SILEX-I  330-TW, 30-fs Ti:Sapphire Laser System

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Abstract. The evolution of Ti:Sapphire laser system named SILEX-I(Super Intense Laser for Experiments on eXtreme ) with the peak power of 330 TW is presented [2]. SILEX-I includes the femtosecond oscillator, the Offner stretcher, the regenerative amplifier, the pre-amplifier, the main amplifier, the power amplifier, the vacuum compressor and the vacuum target chamber. SILEX-I has three order output power: 6 TW, 30 TW, and hundreds of terawatt. And there are corresponding target chamber at the different power output for the different physical experiments. Some technology are added to the laser system to decrease the deleterious effects such as gain narrowing, gain shifting, high order dispersion. Now the peak power with 330 TW is obtained, and the pulse width with 29.8 fs after the compressor. The focal intensity is near 1×10^{21} W/cm^2 with the focal spot of 5.7 µm.

1. Introduction
Over the past ten years, high power ultrashort pulse Ti:sapphire laser technologies have rapidly been developed and a number of large facilities have been built for strong-field studies[1,2,3,4]. A multi-hundred-terawatt Ti:sapphire laser facility named SILEX-I (Super Intense Laser for Experiments on extremes) has been developed at Research Center of Laser Fusion. The laser consists of three stages with 6-TW, 30-TW, and hundreds-TW output powers, each having a compressor and a target chamber to meet different needs from diverse applications. New optical design considerations and technologies, such as active spectral control, super-Gaussian beam relay-imaged propagation, and spatiotemporal adjustment of compressor gratings, have been integrated and demonstrated successfully in the system. to ensure a good alignment of compressor gratings, a diagnostic device was suggested and set up with both temporal and spatial monitoring of the pulses. Near-diffraction-limited far fields were measured and pulse durations of 35 fs were obtained with a Fastlite-fabricated AOPDF for spectral compensation.

2. Description of the laser system
The SILEX-I laser system (see Fig.1) have three stages output[6,7]. The first stage is based on a commercialized 3-TW laser (Alpha 10, Thales). The oscillator works at 76-MHz with an output power of 400-mW and pulse duration of 20fs corresponding to a bandwidth of 51 nm. The stretcher is in an all-reflective triplet Offner configuration using a 1200 gr/mm grating. After the stretcher, the seed pulses are amplified by a regenerative amplifier, a multipass preamplifier and a multipass amplifier to produce 300 mJ pulses. The compressor is in a two-grating, double-pass configuration. The groove density is 1200 gr/mm too and the dimensions are 100 x 150 and 220 x 150,
respectively. The stage compressor could originally compress the pulses to 50fs to 60fs. To compensate for the spectral gain narrowing in the regenerative amplifier, a programmable acousto-optic dispersive filter (AOPDF, “DAZZLER”, Fastlite, France) was installed between the oscillator and the stretcher. With the AOPDF, 30 fs, 5 TW pulses were produced.

The second stage can output 30 TW laser pulse. The 30 TW stage amplifier is a four-pass, relay-imaged configuration with a Ti:sapphire rod 3-cm in diameter and 1.5 cm long cooled by water. The pump beams of 8 J at 0.53 µm from six 10 Hz YAG lasers are relay-imaged onto both faces of the crystal rod within an area 2-cm in diameter. The injection beam from the previous amplifier is first spatially shaped to a supper-Gaussian profile to increase the beam filling factor across the crystal and expanded from 1cm to 2cm in diameter and relay-imaged to the crystal rod for each pass and then to the front face of the first grating in the compressor to avoid diffraction ripple growth. To limit aberrations of the optics for relay-imaging, a 4f system is configured within a vacuum chamber with reflective concave mirrors. The compressor is also in a two-grating, double-pass layout with the same groove density but a bigger size of 165 mm x 220 mm. This stage is able to deliver 20 to 30 TW, 30 fs pulses to targets.

