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Abstract. We are developing an experimental platform that can compress materials quasi-isentropically to very high pressures at ultrahigh strain rates. This laser driven, ramped (shockless) drive is used to study material properties such as strength, equation of state, phase, and phase transition kinetics under extreme conditions. We have achieved a ramped, shockless drive up to 2 Mbar on the Omega laser using both direct laser illumination and indirect x-ray illumination. In order to probe high-Z materials under extreme pressures, we are also developing high energy x-ray backlighters, 17 to 100 keV, created by high intensity ($>10^{18}$ W/cm^2) short pulse lasers (1 to 50 ps) such as the Titan laser at LLNL. Using a micro-wire embedded in a low-Z substrate, we have obtained radiographs with better than 10 μm spatial resolution. This paper will show designs of isentropic platforms that can reach >10 Mbar on the NIF laser, using both direct and indirect drive configurations.

1. Introduction

Material properties under high pressure and high strain rate are important for geosciences and material science. For instance the presence or absence of new phases in the equation of state of iron at high pressure (>3 Mbar) is significant for distinguishing different planetary core models. Damage and collision studies require knowledge of the material yield strength properties at high strain rates. Yield strength models vary wildly at high strain rate ($>10^5$ s^{-1}); experimental measurements are needed to understand materials under these conditions. Most difficult to access experimentally in the laboratory is the regime where the material is dense, relatively cool, but at very high pressure. We use the laser to drive a very strong shock ($P_{shk} >> 1$ Mbar) through a "reservoir", which unloads across a vacuum gap to create stagnating plasma to create quasi-isentropic conditions at pressures of 1-10 Mbar. This quasi-isentropic drives can compress the samples below their melt temperature, hence, remaining in the solid state. It is hoped that the very high pressure phase diagram of a number of relevant materials under the conditions found in planetary interiors can be examined in these types of experiments.

2. Quasi-isentropic drive

A common method of probing material properties under high pressure is the use of shocks. However, Hugoniot shock loading creates the simultaneous heating of the material preventing the experimental platforms from achieving high pressure, high density states. Another way of compressing materials under near isentropic conditions is by ramp compression [1,2,3]. The laser drives a strong shock through a low-Z reservoir, which unloads across a vacuum gap, and stagnates on the sample, generating a nearly isentropic pressure profile in the sample.

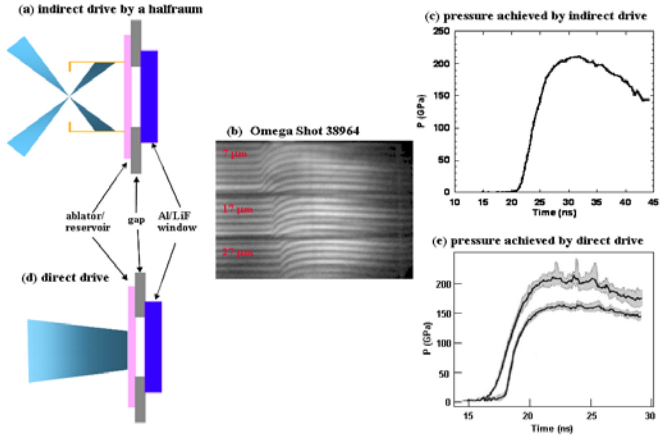

Figure 1. Quasi-isentropic drive platforms up to 210 GPa (2.1 Mbar) from Omega laser. (a) schematic of x-ray illuminating indirect drive target; (b) an example of VISAR data on 7/17/27 μm Al stepped target backed by a LiF window; (c) pressure profile in front of Al sample by indirect drive; (d) schematic of direct laser illuminating target; (e) pressure profile by direct drive.

Many experiments have been performed on Omega to validate the quasi-isentropic platforms. Fig 1 shows some results. The first platform, whose schematic is shown in Fig 1 (a) is indirectly driven by the x-ray radiation from a halfraum. The ablator/reservoir reservoir material is a 180 μm thick 12% Br-doped polystyrene foil ($C_8H_6Br_2$). The vacuum gap in the unloading region is 400 μm thick. The pressure profile is measured from the thin Al sample interface velocity history using a line-imaging velocity interferometer (VISAR). Fig 1 (b) shows an example of VISAR measurements for the Al stepped sample with step heights of 7, 17, and 27 μm; and (c) shows the pressure profile calculated from the velocity data by the back integration method using the well-known Al equation of state [3]. Similar experiments using the direct laser illuminating drives have been performed, as shown in the schematic of Fig 1 (d) and the resulting pressure history in Fig 1 (e) [2]. For the direct drive targets, we used a 28 μm thick polyimide ablator glued onto a 170 μm thick 12% Br-doped polystyrene foil. The gap size was 300 μm. Slight differences in ablator and reservoir materials and the gap sizes explain the difference in the arrival time of the compression waves for these two experiments. This data set demonstrates that we can achieve ramped compression (shockless) up to 210 GPa (2.1 Mbar) using either direct or indirect drive configurations.

