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Energetics measurements of silver halfraum targets at the National Ignition Facility

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ABSTRACT

The energetics of novel silver halfraum targets are presented from laser experiments at the National Ignition Facility (NIF). Four beams from the NIF laser were used to heat the halfraum targets with ~10 kJ of energy in a 1 ns square laser pulse. The silver halfraum targets were spheres 2 mm in diameter with an 800 μm laser entrance hole (LEH). Targets with different spherical wall thicknesses (8–16 μm) were characterized. The energetics and the laser coupling to the targets were determined using the NIF X-ray (i.e. Dante and FFLEX spectrometers) and optical backscatter diagnostics (NBI and FABS). The energy coupled into the targets was 0.85–0.88 of the total laser energy with a defocused laser spot of 400 μm in diameter and no spatial smoothing of the beams with phase plates. The coupling increased to 0.92 when 400 μm spot size phase plates were used to smooth each of the four lasers beams. The energy losses from the targets were through X-ray radiation and backscatter from laser plasma instabilities (SBS and SRS) from the LEH. As expected the different wall thickness had different levels of burn through emission. The thickest walled target (~15.9 μm) had very low radiative losses through the target wall. The thinnest walled targets (~8 μm) radiated about 0.2 of the input energy into X-ray emission.

1. Introduction

High power and high energy lasers are routinely used as energy sources for high energy density (HED) physics experiments. HED experiments include the studying of the properties of materials under extreme conditions [1], the determining of the equation of state (EOS) of materials [2], the development of bright X-ray sources [3] and the producing of a burning fusion plasma for inertial confinement fusion (ICF) [4,5]. The ICF experiments typically use the laser to heat a Au hohlraum platform [6,7] to temperatures ~300 eV. Non gold hohlraum materials have also been investigated for use in the ignition campaign at the NIF [8]. Hohlraum materials that have a higher Z than gold, such as uranium, have higher opacities which can improve hohlraum performance and increase the drive temperature. The emitted X-rays from the hohlraum ablate the surface layer of the ignition capsule. This ablated material through the rocket effect [9] creates a pressure that drives the implosion of the ignition capsule. In material properties experiments, the laser energy is converted to pressure using hohlraum X-rays that drive a graded density piston into the sample material [1]. Alternatively, the laser can directly deposit its energy by directly hitting the back side of the piston [10]. The piston creates a precise pressure wave for the off-Hugoniot loading of the sample under study.

The spherical laser target of the present work is a variant of the hohlraum laser target used in HED experiments. However, instead of having two laser entrance holes, the targets of the present work have only one, giving rise to the name halfraum. The size of the vacuum silver halfraum targets are $\sim 4/3\pi\ (1\ \text{mm})^3 \sim 4.1\ \text{mm}^3$ which is 2/3 the volume of the standard Omega scale target. The Omega scale 1 hohlraum has a volume of 6.4 mm^2. The diameter is 1.6 mm, and the length is 3.2 mm. Furthermore, this volume is 100× smaller than that of a typical hohlraum used in the ignition experiment at the NIF [8,11]. Small halfraums have been studied before at the Omega laser facility [12–14] and at NIF [15,16]. While those targets were made of gold and had right circular cylindrical geometries, we find similar performance in terms of X-ray drive, backscatter and X-ray burn through from the spherical silver vacuum halfraums [17] used in the present work. Recent research has demonstrated an increase in the radiation temperature from about

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230 to 240 eV for rugby ball shaped halfraums when compared to the equivalent sized right circular cylindrical hohlraums [18,19]. Although not related to the purpose of this investigation, our spherical vacuum halfraum is the geometrical limit of the more oval shaped rugby hohlraum design.

In all HED experiments, the target is heated to a hot plasma state by the laser. The laser energy absorbed by the target is converted into either photons (X-rays) or into kinetic energy of the target material, which is partitioned into kinetic energy in both electron and ion distributions. The interaction of the vacuum halfraum target with its environment creates pressure waves that can be tailored for use in a novel experimental platform. This type of a platform is useful to study shocks or high pressure waves in planetary seismology or in various materials for acoustic or seismic studies [20].

The expanding halfraum target forms a spherical pressure pulse that can couple directly into the material under study. The material can be either a gas or a solid. The laser pulse is typically several nanoseconds long, which is an instantaneous deposition of energy with respect to the microsecond time scales over which the pressure pulse evolves. The design of the pressure and shock experiments uses four beams from the NIF laser to deposit approximately 10 kJ of 3ω laser light in 1 ns into a thin walled (7–16 μm) spherical halfraum target made of silver. The pressure or stress waves induced in the gas or solid can be measured by either polyvinylidene difluoride (PDVF) or quartz type pressure gauges [21]. In the work presented here, the characterization of the laser target is discussed in detail. Details of the fabrication and metrology of the targets are given in Ref. [17]. The details of the novel experimental pressure and shock platform are discussed elsewhere [20].

