UCRL-JC-123284
PREPRINT
CONF-960543--8

XUV Probing of Laser Imprint in a Thin Foil Using an X-Ray Laser Backlighter

RECEIVED
MAY 30 1996
OSTI

D. H. Kalantar, L. B. DaSilva, A Demir, S. G. Glendinning,
M. H. Key, N. S. Kim, J. P. Knauer, C. L. S. Lewis, J. Lin,
D. Neely, A. McPhee, B. A. Remington, R. Smith,
G. J. Tallents, J. S. Wark, J. Warwick, F. Weber,
S. V. Weber, E. Wolfrum, and J. Zhang

This paper was prepared for submittal to the
11th Topical Conference on High Temperature Plasma Diagnostics
Monterey, California
May 12-16, 1996

May 6, 1996

Lawrence Livermore National Laboratory

XUV probing of laser imprint in a thin foil using an x-ray laser backlighter

D. H. Kalantar[1], L. B. DaSilva, A. Demir[2], S. G. Glendinning, M. H. Key[3,4], N. S. Kim[3], J.P. Knauer[5], C. L. S. Lewis[6], J. Lin[2], D. Neely[3], A. McPhee[6], B. A. Remington[1], R. Smith[2], G. J. Tallents[2], J. S. Wark[4], J. Warwick[5], F. Weber, S. V. Weber[1], E. Wolfrum[3], J. Zhang[4]

[1]*Lawrence Livermore National Laboratory, Livermore, CA*

[2]*Department of Physics, University of Essex, Colchester, UK*

[3]*Central Laser Facility, Rutherford Appleton Laboratory, Chilton, Didcot, UK*

[4]*Clarendon Laboratory, Department of Physics, University of Oxford, Oxford, UK*

[5]*Laboratory for Laser Energetics, University of Rochester, Rochester, NY*

[6]*Department of Pure and Applied Physics, Queens University of Belfast, Belfast, UK*

For direct drive ICF, a capsule is imploded by directly illuminating the surface with laser light. Beam smoothing and uniformity of illumination affect the seeding of instabilities at the ablation front. We have developed a technique for studying the imprint of a laser beam on a thin foil using an x-ray laser as an XUV backlighter. We use multilayer XUV optics to relay the x-ray laser onto the directly driven foil, and then to image the foil modulation onto a CCD camera. This technique allows us to measure small fractional variations in the foil thickness. We have measured the modulation due to imprint from a low intensity 0.35 μm drive beam incident on a 3 μm Si foil using an yttrium x-ray laser on Nova. We present results from a similar technique to measure the imprinted modulation due to a low intensity 0.53 μm drive beam incident on a 2 μm Al foil using a germanium x-ray laser at the Vulcan facility.

Introduction

Direct drive inertial confinement fusion is achieved by uniformly irradiating the outside surface of a hollow spherical capsule that contains a solid layer of fusionable D-T on its inner surface directly with high power laser beams. The laser pulse shape starts with a low intensity 'foot' at 10^{13} W/cm^2 for several nanoseconds and it builds up to more than 10^{15} W/cm^2 during the main drive portion. Laser ablation of the capsule surface produces a high pressure that accelerates the capsule shell radially inward in a spherical implosion, compressing the fusion fuel at the center.

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[1]. As the laser ablates material from the outer surface of the capsule, 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. We conducted preliminary experiments to study laser imprint with an x-ray laser backlighter on the Nova laser using 0.35 μm laser irradiation at ~$3\text{x}10^{12}$ W/cm^2 of a 3 μm Si foil[2-4]. We follow up with further experiments where we irradiated a 2 μm thick Al foil with 0.53 μm laser light at $2\text{-}8\text{x}10^{12}$ W/cm^2 using the Vulcan laser. We used a germanium (Ge) x-ray laser[5] as an XUV backlighter to measure the modulation in optical depth of the foil on a CCD due to imprint and subsequent Rayleigh-Taylor growth with different laser smoothing schemes. In this paper we describe the x-ray laser and XUV imaging system, and we describe x-ray laser backlit measurements of the imprinted modulation in thin Al foils.

