The GEKKO XII-HIPER (High Intensity Plasma Experimental Research) System Relevant to Ignition Targets

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Abstract To test high gain targets surrogated in the planar geometry, we have constructed a new experimental system (HIPER) which provides the high ablation pressure with a uniform irradiance profile. These performances were achieved by bundling twelve beams of the existing GEKKO XII into a *F*/3 focus cone. The partially coherent light is introduced for the beam smoothing of a green foot pulse consisting of three beams, and the three-directional smoothing by spectral dispersion is utilized for residual nine beams delivering a blue main drive pulse. The detail of design concept and results of initial activation of this system are reported.

1. Introduction

In the inertial confinement fusion research, two big projects, *i.e.*, the NIF at Lawrence Livermore National Laboratory (USA) and the LMJ at CEA (France), have been started for the fuel ignition with the indirect-drive scheme. As for the direct-drive scheme, extensive experiments on the spherical target implosion and on the hydrodynamic stability are being carried at the OMEGA up-grade (University of Rochester, USA) and at the NIKE (NRL, USA). Also the GEKKO XII is a flexible laser system which is being used for comprehensive experiments on the direct-dive implosion, the indirect/direct hybrid drive implosion and hydrodynamic stability issues [1]. To evolve this experimental data base and relevant theoretical analyses to more detailed discussion of the design of high gain target, the further systematic investigation is needed for entropy-controlled targets which are uniformly accelerated (nonuniformity level less than a few %) with high ablation pressure (50~100 Mbar).

For this purpose, the laser irradiation system in the target room II of GEKKO XII has been entirely rearranged from a two-side illumination geometry to a one-side bundle configuration. This new laser program, HIPER (High Intensity Plasma Experimental Research), consists of a front end, a beam switchyard in the pre-amplifier chain, beam transport optics, frequency converters, final focusing optics and beam diagnostic tools. Furthermore another beam line has been prepared for the x-ray backlighting measurement. In this paper the design concept and initial activation of HIPER system are reported.

2. Design Concept and Focusing Geometry of HIPER System

A schematic layout of HIPER irradiation optics is shown in *FIG. 1(a)*. Twelve beams of 32-cm diameter are assembled onto bundled final mirrors. Three of most outer beams are used as a foot pulse to pre-compress a planar target, and the residual nine beams are used for the main drive. The foot pulse is frequency-converted to the second harmonic (green, wavelength, λ = 527 nm) by a quadrature doubling scheme [2] using type II KDP crystals. On the other hand, the main drive pulse is converted to the ultra violet (UV, λ = 351 nm) by the type II/type II (KDP doubler /tripler) configuration. Then the beam bundle subtends a *F*/3 cone angle which consists of twelve *F*/15 focusing lenses. A kinoform phase plate (KPP) is installed