Figure 1 Layout of SILEX-I

The final stage is also four-pass configured with a Ti:sapphire rod 8 cm in diameter and 1.5 cm long. The pumping energy of up to 90 J is provided by a newly built Nd:glass laser facility. To suppress the ASE across the large aperture of the crystal rod, the periphery of the rod is cladded with an index-matched thermoplastic polymer material[1,2]. As the beam diameter is expanded to 140 mm to meet the grating damage threshold, the compressor has to be designed in a four-grating, single-pass geometry. The grating density is 1480 gr/mm and the dimensions are 220 mm x 410 mm. As the first step for commissioning, 29.7 fs pulses at power of more than 200 TW were obtained when the pump laser energy is 49 J.

3. Spectral shaping with AOPDF

For femtosecond-pulse Ti:sapphire laser systems a broad bandwidth of laser pulse must be maintained to obtain short pulses. We have introduced an AOPDF[5,6] between the oscillator and the stretcher. The two principal functions of AOPDF are compensation of spectral gain narrowing and correction of high order phase distortions. With a Gaussian-hole amplitude modulation centered at 790 nm, the bandwidth of the output laser pulses was broadened from 24 nm to 44 nm at the first stage output end, as shown in Figure 2, and then the pulse duration was correspondingly shortened to about 30 fs. We checked the output spectrum for each stage, no significant gain narrowing was observed for the rest of the optical system due to the small gain of the main power amplifiers. At last, a bandwidth of 44 nm and pulses of 29.7 fs were measured at the final stage output.
4. Effects of gratings parallelisms errors on focal spots

Experiments shows that alignment errors of grating groove parallelisms could bring an angle dispersion component leading to elongated far fields. Therefore, to ensure a good alignment of the compressor gratings a diagnostic device was suggested and set up with simultaneous monitoring both pulse durations and focal spots. An excellent alignment was realized to get both near-diffraction-limited far fields and near-Fourier-transform pulse durations of 29.7 fs.

The compressed beam is split for simultaneous monitoring of both temporal and spatial behaviors. The adjustment was conducted for low-energy pulses of 150 mJ at 10 Hz with the first stage in operation only. The focal spots were measured with both an f/2.5 lens outside the target chamber as shown in the figure and an f/4.2 OAP inside the chamber. A focal spot of 8 µm (FWHM) was measured with the f/4.2 OAP. We checked the thermal effect of the second stage crystal on far fields with nonsynchronized 10 Hz full-energy pumping and no degraded beam quality was observed. Also we do not expect an apparent change in far-field dimensions, because the B-integral is estimated still small even at full-energy operation.

Regarding the effects of grating groove parallelisms on far-fields, we have analyzed how they are related. If the groove orientation of one of the compressor gratings is miss-aligned with a rotation in its surface plane about the normal, a dispersive angle component will be produced in the direction perpendicular to the temporal compression axis, leading to an additional beam divergence to that direction along which the far fields are elongated. As given in Figure 3, the elongated focal spot measured after the final compressor is about 30 µm in the long axis, three times of the dimension in the short axis direction, which corresponds to a divergence angle of 120 µrad for the employed lens focal length of 25 cm. In our compressor, the dispersive angle of the 40 nm spectral bandwidth (FWHM) is about 70 mrad. The rotation angle can be simply estimated to be 1.7 mrad. To obtain a round far field here the divergence angle of the beam along the long axis must be reduced to at least 30 µrad. The accuracy of grating rotation angle must, therefore, be controlled to less than 0.5 mrad. Affects of
grating alignment errors on pulse compression and beam far fields for a given compressor have to be analyzed carefully, but it seems that the requirement of grating alignment accuracy for far-field control can not be ignored and it might be more restrictive than that for pulse compression, in particular, in picosecond-pulse laser systems. Simultaneous monitoring technique for temporal and spatial beam behaviors is even more important to grating tiling technique development for high-energy high-power short pulse laser facilities for fast ignition applications.

5. Summary
A multi-hundred-terawatt Ti:sapphire laser system has been built with a number of spatiotemporal beam control measures. An AOPDF has effectively compensated for the gain narrowing to shorten the pulse duration from original 50 fs to 29.7 fs. It has been found and explained for the first time that alignment errors of compressor grating parallelisms lead to elongated focal spots of beams. A precise compressor adjustment technique with simultaneous monitoring both temporal and spatial behaviors has been proposed and used successfully.

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