XUV radiography

We used six beams of the Vulcan laser to generate a Ge J=0-1 x-ray laser at 19.6 nm using a double slab target design, as illustrated in Figure 1. The Ge x-ray laser target consisted of two 18 mm long, 100 μm wide Ge stripes coated on glass slides. They were pre-aligned off-line, and then positioned in the target chamber with a gap of 200 μm between the parallel surfaces, and a separation along the axis of 500 μm.

Three beams were focused at 1.05 μm with f/2.5 spherical lenses and reflected from f/2.5 off-axis spherical mirrors onto each Ge stripe from opposite sides of the target chamber. We used 75 ps laser pulses with a 10-30% prepulse 2.2 ns before the main pulse, and we timed the two sets of three beams with a 60 ps relative delay in a traveling wave configuration. The first three beams were incident on one Ge stripe. Then, the second set of three beams were incident on the other target with the 60 ps delay so that the x-ray laser output from the first target would have maximum amplification in the Ge plasma from the second target.

The Ge x-ray laser had an output divergence of about 30 mrad in the vertical direction, and <10 mrad in the horizontal direction. We placed a thin Al target that was directly driven by a low intensity 0.53 μm laser beam about 3 cm from the output end of the Ge x-ray laser. We then used multilayer optics to image the thin Al in 19.6 nm radiation from the x-ray laser. Note that for these experiments we used thin Al foils since Al has the lowest opacity at 19.6 nm. The product of density times opacity for Al is 2.24 μm^{-1}. It is still highly attenuating, though, which allows us to make measurements of small thickness modulations. A thickness variation of only 50 nm results in a 10% change in signal intensity.

The layout of the XUV imaging optics is shown in Figure 1. We used a near-normal incidence spherical mirror with a 100 cm radius of curvature, positioned approximately 53 cm from the Al foil. The spherical mirror imaged the Al foil onto an

XUV sensitive CCD at 16.8X magnification. The second mirror was a flat mirror that was used to spectrally isolate the backlit image from the thermal background. The mirrors were multilayer coated with multilayer pairs of molybdenum and silicon, resulting in about 20% reflectivity at 19.6 nm with a 1.5 nm bandwidth.

Since we were imaging at near normal incidence with a spherical mirror, we were able to minimize the effect of spherical aberrations. We characterized the resolution by imaging a two-dimensional grid pattern by x-ray radiography with the Ge x-ray laser. The grid was a gold grid with 25 μm line spacing. Figure 2 shows the XUV radiograph image we recorded.

We measured values of the two-dimensional modulation transfer function (MTF) from the backlit grid image by comparing with a simulated image that had 100% contrast. Figure 3 shows the MTF. These points were measured from one-dimensional lineouts of the radiograph in the vertical and horizontal directions. Overlaid on the graph is a lineout of the MTF calculated from an 8 μm full width at half maximum gaussian point spread function. Note that at $\lambda=10$ μm, the value of the MTF is ~0.5, and for $\lambda=6$ μm, it is about 0.2.

Imprint experiments

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 of the foil as a function of time with various laser smoothing schemes. We placed a thin (2 μm) Al foil about 3 cm from the output of the Ge x-ray laser. We then used a single Vulcan laser beam to imprint modulation on the Al foil by direct drive irradiation at 0.53 μm, and we recorded the modulation by XUV radiography. We measured the imprinted modulation due to a static random phase plate (RPP)[6] speckle pattern, a speckle pattern smoothed by one-dimensional spectral dispersion (SSD)[7], and a speckle pattern smoothed by induced spatial incoherence (ISI)[8]. We also made measurements of the modulation imprinted by two overlapped beams with static speckle patterns and with spectrally dispersed speckle patterns.

The direct drive imprint beam was ~12 cm in diameter, and the focus lens had a focal length of 1 m. The phase plate element size was 0.75 mm, resulting in a minimum full 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 1.4 nm at 1.05 μm, and we used a 300 line/mm gating, providing a dispersion of about 0.17 mrad[9]. We used an RPP with ISI smoothing to generate a smoothed irradiation pattern. Figure 4 shows the speckle patterns we recorded for the three cases.