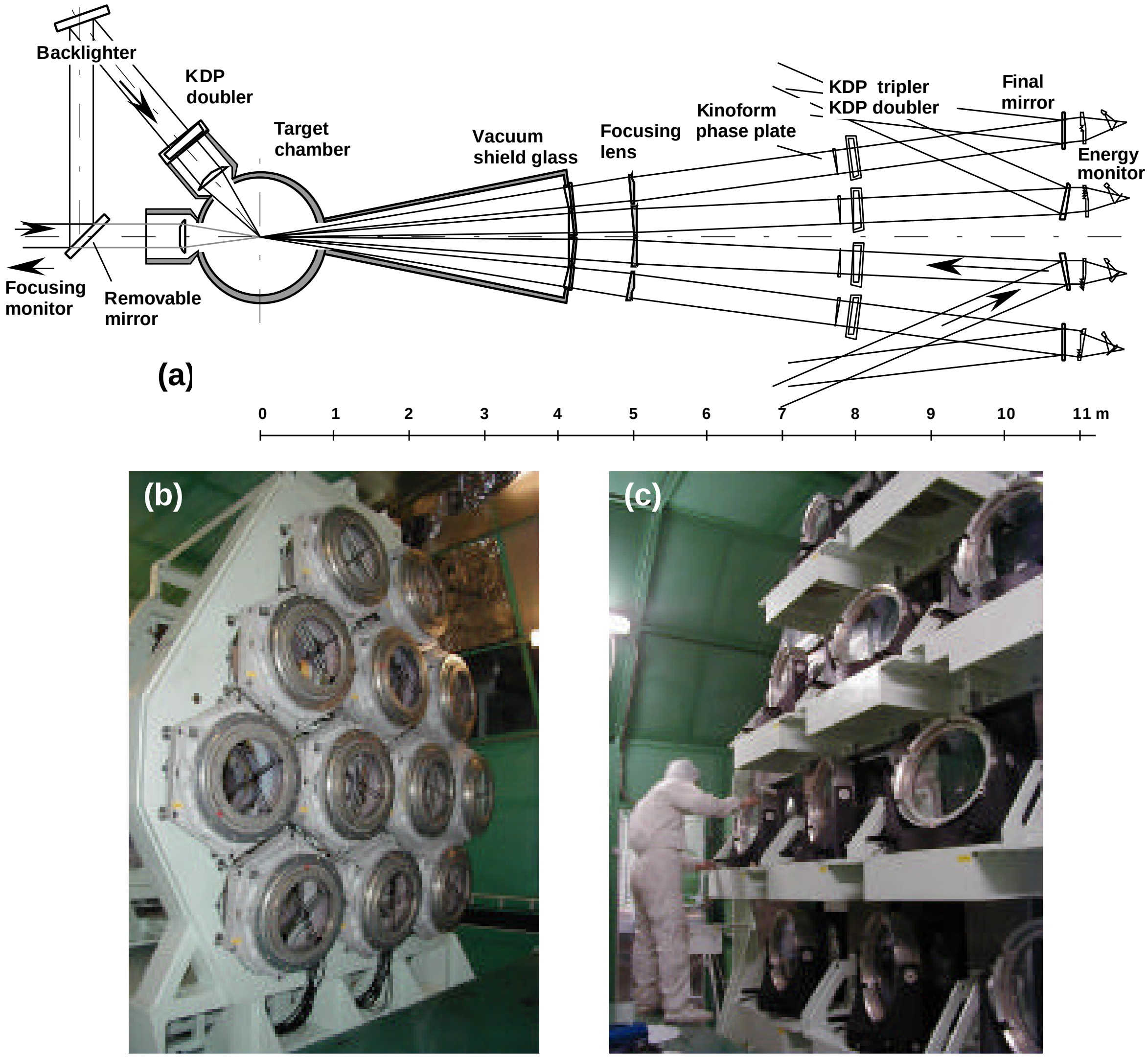

FIG. 1 HIPER focusing system. (a): schematic optical arrangement, (b): arrayed KDP cells, and (c): final mirror bundle.

between the KDP crystal and the focusing lens of each beam in order to obtain a flat-top irradiance profile of ~600-μm diameter. Irradiation intensities on a target are designed to be 5×10^{12} W/cm^2 at the foot pulse and 4×10^{14} W/cm^2 at the main pulse, respectively. Such a combination of green/UV pulses provides us the following advantages. 1) The thermal smoothing effect in the ablation plasma is more effective for the green laser than the UV laser. 2) KDP doubler is appropriate for the broad-band laser. Therefore, the partially coherent light (PCL) [3] is the most favorable approach of the beam smoothing for the foot pulse. 2) UV laser is beneficial to achieve high ablation pressure, and the uniform irradiation of the main pulse is ensured by using the beam smoothing by spectral dispersion (SSD [4]).

3. Beam Smoothing Technologies

3.1 PCL Foot Pulse

In addition to an existing PCL generator (0.6-nm fundamental spectral width, two-dimensional spectral dispersion) [5], new optics have been installed in the front end to respond flexibly to the variety of plasma experiments. In the new PCL generator, the broad band is obtained using the nonlinearity of optical fiber. The 16-GHz cross phase modulation (XPM) in a polarization-preserving single-mode optical fiber is induced by the interference between an output of the Q-switched Nd:YLF oscillator and its Brillouin-shifted component backscattered from a multi-mode silica fiber. The spectral width is controlled within a range ≤ 2 nm by changing the modulation depth. The phase of this frequency-modulated (FM) beam is spatially and temporally randomized by passing through a multi-mode optical fiber, then the one-dimensional angular spectral dispersion (~6 mrad/nm at the front end, 65 µrad/nm at KDP doubler) is introduced into this PCL.

The time averaged characteristic of PCL beam smoothing obeys a scaling of $(\tau_c/T_{av})^{1/2}$, where τ_c is the coherence time and T_{av} is the averaging time. The type-II KDP doubler covers a wide spectral range (*i.e*., $\tau_c \approx 1$ ps). However, to enhance the smoothing speed and to improve the irradiation uniformity at early stage ($T_{av} \approx \tau_c$), it is desired to superpose many independent far-field patterns (FFPs) on the target plane. A method to increase the effective beam number is to create two different far-field patterns having light polarization perpendicular to each other (polarization smoothing).