The characterization of our spherical targets concentrates on determining the energetics and coupling of the laser energy to the target. A large fraction of the incident laser light is absorbed by the target. The absorbed laser light heats the target mainly through inverse bremsstrahlung. A fraction of the absorbed laser energy is converted to X-ray emission. Some of this is radiated out through the thin walls of the halfraum target. Modeling, which is discussed later, predicts that the majority of the absorbed energy is converted into kinetic energy in the halfraum walls within ~10 ns. The laser energy that is not converted into kinetic energy is either lost through the laser entrance hole (LEH) in the form of X-rays or reflected and scattered from the target through interactions between the laser field and plasma instabilities [22]. The fraction of the energy partitioned into kinetic energy is determined by subtracting the energy from these energy loss channels from the measured incident laser energy.

A suite of NIF diagnostics was used to record the X-ray and the visible emission from the target during the characterization, or energetics, experiments. The measurements from the diagnostics allow the energetics of the silver halfraum targets to be quantified with high accuracy. In the pressure and shock platform experiments, gas or seismic material surrounds the halfraum and prevents the X-ray measurements. The time evolution of the absolute X-ray radiant intensity was measured by using the Dante 1 and Dante 2 low resolution spectrometers [23]. The SXI X-ray imagers quantified the location of the X-ray emission [24]. Full-Aperture Backscatter System (FABS) [25] and Near Backscatter Imaging (NBI) [26] systems quantified the incident laser light reflected from the target from laser plasma interactions (LPI). From these measurements, the energy coupled into the targets was determined to be 85–88% of the initial laser energy with a defocused laser spot of 400 μm in diameter and no spatial smoothing of the beams with phase plates. The coupling increased to ~92% when 400 μm spot size Continuous Polarization Phase plates (CPPs) were used to smooth the spatial profile of each of the four lasers beams [27]. For the thickest walled target (~15.9 μm) very little of the radiation was lost through the walls of the target. The thinnest walled targets (~8 μm) radiated about 20% of the input energy into the X-ray spectral region.

The measured energetics of the thin walled (~8 μm) silver targets were determined with high confidence and were sufficient for the novel experimental pressure and shock platform [20]. The coupling of greater than 90% of the laser energy into the target is an excellent result. Therefore, most of the laser energy is made available for the experiment at NIF. There are some discrepancies between the simulations and the experiments which were expected since this was a novel target design. Since the energetic results meet the experimental requirements, the discrepancies are not critical for the pressure and shock platform experiments. However, determining the source of the discrepancies with the modeling is still an important question to answer for HED physics.

2. Laser configuration

The 192 beams in the NIF laser are grouped in sets of 48 quads. The 48 quads are clustered in four separate beam cones. The NIF laser beams enter the chamber in these four cones that have azimuthal symmetry around the vertical axis of the target chamber. The beam cones propagate to TCC with angles of 23.5°, 30°, 44.5°, and 50°. Half the beams in each cone come from the top of the NIF target chamber, while the other half come from the bottom [28]. The laser system can deposit over a Megajoule of energy into an ignition target in about 10 ns. For these experiments, only four beams or one quad of the available 48 quads was used to deliver ~10 kJ of energy in a 1 ns square laser pulse at the 3ω wavelength of 351 nm. NIF was chosen for these experiments due to the energy density and geometric requirements of the pressure and shock experimental platform. The laser energy needs to be delivered in a single narrow cone that minimizes the radiative losses from a large LEH as well as the hydrodynamic perturbations and distortions from a spherical pressure wave in the pressure and shock experimental platform. Currently, only a NIF quad can deliver the required energy in a single and sufficiently narrow cone.

The four beams from Q31B that were used to drive the halfraum targets are located at $\theta = 150°$; $\phi = 236.25°$ on the NIF target chamber. The measured 1 ns flat-top laser pulses are shown in Fig. 1 for all four shots. Power restrictions on the four beams forced a slight energy reduction for the second set of two shots. The laser

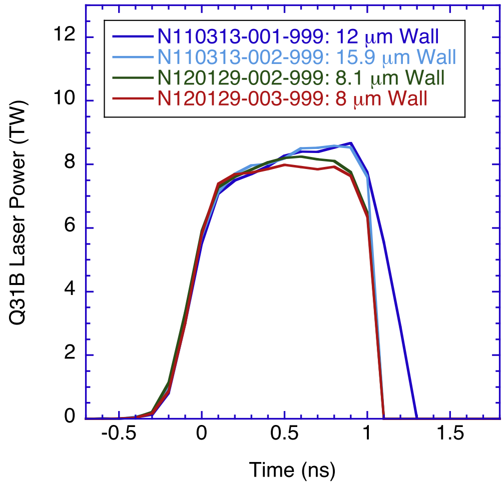

Fig. 1. Measured laser power for NIF shots N110313-001-999, N110313-002-999, N120129-002-999 and N120129-003-999.