Nonuniform Absorption and Scattered Light in Direct-Drive Implosions Driven by Polarization Smoothing

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Laser-direct-drive symmetric implosions on OMEGA illuminate a target with 60 laser beams and are designed to produce spherical implosions. Simulations suggest that direct-drive laser irradiation nonuniformity must be below the 1% rms level to minimize low-mode nonuniformities and hydrodynamic instabilities that quench the implosion.[1] Observations of light scattered from OMEGA implosions do not show the expected symmetry and have a much larger variation than standard predictions. For the first time, we have quantified the scattered-light nonuniformity from individual beams and identified cross-beam energy transfer (CBET)[2] between the polarization components produced by OMEGA's polarization smoothing as the source of the enhanced nonuniformity.

The 3ω gated optical imager (3ωGOI), scattered-light diagnostic[3,4] was developed to image the light scattered from an implosion. The scattered light appears as a symmetric pattern of 60 distinct spots, each corresponding to a beamlet of light collected from one of the 60 beams. Each beamlet originates from a specific point in the far-field profile of a beam, and as it refracts through the plasma, its intensity varies due to absorption and CBET until it ultimately reaches the diagnostic collection optic. An important feature of the 3ωGOI is a Wollaston prism that splits the collected light into orthogonal horizontal and vertical polarization components that are imaged simultaneously.

In a symmetric implosion, all beamlets collected from beams at the same angular distance from the diagnostic are imaged at the same radial distance from the center of the spot pattern. Figure 1 shows the observed variation (blue circles) in beamlet

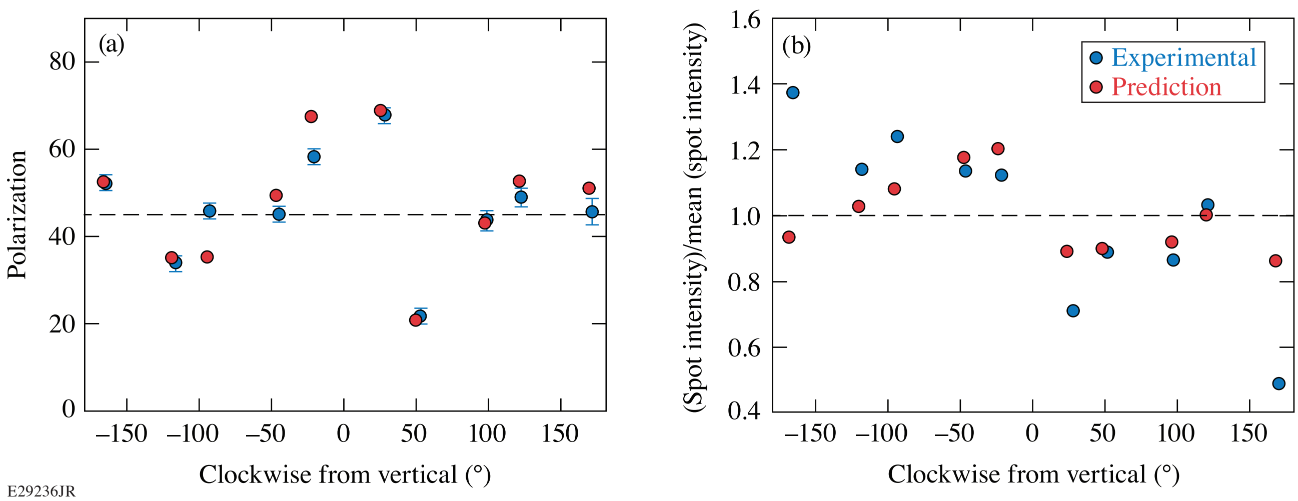

Figure 1
The measured (blue circles) and predicted (red circles) values for the beamlet (a) polarization and (b) intensity as a function of angle from vertical are plotted for a radial beam group.

polarization and total relative intensity for a radial group of beamlets. Truly symmetric laser absorption and CBET should produce constant relative intensity [dashed line in Fig. 1(b)]. Energy exchange due to CBET can rotate the polarization components in the beams,[5] but in a symmetric implosion, the polarization would be altered identically for each beamlet and the polarizations recorded by the 3ωGOI would show symmetry about the vertical and horizontal axes due to the Wollaston prism orientation. No such symmetry about these axes (0°/180° and +90°/–90°, respectively) is observed in Fig. 1(a). Both the observed intensity and polarization of the beamlets indicate that the scattered light from an OMEGA implosion is highly asymmetric.