3. High energy backlighters

High energy backlighters are essential for probing high-Z materials on NIF. The K_α emission mechanism excited by high intensity lasers is a promising way of creating 20-100 keV high energy photons. When a laser with intensity $I_L > 10^{17}$ W/cm^2 strikes a target, a forward directed “spray” of energetic electrons is created, with energies as high as ~100 MeV. As these energetic electrons traverse the target, bound electrons can be knocked out by electron-electron scattering. If a K-shell

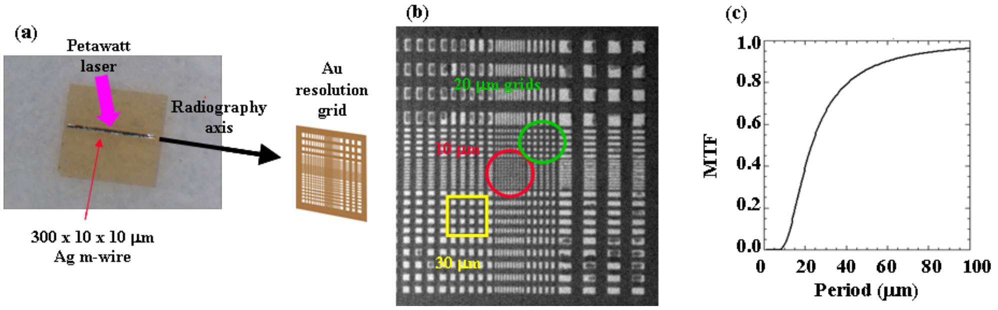

Figure 2. High resolution 22 keV 2-D radiography by a µ-wire target. (a) A 300x10x10 Ag wire target embedded on a low-Z CH substrate. Short pulse laser illuminates the wire and 22 keV Ag K_α photons are generated from the Ag wire creating small x-ray source. (b) Resulting radiography of a test target using 300 J, 40 ps Titan laser at LLNL. 10 µm grids are clearly resolved. (c) Modular transfer function derived from this radiography.

electron is knocked out, this inner shell vacancy is quickly filled by an L-shell or M-shell electron, generating isotropic K_α or K_β radiation. For mid-to-high Z elements, these K_α x-rays can have energies of 20-100 keV, making them ideally suited for high energy radiography.

High resolution 1-D radiography has been demonstrated by “line projection imaging” with a 5-10 µm thin foil, aligned edge-on and parallel to 1-D rippled targets [4]. In this configuration, the spatial resolution in the lateral direction is determined by the thickness of the radiating foil. Our results show that the spatial resolution, as quantified by the average modular transfer function (MTF), was approximately 0.15, 0.4, 0.6, and 0.75 at λ = 20, 40, 80, and 160 µm, respectively.

Extending the idea into 2-D, we fabricated µ-wire targets on low-Z CH substrates. Figure 2 shows a target fabricated with a 300 x 10 x 10 µm µ-wire on a 300 x 300 x 5 µm CH substrate. We use low-Z substrate to reduce the Bremsstrahlung background from the substrate material. A petawatt class laser with intensity >10^{17} W/cm^2 illuminates the front side of this target. To measure the spatial resolution, we took an image of a resolution target consisting of various grid spacing’s. Figure 2 (b) is a resulting image from our experiment on the Titan short pulse laser at LLNL. We used 300 J, pulses with 40 ps duration defocused to a beam spot of 100 µm. The 10 µm grids patterns are clearly resolved. More quantitatively, the point spread function (PSF) is obtained by forming an ideal grid image of the test pattern, then convoluting it with best fitted PSF. The MTF is then derived from this PSF as shown in Fig 3 (c). For 20 µm period grids, the MTF is ~40%. The MTF is a function of the signal-to-noise ratio (SNR). When we are able to use a higher energy laser, such as the 2 kJ ARC on NIF, we expect to achieve a higher MTF and SNR.

