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XUV RADIOGRAPHY MEASUREMENTS OF DIRECT DRIVE IMPRINT IN THIN ALUMINUM FOILS USING A GE X-RAY LASER ON VULCAN

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INTRODUCTION

One key aspect for high gain direct drive inertial confinement fusion is the imprint of perturbations in the outer surface of a capsule due to nonuniformities in the direct laser illumination of the capsule. Direct drive implosions are achieved by uniformly irradiating the outside surface of a hollow spherical capsule that contains a layer of fusionable D-T on its inner surface. The intensity of laser irradiation is down with a low intensity 'foot' at 10^{13} W/cm^2 for several nanoseconds before it builds up to more tha 10^{15} W/cm^2 during the main drive portion of the pulse. Laser ablation of the capsule surface produces a high pressure that accelerates the capsuel shell radially inward in a spherical implosion. During this acceleration, perturbations due to surface roughness and due to imprint from spatial non-uniformities in the laser irradiation undergo Rayleigh-Taylor growth, potentially severely degrading performance.

Our interest is in studying the imprint process and subsequent Rayleigh-Taylor growth of perturbations in a foil target that is irradiated by a low intensity laser speckle pattern. Previous experiments have been done to study laser imprint with an x-ray laser backlighter at the Nova laser using 0.35 μm laser irradiation of at 3 μm Si foil[1,2,3]. In these experiments we irradiated a 2 μm thick Al foil with 0.53 μm laser light at 2-8x10^{12} W/cm^2 using the Vulcan laser. We used a Ge x-ray laser[4] as an XUV backlighter to measure the modulation in optical depth of the foil on a CCD during the initial imprint phase and after Rayleigh-Taylor growth with different laser smoothing schemes.

We used a single Vulcan laser beam with a static random phase plate speckle pattern, smoothing by spectral dispersion, and smoothing by ISI. We compared the results with results from a multiple beam overlap of static speckle patterns and SSD smoothed speckle patterns. We also measured the growth of a single wavelength modulation that was imprinted by a single mode optical intensity modulation onto the target. We used Al foil targets since Al has the lowest opacity for the Ne-like Ge x-ray laser wavelength of 19.6 nm. The Al is still highly attenuating, which limits the experiment to thin foils. It also means, however, that the technique is sensitive to small modulations in the thickness of the foil. At 19.6 nm, the product of opacity time density for Al is 2.24 μm^{-1}. With this high an opacity, a thickness variation of only 50 nm results in a 10% change in signal intensity.

EXPERIMENT

We used six beams of the Vulcan laser to generate a Ge x-ray laser. Three of the six beams of 1.06 μm laser light were focused with an overlapping line focus onto each of two 100 μm wide strips of Ge deposited on glass slides. For these experiments we used two 18 mm targets that had a separation of 200 μm, as illustrated in Figure 1. We used 100 ps pulses with a 10% pre-pulse 2 ns before the main pulse. Under these conditions, the x-ray laser beam had a divergence of about 30 mrad in the plane of the x-ray laser target surface, and 10 mrad normal to the plane.

We placed a thin (2 μm) Al foil about 3 cm from the output of the Ge x-ray laser. We then used two multilayer mirrors to image the Al foil in the x-ray laser wavelength onto an XUV sensitive CCD (Figure 1). A spherical mirror with a 1 m radius of curvature was placed 53 cm from the Al foil, providing a 16X magnified image of the foil on the CCD at near normal incidence (<0.6°). The CCD was filtered with an additional 0.8 μm Al foil to reduce thermal emission from the foil, and a 45° angle of incidence planar mirror was used to relay the image onto the CCD and spectrally isolate the image from the thermal background noise.

The XUV mirror imaging system used near normal incidence reflection from the spherical imaging mirror to minimize spherical aberrations. The resolution of this imaging system was better than 1 μm.

