Hohlraum Energetics and Implosion Symmetry with Elliptical Phase Plates Using a Multicone Beam Geometry on OMEGA

Introduction

The overall coupling efficiency of laser energy to the implosion capsule is an important parameter for inertial confinement fusion (ICF). Indirect-drive-ignition designs planned for the National Ignition Facility (NIF) have predicted coupling efficiencies of about 10% (Ref. 1). The use of phase plates for indirect-drive implosions affects the laser-scattering losses and is a central focus of this article. Laser-beam smoothing with phase plates was shown to reduce stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS) of gas-filled hohlraums and to increase the peak radiation temperature on Nova.[2] Phase plates reduce laser–plasma instabilities by controlling the on-target laser-intensity distribution and the speckle modal power spectrum. These experiments extend the previous work[2] to a multicone beam geometry using 40 beams compared with 10 beams configured in a single cone. An experimental platform on the OMEGA Laser System[3] for the National Ignition Campaign drives hohlraums with three cones of beams smoothed with elliptical phase plates. The 60 beams of OMEGA are symmetrically arranged around the spherical target chamber, so only 40 beams can be used to drive a hohlraum: The cones have angles of incidence 21.4° (cone 1 with 5 beams), 42.0° (cone 2 with 5 beams), and 58.8° (cone 3 with 10 beams) to the hohlraum axis. A multicone beam geometry improves the x-ray-drive symmetry of indirect-drive implosions and will be used on the NIF.[1] The new phase plates were designed to provide favorable coupling of laser energy to x-ray drive for a wide variety of indirect-drive experiments on OMEGA. The coupling of laser energy to x-ray drive for gas-filled hohlraums was significantly improved when phase plates were added. The improved coupling correlates with reduced, cone-dependent losses from SRS and SBS. A high-Z dopant in the gas-filled hohlraum[4] is shown to reduce hard x-ray production and SRS and increase the peak radiation temperature. Indirect-drive implosion symmetry[5] of vacuum and gas-filled hohlraums was investigated for the first time with a multicone laser drive smoothed with phase plates. A shift in symmetry was observed between vacuum and gas-filled hohlraums having identical beam pointing.

Elliptical Phase Plates

The elliptical phase plates can be used to drive hohlraums on OMEGA that have a laser entrance hole (LEH) diameter greater than 800 μm. Elliptical phase plates maximize the beam clearance, while minimizing the peak intensity at the LEH. This is illustrated in the upper row of Fig. 112.9, where the black circle represents the LEH having an 800-μm diameter and the gray spot indicates the size of the beam including the intensity contour, which is 1% of the peak intensity. Each column represents a beam incident on the LEH with the minor axis of the ellipse lying in the plane of incidence for each of the cones. The elliptical laser spot at normal incidence projects to a circular spot at the plane of the LEH when the angle of incidence is 42°. As seen in the upper row of Fig. 112.9, ideal clearance between the edge of the beam and the extent of the LEH is achieved for the cone-2 beam with the elliptical phase plate. The cone-1 and cone-3 beams are slightly elliptical in the plane of the LEH; however, they still have good beam clearance. A single ellipticity was chosen to streamline configuration operations on OMEGA. In contrast to the elliptical far-field laser spot, the lower row of Fig. 112.9 illustrates the limitation of the circular laser spot. To prevent the high-angle, cone-3 beams from clipping the LEH wall, the diameter of the circular laser spot must be reduced to the white circle in Fig. 112.9, which increases the peak intensity of the beam at the LEH. The phase plate is designed to produce an elliptical far field at normal incidence with a super-Gaussian power $n = 5$, a $1/e$ half-width minor radius $\delta_{\min} = 103\ \mu$m, and $1/e$ half-width major radius $\delta_{\mathrm{maj}} = 146\ \mu$m. The single-beam average (I_{50}) and peak (I_{95}) intensities generated with the phase plate and a 500-J, 1-ns square laser pulse are designed to be $I_{50} = 1.3 \times 10^{15}$ W/cm^2 and $I_{95} = 4.5 \times 10^{15}$ W/cm^2, respectively. The far-field intensity distribution produced with the phase plate was characterized on OMEGA using the ultraviolet equivalent-target-plane diagnostic.[6] The portion of the measured envelope having intensities greater than 10% of the peak intensity was modeled with a super-Gaussian profile having $n = 4.1$, $\delta_{\min} = 106\ \mu$m, and $\delta_{\mathrm{maj}} = 145\ \mu$m. Analysis of the single-beam intensity shows the E-IDI-300 phase plate generates an average intensity of $I_{50} =$

1.0×10^{15} and a peak intensity of $I_{95} = 3.8 \times 10^{15}$ W/cm^2 with a 500-J, 1-ns square laser pulse drive. Similar measurements performed for 9 of the 43 phase plates were found to be close to the design specifications with $I_{50} = 1.0\pm0.05 \times 10^{15}$ W/cm^2, $I_{95} = 3.7\pm0.2 \times 10^{15}$ W/cm^2, $n = 4.3\pm0.3$, $\delta_{min} = 106\pm1.4$ μm, and $\delta_{maj} = 144\pm2.7$ μm.