We irradiated the 2 μm thick Al foils with a 1 ns laser pulse at about $2\text{-}8 \times 10^{12}$ W/cm^2 at 0.53 μm. We recorded the modulation in optical depth in the foil due to laser imprint and subseqent Rayleigh-Taylor growth by making XUV radiography measurements at various times relative to the imprint laser pulse over a series of shots. We compared the modulation imprinted in the foil from a single 0.53 μm beam with that due to two overlapping 0.53 μm beams with a static RPP speckle pattern and two beams with a 1-D SSD smoothed speckle pattern with orthogonal dispersion directions.

We show XUV radiographs in Figure 5 that were recorded for each smoothing scheme at tø+0.2 ns, where tø is defined by when the laser pulse reaches half maximum intensity, as illustrated by the laser pulse shape in Figure 6. Figures 5a-c show the modulation due to imprinting a single drive beam for the cases of imprint due to a static RPP speckle pattern (Figure 5a), 1-D SSD smoothed speckle pattern (Figure 5b), and an ISI smoothed speckle pattern (Figure 5c). Figure 5d-e show the modulation due to imprinting with two overlapped drive beams with static speckle patterns (Figure 5d), and 1-D SSD speckle patterns (Figure 5e). These radiographs are shown as modulation in optical depth. The RMS modulations in optical depth are 0.37, 0.17, and 0.20 for the single beam imprint images, and 0.30 and 0.17 for the overlapped beam imprint images. Note that the RMS measured from undriven Al foil targets was 0.13-0.17. This corresponds to a surface roughness of about 60 nm.

The XUV radiograph image for the overlapped static speckle patterns (Figure 5d) appears to show smaller scale structure than for a single static RPP speckle pattern in Figure 5a. The image for the overlapped SSD smoothed beams (Figure 5e) shows streaks in two directions because the dispersion directions on the two beams were orthogonal.

We show the optical depth modulation as a function of time recorded by XUV radiography in Figure 6. The laser pulse shape is shown overlaid as a reference for the timing. Figure 6 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 grows late in time. The ISI smoothed beam, however, does not show significant growth at any time up to 0.8 ns. Note that the slightly higher RMS for the ISI imprinted modulation is due to the surface finish of the targets used for those shots. The ISI smoothing technique that is implemented on the Vulcan laser introduces a time skew in the drive beam of about 0.22 ns, slowing the rising edge of the laser pulse shape.

Summary

These experiments demonstrated that we could make measurements 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 a single imprint beam using various laser smoothing schemes. We also made measurements of the modulation imprinted by a two overlapped beams. Results show that laser beam smoothing does reduce the imprinted modulation. ISI smoothing reduced the modulation recorded significantly compared to both a single SSD smoothed beam and two overlapped SSD smoothed beams.

Acknowledgments

We thank the Vulcan laser operations, target preparation, and engineering groups for their help and cooperation in these experiments. This work was partially supported by the Lawrence Livermore National Laboratory under the auspices of the U.S. Department of Energy under Contract No. W-7405-ENG-48.

List of figures

Figure 1: Diagram showing the two slab Ge x-ray laser target geometry and the layout for the XUV imaging optics.

Figure 2: XUV radiograph of the two-dimensional grid obtained to characterize the resolution of the imaging system. The scales are in microns at the target plane.

Figure 3: Modulation transfer function of the XUV imaging system used for these experiments.

Figure 4: Far field images of the laser speckle pattern used to imprint modulations in the 2 μm Al foils. We show a) the static speckle pattern, b) an SSD smoothed speckle pattern, and c) an ISI smoothed speckle pattern. The scales are microns at the focal plane of the imprint beam.

Figure 5: XUV radiographs of Al foils imprinted by direct drive irradiation with a single 0.53 μm beam (a-c) and two overlapping 0.53 μm beams (d-e). The scales are in microns at the target plane.

Figure 6: RMS modulation of the Al foil as a function of time. The imprint beam pulse shape is overlaid for timing.

