transient collisional excitation (TCE) X-ray laser is one of the most effective pumping schemes. The high directive Ni-like Mo 18.9 nm soft X-ray laser pumped by modest laser energy has already been demonstrated by using the tabletop size Ti:sapphire/Nd:glass laser system that delivering energy of 150 mJ in 475 fs at the center wavelength of 1054 nm. The total energy in the pre-pulse and the main pulse was 150 mJ, which will make possible multi-hertz operation. To pursue the high repetition rate of the laser-driven TCE X-ray laser, we have designed a new 20 TW Ti:Sapphire laser system (600 mJ, 30 fs, 10 Hz). Special attention was paid to improve the contrast ratio, control of pulse shape as well as phase by an acoustic optic programmable dispersive filter (AOPDF) and 1 kHz preamplifier. Preliminary data have shown good laser characteristics. As the preliminary experiments, we have investigated high order harmonics generation from low-density laser plasma by using the solid target irradiated by a femtosecond laser pulse. The highest order was the 51st. harmonic at wavelength of 15.61 nm.

Keywords: High density plasma; High field physics; High order harmonics generation; TCE longitudinally X-ray laser; Ultra-fast laser

1. INTRODUCTION

So far, extensive studies have been devoted to develop coherent X-ray and extreme ultraviolet (XUV) laser generation, which are expected to open new fields in physics, chemistry, and biophysics (Neumayer *et al.*, 2005; Lan *et al.*, 2004; Bellini *et al.*, 2004; Merdji *et al.*, 2004; Morlens *et al.*, 2004) . Development of high repetition rate X-ray laser is an important factor for a real application experiment. Recently, capillary discharge (Benware *et al.*, 2001) and optical-field ionization schemes (Sebban *et al.*, 2002) have achieved the high repetition rate X-ray laser generation. The longitudinal-pumped TCE X-ray laser and XUV generation from femtosecond laser produced solid surface plasma were studied in our group (Ganeev *et al.*, 2004; Ishizawa *et al.*, 2002; Kuroda *et al.*, 2002*a* or *b*; Li *et al.*, 1998; Ozaki *et al.*, 2002*a–d*). Since the development of high directive Ni-like Mo 18.9 nm soft X-ray laser pumped longitudinally by only total 150 mJ laser (Ozaki *et al.*, 2002*a–d*), there has been strong interest in making tabletop soft X-ray laser pumped by such modest energy and equipped with qualified laser characteristics. In order to develop the high repetition rate of the laser-driven TCE X-ray laser, the longitudinal-pumped TCE X-ray laser is the most effective pumping scheme. In our demonstration, the new aspects of pulse shape control (energy and duration of pedestal), and concave electron density are discussed and compared with simulations of X-ray laser propagation (Ozaki *et al.*, 2002*a–d*). Recently, Keenan *et al.* (2003) reported a different scheme using traveling wave grazing incidence pumping. They showed the Ni-like Mo 18.9 nm lasing pumped by total 300 mJ (main pulse 70 mJ) of which energy is 1/20 of usual transverse pumping. Nickels also reported on the success to reduce the pumping energy by a factor 1/5–1/6 by changing

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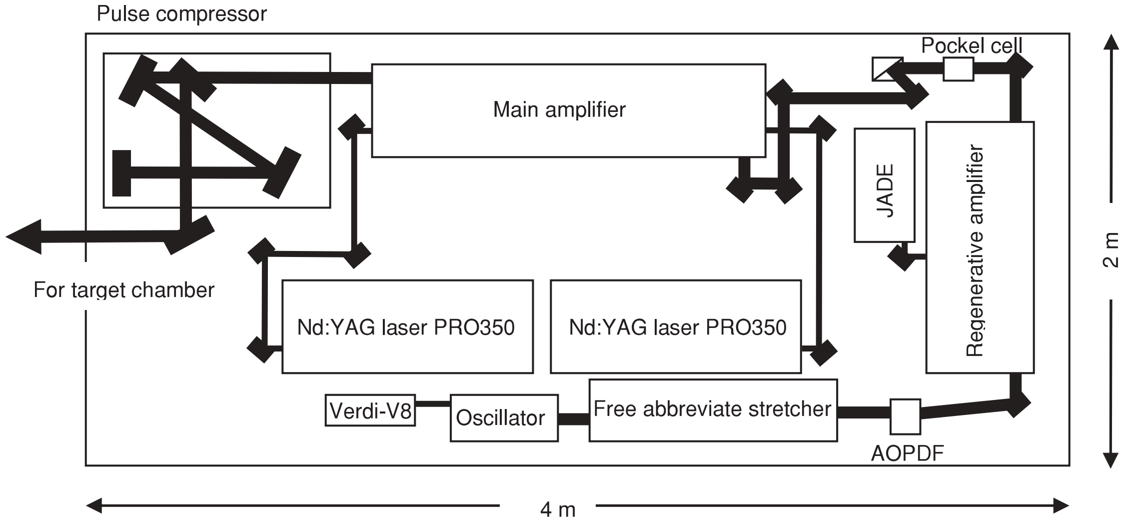

Fig. 1. Layout of the 20 TW Ti:Sapphire laser system. The system consists of a femtosecond oscillator, a free abbreviate stretcher, an AOPDF, a kHz regenerative amplifier, a 6-pass main amplifier, and a vacuum pulse compressor.

the shape of pump pulses, including its shape, and amplitude of pedestals (Janulewicz *et al.*, 2004). It is an important factor of the pedestal, contrast ratio, and phase of laser pulse to generate the TCE X-ray laser.

