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Abstract. Polar-direct-drive experiments at the National Ignition Facility (NIF) are being used to validate direct-drive–implosion models. Energy coupling and fast-electron preheat are the primary issues being studied in planar and imploding geometries on the NIF. Results from backlit images from implosions indicate that the overall drive is well modeled although some differences remain in the thickness of the imploding shell. Implosion experiments to mitigate cross-beam energy transfer and preheat from two-plasmon decay are planned for the next year.

1. Introduction

Direct-drive couples 3× to 5× more laser energy into the kinetic energy of imploding shell than x-ray drive, making it possible to create ignition-relevant designs in a less-challenging regime. Experiments on the National Ignition Facility (NIF) [1] are necessary to study the interaction of the laser with the coronal plasma in an imploding geometry at coronal-density scale relevant to ignition. Validation of laser deposition and heat conduction models at ignition-relevant scales and demonstrating mitigation strategies for various laser plasma interactions are important to gaining confidence in direct-drive–ignition predictions.

Implosion experiments on the NIF, as described in this paper, are performed in the "polar-direct-drive" (PDD) [2] configuration. Since the NIF is configured for x-ray drive, beam ports are missing at the equator. To compensate for the reduced equatorial drive, beams located closer to the poles are displaced toward the equator. Additionally, to improve equatorial drive, beam energies of some of the

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beams are adjusted. PDD offers a platform where the physics of direct-drive implosions can be studied. These implosions use existing hardware on the NIF including indirect-drive–ignition phase plates and indirect-drive smoothing.

2. Physics issues in ablatively driven NIF implosions

In direct drive, the implosion velocity and the ablation pressure are primarily determined by the coupling of the laser into the coronal plasma and the conduction of heat to the ablation surface. The equation of state has also been shown to influence these quantities, although to a smaller extent [3]. Modifications to collisional absorption caused by cross-beam energy transfer (CBET) have been used in OMEGA [4] experiments to explain observables including capsule trajectory, scattered-light spectra and time histories, bang times, etc. [5]. The CBET gain scales with the volume of the resonance region. This volume in the NIF implosions is larger than those in OMEGA implosions, necessitating experiments to validate models.

Nonlocal heat conduction has also been identified in OMEGA experiments as being critical to modeling the imploding shell [4]. The coronal plasma is treated as a thermal source and the energetics tails in the Maxwellian-distributed electrons in the corona conduct heat to the ablation surface, providing additional drive. Ongoing NIF implosions have higher coronal temperatures (~3.2 keV) compared to OMEGA-scale coronal temperatures (~2.75 keV). Again, the nonlocal model requires validation in this regime.

Plasma waves excited by the laser can accelerate electrons to energies ($\gtrsim$50 keV) that can be detrimental to compression. On OMEGA and NIF implosions, the magnitude of the hot-electron source, as measured by the x rays generated by bremsstrahlung radiation from these electrons, has been shown to scale with the threshold parameter η [6], given by

$$\eta = I_{n_c/4}\left(\times 10^{14}\ \text{W/cm}^2\right)L_{n_c/4}\left(\mu\text{m}\right)\Big/\left[233\,T_e\left(\text{keV}\right)\right],\tag{1}$$

where $I_{n_c/4}$ is the laser intensity, $L_{n_c/4}$ is the density scale length, and T_e is the electron temperature, all at the quarter-critical surface. The threshold parameter is larger for NIF implosions compared to OMEGA implosions. For the same ignition-relevant on-target intensity at the initial radius of ~8 × 10^{14} W/cm^2, OMEGA-scale targets have density scale lengths of ~150 μm compared to the NIF-scale density scale lengths of ~360 μm. Therefore, NIF experiments are important to understanding the two-plasmon–decay (TPD) source and its effect on compression.

3. Results

Room-temperature plastic (CH) shells of ~1200-μm radius filled with 20 atm of deuterium gas are imploded on the NIF in PDD geometry. Existing indirect-drive–ignition phase plates, defocused to 1 cm, are used to irradiate these capsules. Trajectories are inferred from framing camera images located at the pole and the equator. The equatorial camera captures images obtained by backlighting the implosion with an iron backlighter. The radius of peak absorption as a function of polar angle is identified [7], providing information about the nonuniformity in the polar angle. The average of this radius provides the location of the peak absorption as a function of time, i.e., a trajectory of the peak absorption location. The polar camera captures images of the emitting target and a similar procedure is used to extract the radius as a function of polar angle and average radius as a function of time [8].