To realize the pure polarization smoothing, perpendicularly polarized two PCL beams, of which spectral dispersions are also orthogonal to each other, are generated. Then they are synthesized (2-D PCL: 2-directionally dispersed PCL), and each near-field image on a diffraction grating is relayed onto a final focusing lens at the target chamber, so that the spectral dispersion direction is aligned parallelly to the extraordinary axis of either KDP crystal. If 2-D PCL is frequency doubled with the quadrature scheme, the birefringence of 1.2-cm thick KDP crystal causes 1.3 ps time delay ($>\tau_c$) between two orthogonal polarization components, and thus we can expect instantaneous superposition of two independent speckle patterns.

3.2 SSD Main Drive Pulse

The SSD beam is also generated with a manner similar to PCL except that the phase modulation is kept periodic. We adopted a new type of SSD which has three-directional spectral dispersion (3-D SSD), and it gives a better performance in irradiation uniformity compared with the usual two-orthogonal dispersions [6]. Modulation frequencies were 16 GHz (fiber phase modulation same as that of PCL), 5.5 GHz (bulk electro-optic modulator, EOM) and 9.4 GHz (EOM). Bulk EOMs are made of $LiTaO_3$ crystal which is periodically domain inverted to compensate the velocity mismatching between the light and the co-propagating microwave which is fed into a micro strip line resonator coated on the crystal. These three modulators are arranged in series, and each modulator is followed by a set of diffraction grating and an image rotating prism. As a result, we obtain a large number of side band components which are distributed in a hexagonal FFP as shown in *FIG. 2 (a)*. This FFP feature is superior to 2-D SSD which has square FFP consisting of fewer side bands. The spectral components of 3-D SSD covering 0.5-nm width are overlapped with each other by the KPP creating a quite smooth far-field pattern. Moreover KPP originally designed for this system consists of 3×3 segments of sub- KPP, which is effective to reduce the distortion of the intensity envelope of FFP caused by the phase aberration in the beam cross section.

3.3 Beam Switchyard

PCL and SSD pulses are combined in series with an appropriate time gap, and then injected into a preamplifier chain. The polarization of PCL is rotated by 90˚ using a Pockels cell installed just before the beam dividing optics. Thus the PCL is switched out to be transferred to three main amplifier chains selected for foot pulse. On the other hand, the polarization of SSD remains to be amplified in other nine main amplifier chains. In this beam dividing section, the time synchronization between PCL and SSD pulses is adjusted so that the end of PCL pulse coincides with the rise of SSD pulse at the target plane.

4. Preliminary Performance on Irradiation Uniformity of 3-D SSD

The temporal characteristic of irradiance profile smoothing of 3-D SSD was examined at the front end. FFPs calculated without a phase plate and measured with a random phase plate (2.5-ns pulse width) are shown in *FIGs. 2 (a)* and *(b)*, respectively. By changing the pulse width, we compared the temporal smoothing feature measured for 3-D SSD with that of incoherent laser as shown in *FIG. 2 (c)*. Experimental data showed a reasonable smoothing characteristic close to the $T_{av}^{-1/2}$ scaling, and the smoothing effect continues for 2 ns because the same phase distribution does not appear during this time scale.

Measured spectral widths of the third harmonic were ~0.3 nm (0.73 THz) in a fundamental intensity range of ~0.5 GW/cm^2 at the KDP. The tripling efficiency was ~25% because of existing thin KDP crystals. *FIG. 3* shows a simulated single-beam FFP of 2-ns 3-D SSD pulse with the segmented KPP. The inferred single-beam nonuniformity is 4.2%, and thus we expected to achieve 1.4% nonuniformity when nine beams are overlapped on the target plane.