In this paper, we report the investigation on the longitudinally pumping TCE X-ray lasers and high order harmonic generations from solid surface of plasmas. According to results from our investigations, we have designed a new 20 TW Ti: Sapphire laser system (600 mJ, 30 fs, 10 Hz) and describe the necessity of its new technology for high repetition X-ray lasers. As the preliminary experiments, we investigated high order harmonics generation from low-density laser plasma by using the solid target irradiated by a femtosecond laser pulse. We show the preliminary results of this experiment.

2. NEW 20 TW LASER SYSTEM DESIGN AND PERFORMANCE

Layout of the 20 TW Ti:Sapphire laser system (Ultra-laser Inc. Beijing) presently under construction at our laboratory is shown in Figure 1. The whole of tabletop 20 TW Ti:Sapphire laser system consists of a femtosecond oscillator, an Offner-type stretcher, an AOPDF, a kHz regenerative amplifier, a 6-pass main amplifier, and a vacuum pulse compressor. Special attention was paid to improve the contrast ratio and control of pulse shape, and phase by adaptive AOPDF and 1 kHz preamplifier. Preliminary data have shown good laser characteristics. The femtosecond oscillator is pumped by a compact solid-state diode-pumped, frequency-doubled Nd:Vanadate (Nd:YVO_4) laser (Verdi-V8, Coherent Inc.) that provides single-frequency

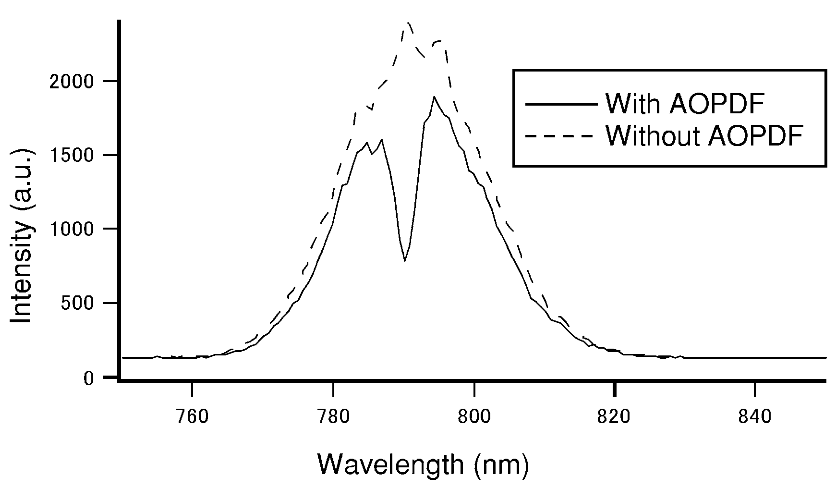

Fig. 2. Spectra property of the laser pulse from AOPDF. Using the AOPDF, the spectra shape can be controlled.

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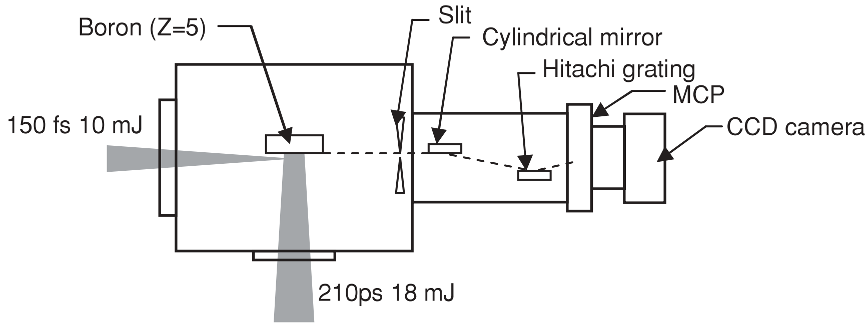

Fig. 3. Schematic of experimental setup on high order harmonic generation. The delay time between pre-pulse and main pulse was 18 ns. The main pulse was focused onto the position 0.1 mm above boron target.