References

[1] M. H. Emery, J. H. Gardner, R. H. Lehmberg, and S. P. Obenschain, *Phys. Fluids B* **3**, 2640 (1991).

[2] M. H. Key, T. W. Barbee, Jr., L. B. DaSilva, S. G. Glendinning, D. H. Kalantar, S. J. Rose, and S. V. Weber, *J. Quant. Spectrosc. Radiat. Transfer* **54**, 221 (1995).

[3] D. H. Kalantar, T. W. Barbee, Jr., L. B. DaSilva, S. G. Glendinning, M. H. Key, J. P. Knauer, F. Weber, and S. V. Weber, *Rev. Sci. Instrum.* **67**, 781 (1996).

[4] D. H. Kalantar, M. H. Key, L. B. DaSilva, S. G. Glendinning, J. P. Knauer, B. A. Remington, F. Weber, and S. V. Weber, *Phys Rev. Letters* **76**, 3574 (1996).

[5] J.C. Moreno, R.C. Cauble, P. Celliers, L.B. DaSilva, J. Nilsen, and A.S. Wan, *Soft X-Ray Lasers and Applications*, Proc. Soc. Photo-Opt. Instrum. Eng. **2520**, 97 (1995).

[6] Y. Kato, K. Mima, N. Miyanaga, S. Aringa, Y. Kitagawa, M. Nakatsuka, and C. Yamanaka, *Phys. Rev. Lett.* **53**, 1057 (1984).

[7] S. Skupsky, R. W. Short, T. Kessler, R. S. Craxton, S. Letring, and J. M. Soures, *J. Appl. Phys.* **66**, 3456 (1989).

[8] R. H. Lehmberg and S. P. Obenschain, *Optics Communications* **46**, 27 (1983).

[9] D. A. Peplar, C. N. Danson, R. Bann, I. N. Ross, R. M. Stevenson, M. J. Norman, M. Desselberger, and O. Willi, *Lser Coherence Control: Technology and Applciations*, Proc. Soc. Photo-Opt. Instrum. Eng. **1870**, 76 (1993).