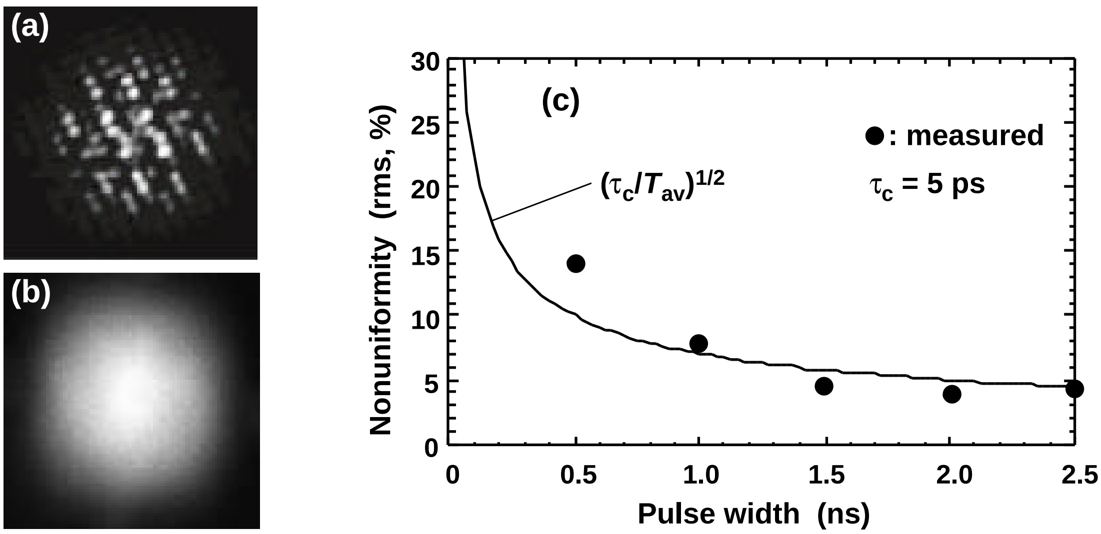

FIG. 2 Front end performance of 3-D SSD. (a): calculated FFP without phase plate, (b): measured FFP with an random phase plate, and (c): rms nonuniformity as a function of pulse width.

5. Backlighter Beam Line

On the plasma diagnostics, single-beam backlighter system, which is synchronized to GEKKO XII with a timing jitter of ~±50 ps, has a capability of a few kJ output energy with the flexible pulse shaping. This system is based on the Peta Watt laser module (PW-M) [7], and we added a Q-switched Nd:YLF oscillator and a fast Pockels cell. The pulse length can be changed within 0.16-8 ns according to the backlighting purpose. There is another CW mode-locked Nd:YLF oscillator coupled to a regenerative amplifier which is routinely used for the KDP tuning. A 40-ps pulse delivered from this laser is also used for the single-frame, two-dimensional x-ray backlighting. The output beam of PW-M can be switched to both the target room I (chirped pulse amplification mode) and the target room II (HIPER backlighter mode). The backlighter beam is frequency-converted by a KDP cell, and then focused onto a backlighter target by *F*/3 lens. The current operation level is 150 J (0.16 ns) or 1 kJ (4.8 ns) at 527-nm wavelength. *Figure 4* shows a typical example of streaked side-on backlighting of an accelerated 25-μm thick plastic foil.

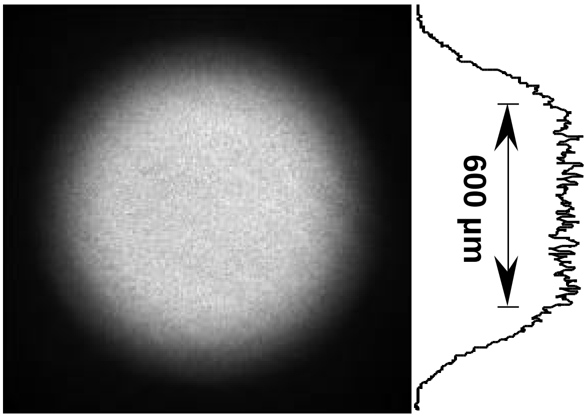

FIG. 3 Simulated FFP of the third harmonic of 3-D SSD with a segmented kinoform phase plate.

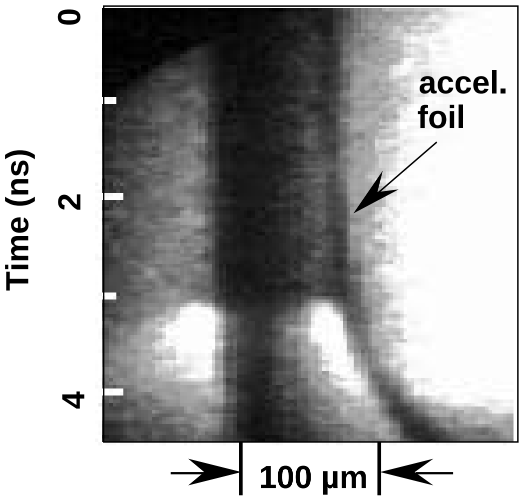

FIG. 4 Streaked x-ray shadowgraph of an accelerated foil target.

6. Summary

The initial activation of HIPER system has been successfully completed. Several basic experiments on the foil acceleration have been carried out with the irradiation of the third harmonic of 3-D SSD pulse (2.5 ns, $<2.6\times10^{14}$ W/cm^2) associated with the second harmonic PCL foot pulse (2.3 ns, $<7\times10^{12}$ W/cm^2). The target acceleration and the hydrodynamic stability (Rayleigh-Taylor instability growth and laser nonuniformity imprint) were diagnosed by x-ray backlighting using additional beam line prepared for this system. In the next step, the detailed measurement and analysis of laser irradiation uniformity on the target plane, the data accumulation on the system operation and the improvement of tripling efficiency (using a dual tripler scheme [8] with an optimized KDP thickness) are needed for the precise study relevant to the high gain implosion.

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