Status of the SG-III Solid-state Laser Facility

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Abstract. SG-III laser facility beam begins with a nanojoule energy laser pulse from the master oscillator and a fiber front-end system that can provide a variety of pulse shapes suitable for a wide range of experiments. The chirped pulse stacking method is used in the front-end system to generate arbitrarily shaped pulse with a rise time less than 50ps. The system stacks a set of 100-ps chirped pulses in fiber time-delay lines to obtain a 5-ns flat-top pulse with a spectral bandwidth of 1.2nm. The pulse is then transported to preamplifier modules under the middle of CSF for amplification and beam shaping. There is a total of 48 preamplifier modules on SG-III, each feeding a single laser beams. The main amplifier column of 4 high by 2 wide has been chosen as a module and the clear optical aperture is 40cm×40cm. Small PEPC are chosen for system isolation and beam can be rotated by 90 degree in U-turn beam reverser located in the middle of TSF. After main amplifier, beams are subsequently redirected to final optics assembly in switchyard and are focused on the center of the target chamber with the diameter of 6m.

1. Introduction
The SG-III laser facility, which is one of the most important parts of the China ICF Program, is now under construction in the Research Center of Laser Fusion (LFRG) of China Academy of Engineering Physics (CAEP). The engineering design of the facility has already been completed and the construction of building housing the laser system will be completed in late 2007. SG-III will be used to investigate target physics before ignition for both direct-driven and indirect-driven ICF [1] and will be operating in 2012. The facility is designed to provide up 48 energetic laser beams (six bundles) and laser energy output of 150-200kJ (3ω) for square pulse of 3ns. If fast ignition is workable, SG-III will couple with a PW laser of tens KJ to demonstrate fast ignition.
This paper provides a detailed look the SG-III facility and the laser system.

2. Description of SG-III laser facility
The SG-III laser facility is shown schematically in Figure 1. The entire laser system and target area are housed in an environmentally controlled building. The building is mainly divided into three parts, which are main experimental area, target area and optics assembly area. The main experimental area,
approximately 24 meters wide and 121 meters long, is the core area where the main control room, front-end system, preamplifier, main amplifier and capacitor reside. The optics assembly building is located at one side of building for assembling and installing the precision optical and opto-mechanical components that make up the SG-III laser system. All areas are one level except for the target area, which have five floors and in the central core where elevated floors provide space for facility utility equipment.

3. Laser description

SG-III’s laser system, the heart of the facility, is comprised of 48 high-power laser beams. For inertial fusion studies, these laser beams will produce 180,000 joules (approximately 60 trillion watts of power for 3 nanoseconds) of laser energy in the near-ultraviolet (351-nanometer wavelength). The system is shown schematically in Figure 2. It consists of a number of subsystems including front-end, preamplifier, main amplifier, target diagnostic unit, beam control and diagnostic unit, and the integrated computer control system.

3.1. Front-end system

The front-end system mainly consists of four parts: 100-ps standard pulse unit, pulse shaping unit, fiber transport/amplify unit and power amplifier unit.
The pulse begins in a passively mode-locked Yb-fiber laser which generates a train of stable 200-fs pulses at the central wavelength of 1053 nm with a bandwidth of 10 nm. A polarization-independent waveguide modulator is used as the pulse selector to decrease the pulse repetition rate from 20 MHz to 1 Hz. The selected pulses are coupled into a Yb-fiber amplifier with a ~1 nm fiber grating filter centering at 1053 nm, and after passing through a chirped fiber grating the amplified pulse is stretched to ~100 ps called standard pulse.

These ~100 ps standard pulses are input into a compact pulse shaping system based on temporal stacking of pulses. The system can generate shape-controllable pulses with fast rise time of 50 ps with a spectral bandwidth of 1.2 nm. The pulse stacker, the main part of the system, is made up of eight 4-channel modules, each of which consists of a 1×4 divider, a 4×1 multiplexer and four variable optical attenuators (VOA). By using another two pairs of 1×4/4×1 and one pair of 1×2/2×1 fiber couplers, these modules are arranged in a parallel configuration which constructs a 32-channel pulse stacker, as shown in Figure 3. Since a number of fiber dividers, multiplexers and VOAs are used in the stackers that introduce a relatively high loss, two successive Yb-fiber amplifiers are adopted to amplify the shaped pulse.