4. NIF experiments with P>10 Mbar quasi-isentropic platforms

4.1. Direct drive platform

We have designed a direct drive platform for NIF that can reach >10 Mbar on the sample. This will require the use of phase plates to smooth out the laser beam non-uniformities. Fig 3 (a) and (b) show simulation results for a design with a Mo sample achieving up to 1000 GPa (10 Mbar) peak pressure, in a solid-state [5]. The design consists of a 160 µm Be ablator, backed by a 290 µm CH(6% I) radiation shield, then a 550 µm carbon foam graded density region (in 9 steps). Next follows a 1.2 mm vacuum gap, followed by a 30 µm CH(2% Br) heat shield, the 100 µm Mo sample, and finally a 400 µm vanadium tamper. Fig 3 (b) is the pressure profile at depths of 5, 10, 20, and 40 µm into the Mo sample, for a design based on a one-dimensional simulation, assuming a laser intensity of I_L = 3.8 x 10^{13} W/cm^2 for 49 ns. If we assume that 50% of the laser energy is contained in the useful 3.4 mm diameter spot, this design corresponds to total laser energy of 0.34 MJ.

4.2. Indirect drive platform

We also designed an isentropic platform driven indirectly by x rays emitted by hohlraums for NIF experiments [6]. For this design, two-dimensional simulations of a laser driven gold hohlraum lined with 2 μm of plastic were performed using the LASNEX hydrodynamics code to produce the drive source for one-dimensional modeling of the package reservoir and sample that yields a peak radiation temperature of 175 eV with 1 MJ laser energy and 10 ns pulse duration. This radiation source is then used to model the hydrodynamic response of the ablator and reservoir materials. Figure 3 (c) shows the our design of a target package that consists of beryllium as the ablating material, SiO_2 and Cu as the shielding for the Au M-band from the hohlraum, and a graded density reservoir that controls the first few nanoseconds of sample compression and prepares the sample for the impact of the Cu and SiO2 layers. The sample itself is made up of three parts: a Be heat-shield, a Mo sample, and a high density carbon tamper. The large sample size allows us to investigate multiple crystal grains of varying sizes. Figure 3 (d) shows the pressure history at the front of the molybdenum sample. The individual layers of the reservoir materials are responsible for the individual "steps" seen in the pressure history. In this design, we can maintain a pressure on the target of >10 Mbar for approximately 10 ns. This design does not require phase plates in the drive laser.

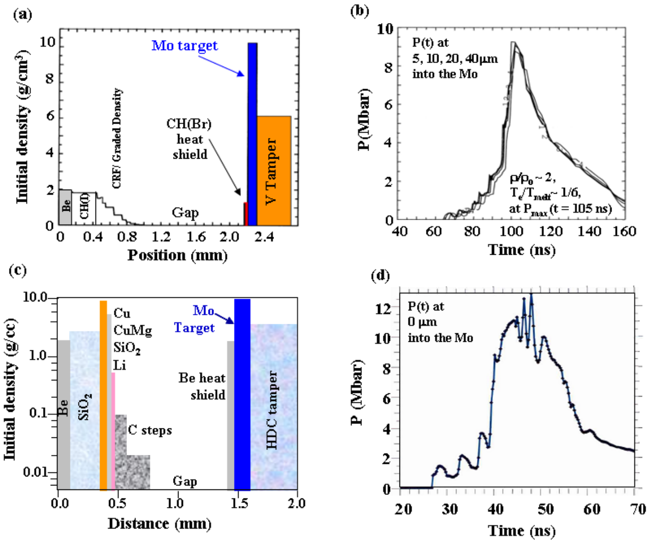

Figure 3. Simulation results up to 1000 GPa (10 Mbar) peak pressure, solid-state design for a Mo sample as a candidate experiment for the NIF by laser illuminating direct drive and x-ray illuminating indirect drives. (a) Initial target density profile for direct drive design. (b) Pressure time history of direct drive design into the Mo sample. (c) Initial target density profile for indirect drive design by a hohlraum. The peak Tr of this design is ~175 eV using 1 MJ laser energy of 10 ns pulse duration. (d) Pressure profile of indirect drive design

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