On OMEGA, each beam is polarization smoothed by passing the laser beams through distributed polarization rotators (DPR's)[6] that split it into two orthogonal polarizations. The split beams exit the DPR with a minute difference in direction that results in an on-target offset of 90 μm. The total on-target overlapped far-field beam profile has two opposite regions in the direction of the offset where the light is mostly linearly polarized. A 3-D CBET model[7] was developed to follow the evolution of the polarization of each split beam as it propagates through the plasma and interacts with crossing beams. When both the DPR-produced polarizations and offsets were used to predict the beamlet polarizations and intensities (red circles in Fig. 1), the measured variation in both was explained. The high correlation between the measured and predicted polarization of the beamlets in Fig. 1(a) demonstrates the accuracy of the modeling, while the correlation between the measured and predicted intensity of the beamlets provides confirmation that the DPR's are responsible for the observed asymmetry in the scattered light.

Enhanced CBET in the strongly polarized regions created by the DPR split offset is a source of asymmetry during an implosion. To illustrate the magnitude of this effect, the 3-D CBET + DPR model was applied to a typical OMEGA cryogenic target implosion and the total time-integrated nonuniformity was calculated. Figures 2(a) and 2(b) show that the total time-integrated nonuniformity over the entire course of an implosion due to CBET and the DPR-polarization split is predicted to be significant for an otherwise symmetric implosion. Figure 2(a) shows the calculated total scattered light over the inner surface of the target chamber wall. The predicted variation in radial exposure is 5.4% rms with a peak to valley over 30%. This large variation demonstrates the significance of this effect on scattered light. Measurements must account for the effect of the DPR offsets to accurately infer laser absorption during implosions on OMEGA.

A relatively simple solution to the issue of DPR + CBET-induced nonuniformity is to fabricate and deploy new DPR's with a decreased spot separation of 10 μm in the far field, which the model predicts will reduce the scattered-light rms variation by a factor of more than 5 to only 0.92%.

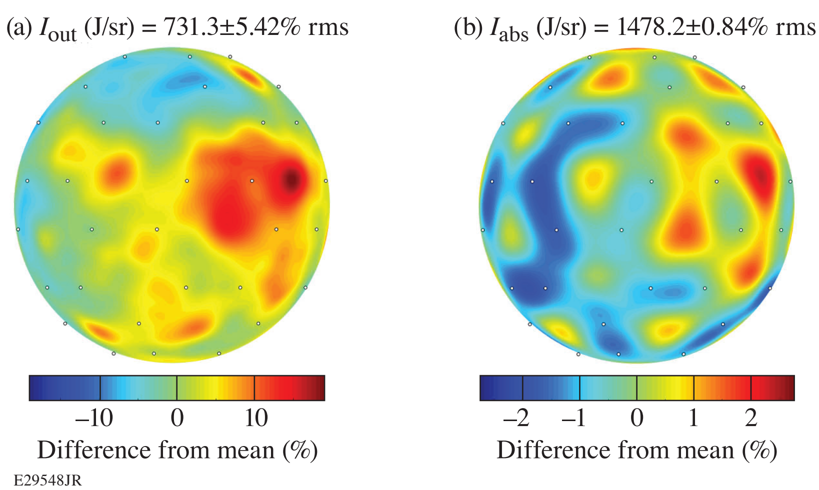

Figure 2
Predicted variation from mean of the (a) scattered light and (b) absorption radiant exposure (J/sr) distributions over a spherical surface for an OMEGA cryogenic implosion using the current DPR's that create a 90-μm offset on target chamber center between the polarization split sub-beams.

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