3.2. Preamplifier system

Each of the 48 pulses from the Front-end enters the Preamplifier system on a single-mode optical fiber, where it is amplified first by a repetition amplifier module, then by a LD-array pumped thin-slab amplifier and a double-pass rod amplifier. After aligned and isolated, the pulse from the Front-end system is first injected into the high-gain amplifier where experiences a gain that raises its energy from ~10 μJ to ~10 mJ. After being switched out of the high-gain amplifier, the pulse traverses a spatial shaping module that transforms the Gaussian spatial shape to a profile that is designed to compensate for the spatial nonuniformity of the gain throughout the rest of the laser. The ability to accurately shape the spatial profile allows the SG-III to produce beams at the output of the system that have a flat irradiance distribution across the central part of the beam.

After passing through the beam-shaping module, the pulse is injected into thin-slab amplifier pumped by LD array, where the pulse makes ~12 round trips and improves its energy from ~10 mJ to ~1J. Then the pulse makes double pass through a flashlamp-pumped rod amplifier, yielding a nominal net energy gain of 5. The overall energy gain of the preamplifier system is of the order of 10^6.

3.3. Main amplifier system

Figure 3 shows a schematic of a single beamline of the main laser. The beam from the preamplifier is injected into the main amplifier from the pinhole of the cavity spatial filter (CSF). In this way, the total gains of the main amplifier can be increased. It also can ease the pressure to system isolation and simplify the process of alignment. The beam traverses the main amplifier (MA), reflects off a deformable mirror that is used to correct wavefront distortions, and then goes through the MA and CSF again. It then passes through the booster amplifier, and enters U-turn beam reverser through the inject pinhole located near the focal plane of the transfer spatial filter (TSF). The U-turn beam reverser adopts an 80 × 80mm² tightly packed plasma-electrode Pockell cell (PEPC) to isolate the system. This kind of switch works efficiently in the technical integrated line (TIL) of SG-III.

The amplifiers, with 16 glass slabs per beam, are arranged with 9 slabs in the main amplifier section and 7 slabs in the boost amplifier section. The laser glass slabs, measuring 46 cm × 81 cm × 4 cm, consist of neodymium-doped phosphate glass.

3.4. Final optics assembly

After the TSF, the main pulse proceeds to the switchyard where four or five transport mirrors direct it to one of a number of final optics assemblies (FOAs) symmetrically located about, and mounted on, the target chamber. Each FOA contains a 1w vacuum window, focal-spot beam-conditioning optics, three frequency conversion crystals to reach 351 nm wavelength, a focusing lens, a beam sampling
grating (BSG) that serves as a beam diagnostic pickoff to measure energy and power, and a 1–3 mm thick disposable debris shield.

The FOA combines a number of critical functions into a single compact package: frequency conversion, focusing, color separation, diagnostic beam sampling, vacuum isolation and debris shielding. The frequency converter is a cascade broadband third-harmonic generation design consisting of a 1.2-cm thick Type-I KDP doubler and two 0.9-cm thick Type-II KDP triplers with a special angle offset respectively. The multicrystal design is optimized to achieve >70% energy conversion efficiency and ~1 nm conversion bandwidth at a 1w drive irradiance of 2 GW/cm². A fused-silica final focus lens is of wedged design to provide color separation at the target via lateral dispersion. Two focal spot beam conditioning techniques: phase plate and smoothing by spectral dispersion (SSD) are applied in the SG-III. All components inside the FOA are operated at a pressure of 1000 Pa with clean dry air, separated from the argon environment of the beam transport system by a 1w pressure window, and the hard vacuum of the target chamber by a 1-cm thick gas-seal debris shield.

Figure 3. Schematic of one of the 48 beamlines in the SG-III facility

Figure 4. Schematic layout of the final optics assembly on the SG-III

4. Summary

The SG-III facility/beampath has been successfully designed, and the construction housing the laser system is going to completed at the end of this year. During the next four years, a relatively small staff of engineers, designers, and construction staff will assist in completing this project. Based on the success of checking the key systems and unit techniques, such as multi-segment amplifiers, the whole solid-state fiber front-end technique etc on the technical integrated line of SG-III, we have high confidence in the project.

References
[1] John D. Lindl, et al., PHYSICS OF PLASMAS, Vol. 11, No. 2, 2004, 339–491