We conducted a series of experiments to study the imprinting of a 0.53 μm laser beam on a thin Al foil by measuring the modulation

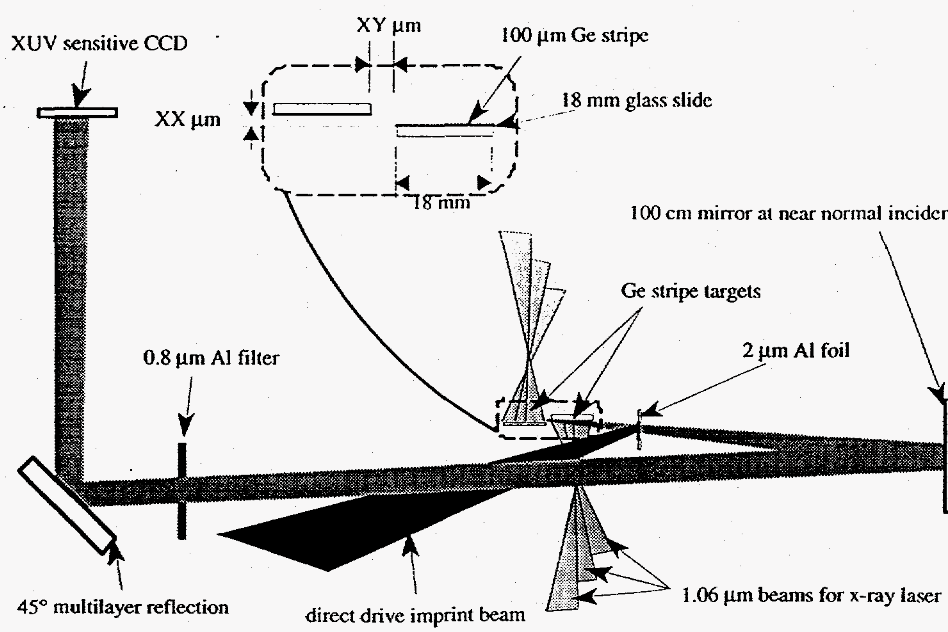


Figure 1: Geometry for the x-ray laser target and XUV imaging system to measure the modulation in optical depth of a thin Al foil due to direct drive laser imprint on Vulcan.

of the foil as a function of time with various laser smoothing schemes. This modulation was imprinted by variation in optical intensity and enhanced by Rayleigh-Taylor growth at late time.

We used up to two beams of the Vulcan laser as drive beams to directly irradiate the Al foil with the following series of configurations:

1. Multiple mode laser intensity modulation:
   - a) single beam irradiation
     - static speckle pattern
     - 1-D SSD smoothed speckle pattern
     - ISI smoothed speckle pattern
   - b) two beam overlap
     - static speckle pattern
     - 1-D SSD smoothed speckle pattern

2. Single mode laser intensity modulation
   - a) 15 μm wavelength
   - b) 30 μm wavelength

In this report, we present preliminary results from the experiments using a multiple mode laser intensity modulation.

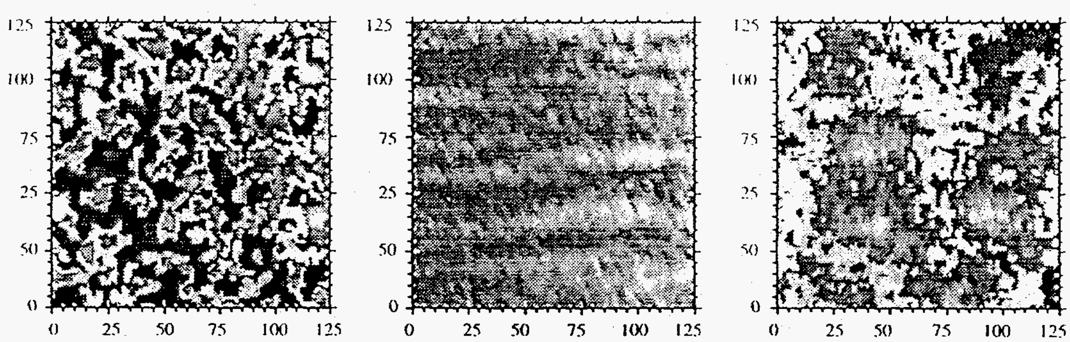
RESULTS AND DISCUSSION

In Figure 2, we show optical far field images of the single beam laser focal spot recorded during these experiments on photographuc film in an equivalent target plane. This figure shows intensity modulation of a) a static RPP speckle pattern, b) a 1-D SSD smoothed speckle pattern, and c) for an ISI smoothed RPP speckle pattern. Each image shows a 125 μm square region in the focal plane. The static speckle pattern shows small scale modulation in intensity. The irradiation beam was 12 cm in diameter, with a focal length of 1 m. The phase plate element size was 0.75 mm, resulting in a minimum speckle size of about 9 μm. The modulation is smoothed with one-dimensional streaks due to the dispersion of the grating used for SSD. The bandwidth of the laser pulse was about 0.5 nm at 0.53 μm, and we used a 300 line/mm gating, providing a dispersion of about 0.17 mrad. We used an RPP with ISI smoothing to generate the smoother irradiation pattern shown in Figure 2c.