Simulations are performed with the two-dimensional (2-D) axisymmetric code *DRACO* [9]. Laser deposition is modeled using a fully three-dimensional (3-D) ray trace that models collisional absorption. The deposition from CBET using the formulation of Randall *et al.* [10] modifies the laser deposition. Nonlocal heat conduction is modeled diffusively [11]. The far-field defocused spot shapes that are used in *DRACO* are calculated using *Zhizhoo'* [12] based on the near-field spot shapes [13]. The first-principles equation of state [3] is used with opacities from the LANL astrophysical tables [14]. Simulations are then post-processed with the ray-tracing package *Spect3D* [15] to generate synthetic images. Both the measured and simulated images are post-processed similarly to extract radius as a function of polar angle and time.

Figure 1 plots the average locations of the radius versus time for the simulated and measured images. The backlit trajectory is reproduced very well with the simulations indicating that the global energetics is also modeled well with simulations. Simulations indicate that CBET reduces the implosion velocity by ~15% and the ablation pressure by ~45% in these implosions. As figure 1 also indicates, the trajectories from the self-emission images are overdriven in the simulation relative to the experiment. This indicates that the shell is thicker in the experiment than the simulation. Although the exact reasons for this decompression are unknown, potential reasons include fast-electron and/or radiative preheat and instability growth from laser imprint. Experimentally, the magnitude of the hot-electron source has been inferred using the filter-fluorescer x-ray (FFLEX) diagnostic [16], which measures the x-ray emission from bremsstrahlung of the fast electrons in ten channels in the 20- to 500-keV range. Using the measured radiation and the stopping power of electrons in CH, a total energy of ~2.5±0.3 kJ with a hot-electron temperature of ~46±2 keV is inferred [17]. This extent of preheat has a small influence on the trajectories in simulations, suggesting that fast-electron preheat is not the source of this decompression. *DRACO* simulations with imprint with modes $\ell \leq 200$ show significant distortion of the ablation surface without affecting the shell. Images from these simulations indicate that imprint could provide a plausible mechanism for the apparent decompression of the shell. Low-intensity implosions, where preheat is reduced, will be studied. Improved smoothing with multi-FM [18] is required to further disentangle the effect of preheat and laser imprint on shell decompression.
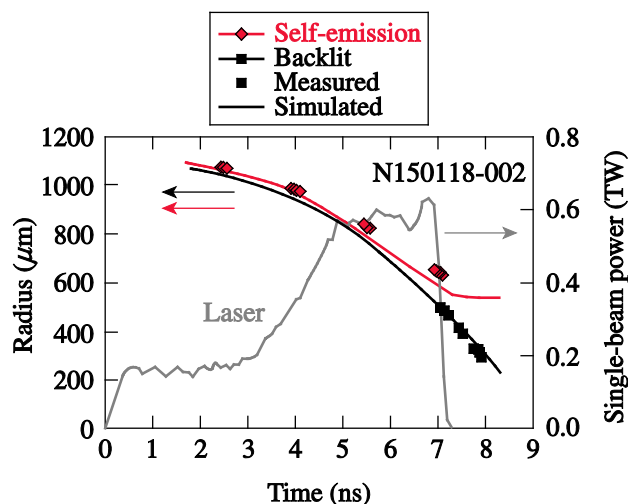

Figure 1. Trajectories of the peak self-emission surface (red) and peak absorption surface (black) inferred from framing camera images in the experiment (symbols) and simulated framing camera images (lines).

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4. Future work

Reducing the extent of energy transfer between the rays in NIF implosions will be studied by exploiting the NIF capability of irradiating the target with somewhat different wavelengths for the various cones [19]. This will move the stimulated Brillouin scattering resonance to regions that are less detrimental to laser-energy deposition. These experiments will begin in FY16. CBET, however, is expected to influence TPD. With only collisional absorption in the models, the intensity at the quarter-critical surface is higher by ~60%, while not significantly influencing the scale length or the electron temperature. Therefore, mitigating CBET in NIF implosions will increase η by the same factor of 60%, increasing the hot-electron source. Mid-*Z* ablators have been demonstrated to decrease the hot-electron source by primarily increasing the temperature at the quarter-critical surface. Mid-*Z* ablators will be imploded to study the extent of TPD in NIF-scale implosions with the wavelength-detuning mechanism for CBET mitigation in FY16.

5. Conclusions

Results from PDD NIF implosions have been presented. The goal of these experiments is to validate modeling relating to implosion energetics on coronal density scale lengths larger than those available on the OMEGA laser, which has been traditionally used for direct-drive–implosion studies. Cross-beam energy transfer and nonlocal heat conduction are primary physics issues being investigated on

the NIF. Comparison of the simulated and measured images and trajectories indicate that energetics is well modeled. Mitigation of CBET via wavelength detuning of the resonance will be studied in the following year. It is expected that mitigating CBET will increase the hot-electron source from the corona that can potentially preheat the imploding shell, thereby compromising compression. Mid-Z ablators have been demonstrated on OMEGA and the NIF to reduce this source. Implosions with CBET mitigation through wavelength detuning will be studied with mid-Z ablators to estimate the hot-electron preheat in the future.

Acknowledgments

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