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Letter

First demonstration of improving laser propagation inside the spherical hohlraums by using the cylindrical laser entrance hole

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Abstract

The octahedral spherical hohlraums have natural superiority in maintaining high radiation symmetry during the entire capsule implosion process in indirect drive inertial confinement fusion. While, in contrast to the cylindrical hohlraums, the narrow space between the laser beams and the spherical hohlraum wall is usually commented. In this Letter, we address this crucial issue and report our experimental work conducted on the SGIII-prototype laser facility which unambiguously demonstrates that a simple design of cylindrical laser entrance hole (LEH) can dramatically improve the laser propagation inside the spherical hohlraums. In addition, the laser beam deflection in the hohlraum is observed for the first time in the experiments. Our 2-dimensional simulation results also verify qualitatively the advantages of the spherical hohlraums with cylindrical LEHs. Our results imply the prospect of adopting the cylindrical LEHs in future spherical ignition hohlraum design.

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The hohlraum is essential in indirect drive inertial confinement fusion (ICF) [1,2], and the choice of hohlraum shape and the number of Laser Entrance Holes (LEH) are crucially important in ignition hohlraum design because they directly influence the capsule symmetry and the energy coupling efficiency. The cylindrical hohlraums with 2 LEHs are used most often in indirect drive ICF study and chosen as the ignition hohlraum at the National Ignition Facility [3]. However, a high symmetry on capsule inside the cylindrical hohlraums is realized by tuning via beam-phasing technology and three-color technology, while the tuning experiments have shown that none of layered implosions to date meet the symmetry requirement for ignition [4−7]. In fact, many experimental and theoretical works have shown that the

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octahedral spherical hohlraums with 6 LEHs [8−10] and the tetrahedral spherical hohlraums with 4 LEHs [11,12] have natural superiority over the cylindrical hohlraums in maintaining high radiation symmetry during the whole capsule implosion process and are much more insensitive to the random variations [13]. As a result, the spherical hohlraum is a hopeful candidate for ignition hohlraum. According to the study on the laser arrangement for the octahedral hohlraums [10], the laser injection angle of 50°−60° is proposed as the optimum range. However, this injection angle range might be a potential problem for the laser propagation and bring serious laser plasma interaction for the octahedral spherical hohlraums. The reason is that the spherical hohlraum's geometrical curvature near the LEH leaves a narrow space between the laser beams and the hohlraum wall, and therefore the dense plasmas blown off from the hohlraum wall might enter the laser path, shift the laser deposition region closer to the LEH and aggravate the laser plasma interactions.

In this Letter, we address above crucial issue and report our experimental work which unambiguously demonstrates for the first time that a simple design of cylindrical laser entrance hole [14] can dramatically improve the laser propagation inside the spherical hohlraums. The experiments are conducted on the SGIII-prototype laser facility [15,16], consisting of eight laser beams with 800 J per beam at 0.35 mm, and the eight laser beams simultaneously irradiate hohlraum from two ends at an incidence cone of 45° angle. It should be noted that the four laser beams from one LEH have 45° difference in azimuthal direction with those from the other LEH on the SGIII prototype. From our study, the gold M-band (between 1.6 keV and 4.4 keV) emission mainly comes from the nonequilibrium corona where most of the laser energy is absorbed. Therefore, we image the laser spot movement by using an X-ray Framing Camera (XRFC), which observes the M-band emission through an observation slit on hohlraum wall. The slit of 400 mm width is parallel to the hohlraum axis. The laser spot motion inside the cylindrical hohlraums has been observed by using time-resolved pinhole camera on NOVA [17] and XRFC on OMEGA [18] in order to investigate the motion of hohlraum wall. Considering the laser arrangement of the SGIII-prototype, the spherical hohlraums with two LEHs are used in the experiment. In Fig. 1, we present the schematic of the experimental setup and the view field of the XFRC for the two kinds of hohlraums. Due to the existence of observation slit, seven laser beams are used in the experiments, with four entering hohlraum from the upper LEH end and three from the lower LEH. In the experiments, a constant power (flattop) laser pulse of 2 ns with 150 ps rising and falling time is used. The Continuous Phase Plates (CPPs) are installed at the SGIII-prototype to improve the quality of laser beams. The laser focal diameter is about 500 mm at the LEH plane and the peak laser intensity is about 1.8×10^{14} W/cm^2. The stimulated backscattered laser energy is measured by a full aperture backscatter station (FABS) and a near backscatter imager (NBI). A group of flat response X-ray detectors (FXRD) are used to measure the radiation flux from the upper LEH at different angles. Here, we focus on the observation results of the laser spot movements.