Hohlraum Energetics and Indirect-Drive-Implosion Symmetry Experiments

Hohlraum energetics experiments were conducted using thin-walled (5 μm Au), scale-1, vacuum and gas-filled (0.9 atm C_5H_{12}) Au halfraums irradiated with the shaped laser pulse PS26. The halfraums have an equal length and diameter of 1.6 mm and an LEH diameter of 1.07 mm. The fully ionized n_e of the hohlraum plasma for the gas-filled targets is 9×10^{20} cm^{-3}. The gas fill is contained with a 0.6-μm-thick polyimide window over the LEH. Time-resolved, absolute levels of the x-ray flux were recorded with the Dante diagnostic.[7] Time-integrated levels of SRS and SBS that scattered back through the OMEGA focus lens were recorded with the full-aperture backscatter station (FABS), and light scattered just outside the lens was recorded with the near-backscatter imaging (NBI) diagnostic.[8] The coupling of laser energy to x-ray drive is significantly improved for gas-filled halfraums with phase plates, consistent with earlier work.[2] The targets were irradiated with an ~7-kJ PS26 laser pulse using 20 beams. As shown in Fig. 112.10(a), the peak radiation temperature T_r inferred from the measured levels of the x-ray flux increased by 17 eV when the laser beams were smoothed with phase plates, corresponding to a 44% increase in the peak x-ray flux. The improved coupling is correlated with reduced laser-scattering losses. A shot-by-shot scan was performed to measure the cone-dependent laser-scattering losses. It was assumed that the laser-scattering losses were caused by single-beam interactions; consequently, all of the heater beams had phase plates. Shots were taken with and without phase plates in the interaction beam to complete the shot matrix. As shown in Figs. 112.10(b) and 112.10(c), laser-beam smoothing with phase plates reduces the cone-dependent FABS SRS and FABS SBS signals. The most energetically significant reductions occur for FABS SRS in cone 1 (23% to 10%) and cone 2 (17% to 4%). The total FABS scattering levels are higher for SRS than SBS (11% versus 5% without phase plates and 4% versus 2% with phase plates). The NBI SBS signal was 2% without phase plates and was negligible with phase plates. NBI SRS signals are not available. The scattering losses measured with FABS SRS, FABS SBS, and NBI SBS were reduced by nearly a factor of 3 with phase plates (18% without phase plates and 6% with phase plates).

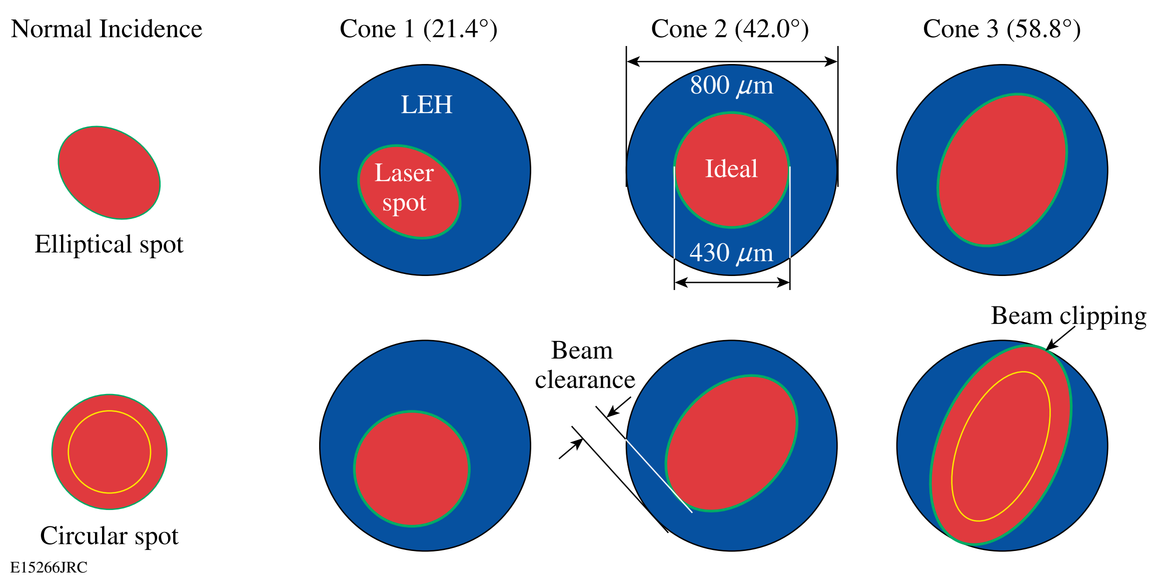

Figure 112.9
Beam clearance for each of the three cones for an elliptical beam (upper trace) and a circular beam (lower trace). The black circle represents the LEH having an 800-μm diameter; the gray spot indicates the size of the beam including the intensity contour, which is 1% of the peak intensity. The circular spot needs to be reduced to the white circle to prevent beam clipping on the LEH wall.