We irradiated the 2 μm thick Al foils directly by an intensity of 3-8x10^{12} W/cm^2 of 0.53 μm laser light using the different speckle patterns shown above in Figure 2. We recorded the modulation in optical depth in the foil due to laser imprint and subseqent Rayleigh-Taylor growth using the Ge x-ray laser backlighter. We show several XUV radiographs as modulation in optical depth recorded at 0.2 ns into the laser pulse in Figure 3 for the three cases of imprint due to a static random phase plate (RPP) speckle pattern, an speckle pattern smoothed by spectral dispersion (SSD), and an speckle pattern wth induced spatial incoherence (ISI smoothing). Power spectra for the imprinted modulation measured in these images are shown in Figure 4. These are plotted as power per mode, such that the square root of the integral under the curves is the root mean square (RMS) modulation in the radiograph image. Note that we also show the power spectrum obtained for an undriven target for comparison in this figure.

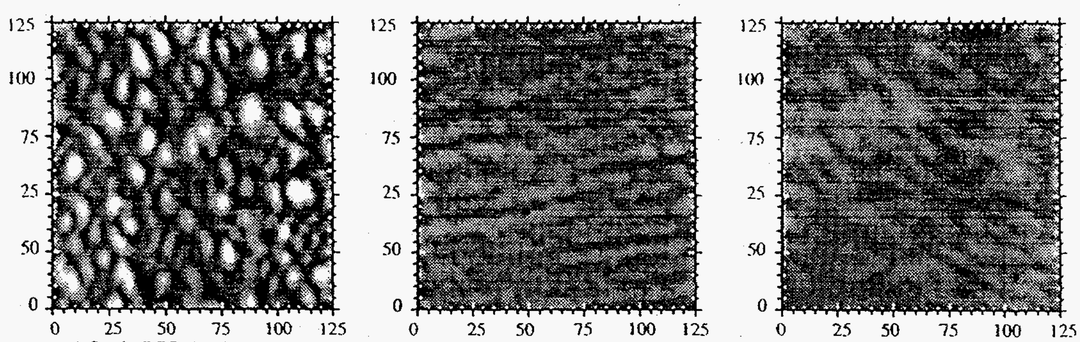
The RMS modulation in optical depth we measured from the XUV radiographs shown in Figure 3 were 0.37, 0.17, and 0.20. The RMS measured from undriven Al foil targets was 0.13. This corresponds to a surface roughness of about 60 nm. We show the optical depth modulation as a function of time recorded by XUV radiography in Figure 5. This figure shows that the modulation imprinted due to a static speckle pattern grows faster than for a smoothed speckle pattern. The SSD smoothed case shows a strong reduction in the modulation, but it still late in time. The ISI smoothed beam, however, does not show significant growth at any time up to 0.8 ns. In this case, the ISI smoothing technique that is implemented on the Vulcan laser introduces a time skew in the drive beam of about 0.22 ns, so it takes much longer to rise up to the nominal intensity for the 1 ns laser pulse.

We further compared the modulation imprinted in the foil due to overlapping drive beams. We used two beams, both with a 1 ns pulse at 0.53 μm. We overlapped two beams with a static RPP



a) Static RPP speckle pattern b) SSD smoothed speckle pattern c) ISI smoothed speckle pattern

Figure 2: Equivalent target plane images of the laser focal spot recorded with a) a static RPP speckle pattern, b) a 1-dimensional SSD smoothed speckle pattern, and c) an ISI smoothed speckle pattern. The scale is in microns at the target.



a) Static RPP speckle pattern b) SSD smoothed speckle pattern c) ISI smoothed speckle pattern

Figure 3: Modulation in optical depth of an Al foil irradiated by a 0.53 μm direct drive laser beam smoothed with a) a static RPP speckle pattern, b) a 1-dimensional SSD smoothed speckle pattern, and c) an ISI smoothed speckle pattern. These images were recorded at 200 ps into the drive pulse using the Ge x-ray laser backlighter. The scale is in microns at the target, and they are plotted on the same grayscale from -1.2 to +1.2 in optical depth.