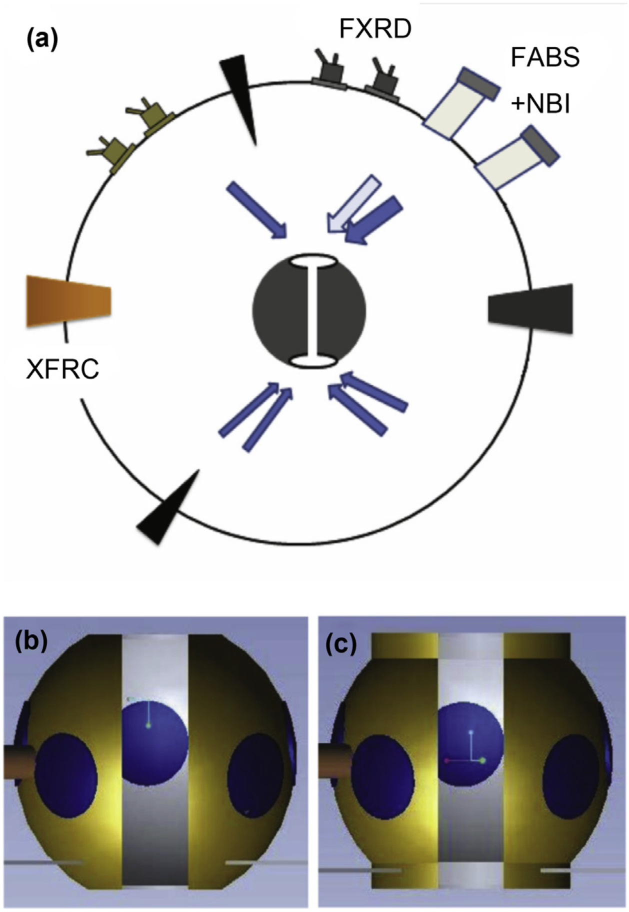

Fig. 1. Schematic diagrams of the experimental setup (a), the view fields of the X-ray framing camera for the spherical hohlraum with plain LEHs (b) and for the spherical hohlraum with cylindrical LEHs (c). Notice that the spot viewed by the X-ray framing camera is generated by a laser beam entering from the lower LEH, which has higher position than the spots generated by lasers entering from the upper LEH because the lasers enter at 45° and focus at their corresponding LEH planes.

In order to observe the effect of the cylindrical LEH on laser propagation, two kinds of empty gold spherical hohlraums are used in the experiments, one with plain LEHs and the other with cylindrical LEHs, as shown in Fig. 1. The size of the spherical hohlraums is designed by using the extended plasma-filling model [19] with the criterion of $n_e = 0.1$. Here, n_e is the average electron density in laser hot channel at filling time, which is normalized to the critical density. Presented in Fig. 2 are contour lines of $n_e = 0.08$, 0.1, and 0.12 on the plane of sphere radius and laser energy, which are obtained from the extended plasma-filling model. Since the beam smoothing technology is used in the experiment, the backscatter is neglected in the initial design. In the initial design, the drive laser is considered to be a pulse of 6 kJ. As a result, we take 850 mm as the radius of the spherical hohlraums. The LEH radius R_L is 400 mm, and the radius of the cylindrical LEH outer ring is taken as 1.5 $R_L = 600$ mm.

In Fig. 3 we present the XRFC viewed images of the laser spot in the spherical hohlraum with plain LEHs at nine different time for the shot SGIIIP-2014391. In each image of