green (532 nm) output with maximum power of 8 W. The oscillator with 1.1 W output power and pulse width of 30 fs pulse duration at 83 MHz repetition rate is obtained for a 6.5 W pump power of the Verdi-V8. The FWHM spectral bandwidth of 48 nm is obtained for the center wavelength of 800 nm. The short pulse from the oscillator is stretched to 300 ps by the Offner-type stretcher. In order to control the dispersion and shaping of the laser pulse, the AOPDF (800 WB-AT, Fastlite, Inc.) was installed after the Offner-type stretcher (Monmayrant *et al.*, 2003). The AOPDF can control the pedestal and shape of the laser pulse in X-ray and XUV laser experiments. Figure 2 shows the laser spectrum shape controlled by the AOPDF. To improve the stability of laser and contrast ratio, the regenerative amplifier was operated at 1 kHz repetition rate. This also allows a beam pattern with high quality. The stretched pulse is amplified to 3 W by the 1 kHz Ti:Sapphire regenerative amplifier which pumped by a diode-pumped laser providing average power in excess of 20 W at second harmonics wavelength of Nd: YLF (JADE, THALES LASER). The amplifier with ~2.3 W output power is obtained with 15 W pump power of JADE. The amplified pulse from the regenerative amplifier, change the 1 kHz to a 10 Hz repetition rate by using the Pockels cell. The 10 Hz laser pulse from the Pokels cell is amplified to 1.2 J with the 6-pass Ti: Sapphire amplifier pumped by using two Nd: YAG lasers (Spectra Physics PRO350), which provides pump laser energy of 1.4 J in 8 ns pulse at a wavelength of 532 nm. The pulse compressor is composed of two gratings of 1800 lines/mm in a vacuum chamber. The compressed pulse width is 30 fs by measuring the second order auto-correlation. In our estimations, the laser would generate more than 20 TW after compression.

3. HIGH ORDER HARMONIC GENERATION FROM LOW DENSITY LASER PLASMA

Experimental setup is shown in Figure 3. The 210 ps laser pre-pulse was focused onto the boron ($Z = 5$) target by using the spherical lens. After that the femtosecond main pulse (150 fs) was focused from longitudinal direction on the pre-plasma. The diameter of focal spot of pre-pulse was

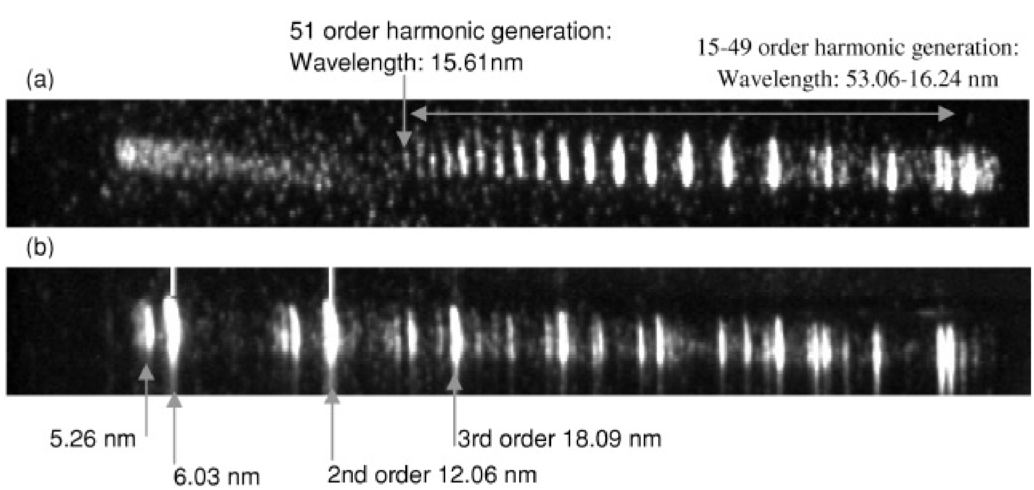

Fig. 4. (**a**) Harmonic spectrum from boron target plasma. The harmonic order between 15th and 51st at the wavelength from 15.61 nm to 53.06 nm were observed. (**b**) Soft X-ray generations from Boron laser plasma were obtained.

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0.6 mm. The delay between main pulse and pre-pulse duration was 18 ns. The pump energies of the pre-pulse and main pulse were 18 and 10 mJ, respectively. The generated harmonics were measure by a Hitachi 1200 grooves/mm flat-field soft X-ray spectrometer (Kita *et al.*, 1983.) equipped with micro channel plate (MCP) and CCD camera.

Figure 4 shows the intensity trace of high order harmonic generation from boron laser plasma. The highest order was the 51st at the wavelength of 15.61 nm. We measured between 3rd 11th harmonics by using ACTON VM-502 vacuum monochromator. Only odd harmonics were obtained in this experiment. The physical mechanism is now investigated and will be published elsewhere.

4. SUMMARY

In order to develop the high repetition rate X-ray laser, the longitudinal-pumped TCE X-ray laser is one of the most effective pumping schemes. We have described the results of longitudinally pumping TCE X-ray laser and high order harmonic generation from the solid surface plasma. The most important factor of the longitudinally pumping X-ray generations is concave density profile of pre-plasma and pedestal of the pumping laser pulse. To pursue the high repetition rate of the laser-driven TCE X-ray laser, we have designed a new 20 TW Ti:Sapphire laser system (600 mJ, 30 fs, 10 Hz). Special attention was paid to improve the contrast ratio and control of pulse shape and phase by adaptive AOPDF and 1 kHz pre-amplifier. As the preliminary experiments, we have investigated high order harmonics generation from a low density laser plasma by using the solid target irradiated by a femtosecond laser pulse. The highest order was the 51st harmonic at wavelength of 15.61 nm. The physical mechanism is now investigated and will be published elsewhere.

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