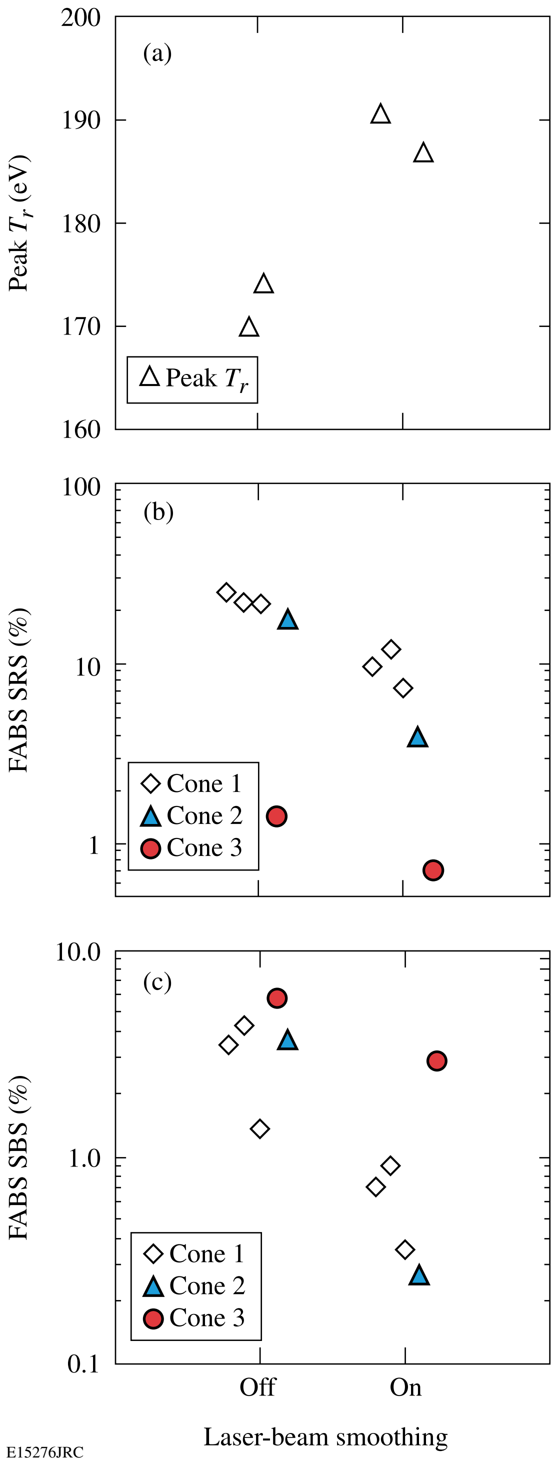

Figure 112.10
(a) The peak T_r with and without laser-beam smoothing with phase plates for gas-filled halfraums. Percent of incident beam energy detected by (b) FABS SRS and (c) FABS SBS for each beam cone.

The symmetry of imploding gas-filled (D_2 doped with Ar) plastic capsules driven with gas-filled, scale-1, Au hohlraums having lengths of 2.3 and 2.5 mm was measured on OMEGA using phase plates in the drive beams. Axial and radial gated-x-ray images of the implosion around the time of peak compression were recorded. Figure 112.11 shows that a shift of 150 μm in symmetry was observed between vacuum and gas-filled (0.9 atm CH_4) hohlraums having identical beam pointing. The fully ionized n_e of the hohlraum plasma for the gas-filled targets is 2.2×10^{20} cm^{-3}. The ratio of x-ray drive at the poles of the capsule relative to the waist increased for the gas-filled hohlraum. As shown in Fig. 112.10, the inner cone beams (cone 1) have the highest level of SRS. The differential laser-scattering levels between the cones, which is more pronounced for the gas-filled hohlraum, could affect the indirect-drive-implosion symmetry and is the most likely cause for the observed symmetry shift seen in Fig. 112.11.

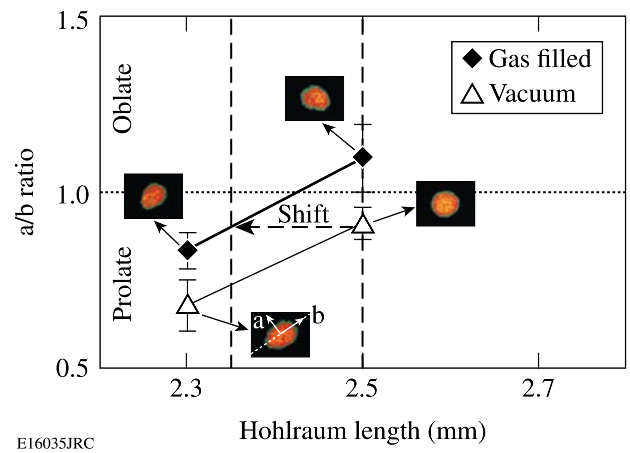

Figure 112.11
Symmetry of indirect-drive implosion quantified from gated-x-ray images ($h\nu > 3$ keV) of implosions taken along a radial view [hohlraum radial and axial directions are (a) and (b), respectively]. A 150-μm symmetry shift was observed between vacuum and gas-filled hohlraums having identical beam pointing.

In conclusion, elliptical phase plates are benefiting indirect-drive experiments on OMEGA.

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