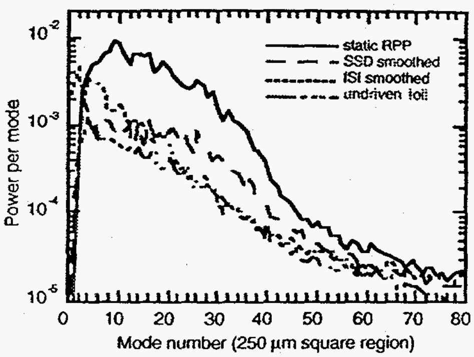


Figure 4: Power per mode caluclated from the XUV optical depth modulation measured from the radiograph images shown in Figure 3.

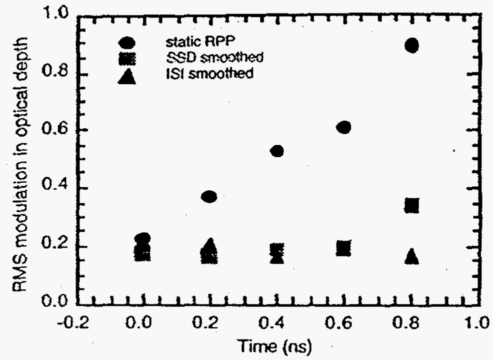


Figure 5: RMS modulation in optical depth of the Al foil measured as a funtion of time for static, SSD smoothed, and ISI smoothed drive beams.

speckle pattern and two beams with an SSD smoothed speckle pattern.

Figure 6 shows XUV radiographs recorded at about 0.2 ns for these two cases with an intensity of about XX. The equivalent focal plane image for the overlapped static speckle patterns appears to show smaller scale structure than for a single static RPP speckle pattern in Figure 3a. The image for the overlapped SSD smoothed beams shows streaks in two directions because the dispersion direction on the two beams was orthogonal. The RMS modulation in optical depth with two overlapping static speckle patterns was 0.30. It was 0.17 for the two overlapped SSD smoothed beams.

We also conducted preliminary experiments to compare the imprint and RT growth of single mode vs multimode modulations in a thin Al foil. We placed a two-slit aperture in the 0.53 μm laser drive beam that provided an Airy pattern to illuminate the target at about 2×10^{13} W/cm^2. The slits were designed to provide and interference pattern with a single dominant wavelength at 15 μm and 30 μm. We recorded a series of images at different times to measure the growth of the modulation. Preliminary results from these measurements are presented separately in this proceedings.

SUMMARY

These experiments showed that we could make measurments of the modulation imprinted by direct drive on a thin foil using the Ge x-ray laser at the Vulcan laser facility. We made measurements of the imprinted modulation and subsequent Rayleigh-Taylor growth as a function of time with various laser smoothing schemes. We also made measurements of the modulation imprinted by a single mode optical perturbation.

Full analysis of the imprint and subsequent Rayleigh-Taylor growth measurements is in progress, and will be reported in full detail in future publications. This will include comparisons of the imprinted modulation with previous experiments made on the Nova laser that used a 0.35 μm laser imprint wavelength, as well as with simulations.

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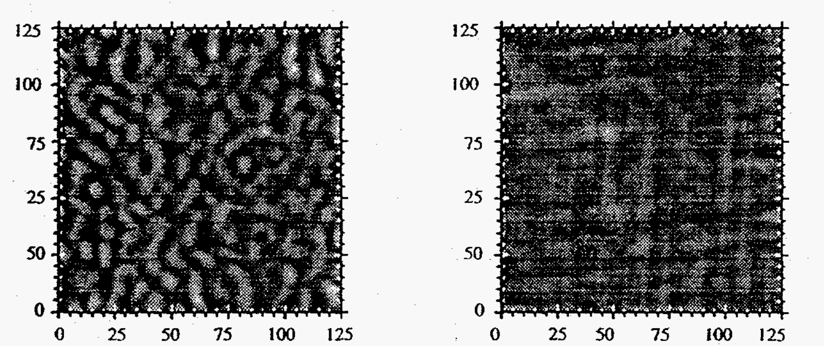
[4] J. Zhang about the Ge x-ray laser



a) Overlapped static RPP speckle patterns b) Overlapped SSD smoothed speckle patterns

Figure 6: modulation in optical depth of an Al foil irradiated by two overlapping 0.53 μm laser beams with a) static RPP speckle patterns, and b) SSD smoothed speckle patterns.