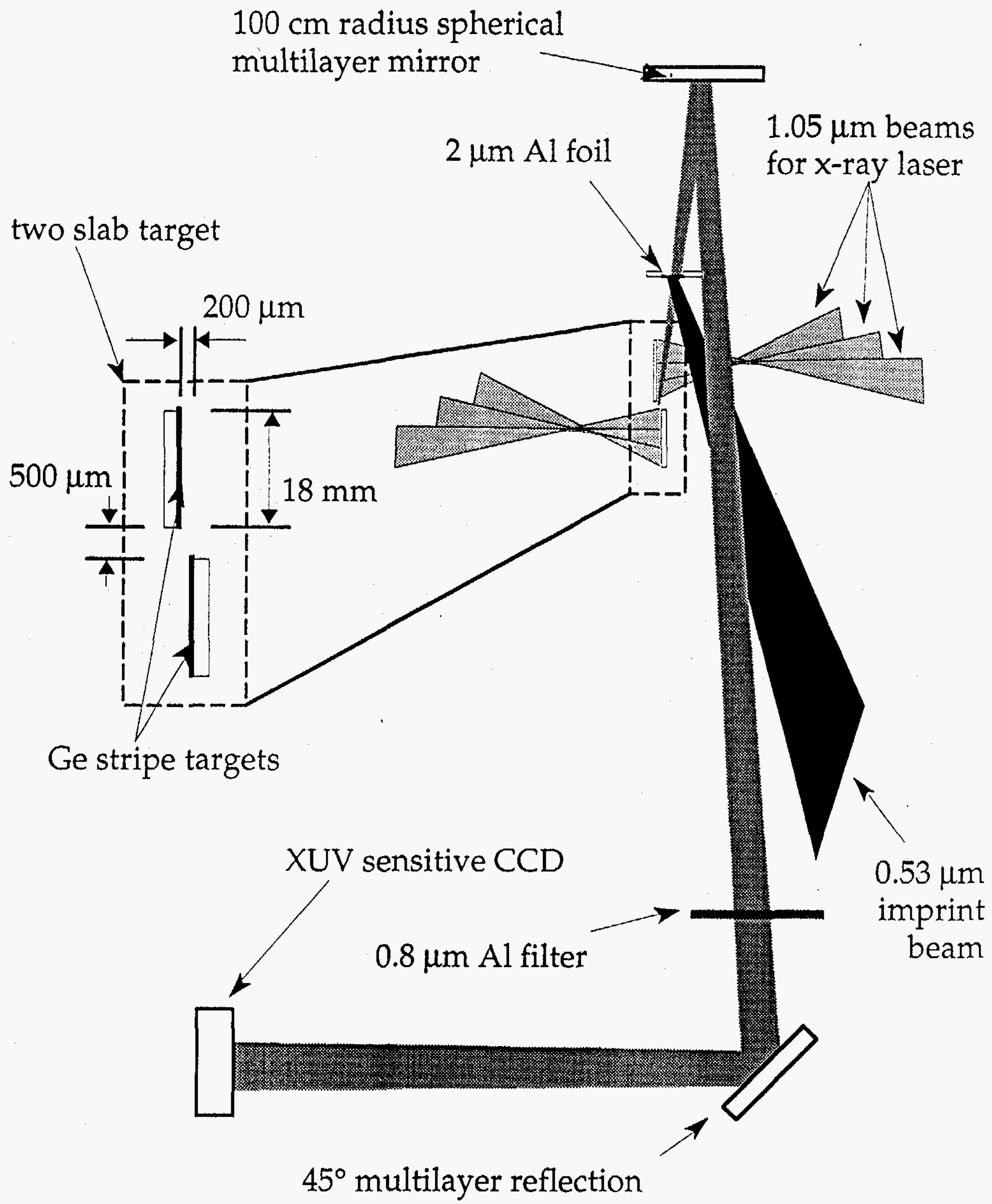


Figure 1: Diagram showing the two slab Ge x-ray laser target geometry and the layout for the XUV imaging optics.

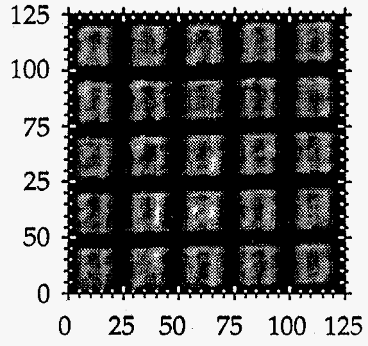


Figure 2: XUV radiograph of the two-dimensional grid obtained to characterize the resolution of the imaging system. The scales are in microns at the target plane.

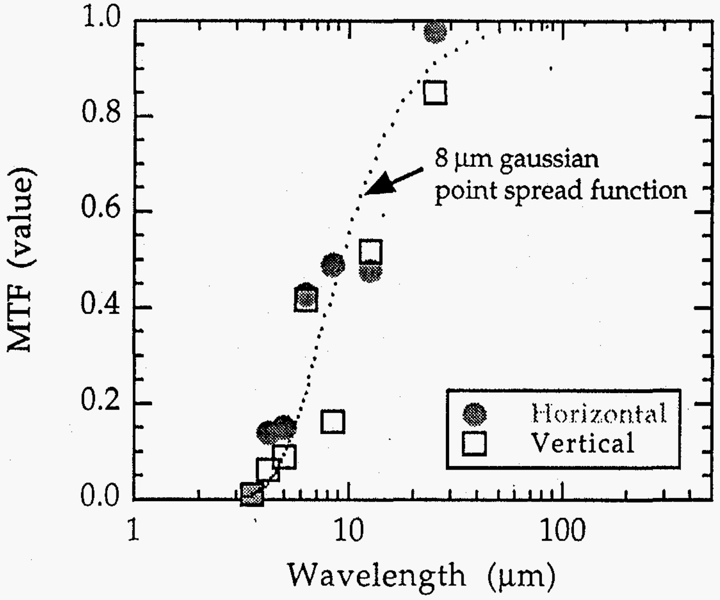
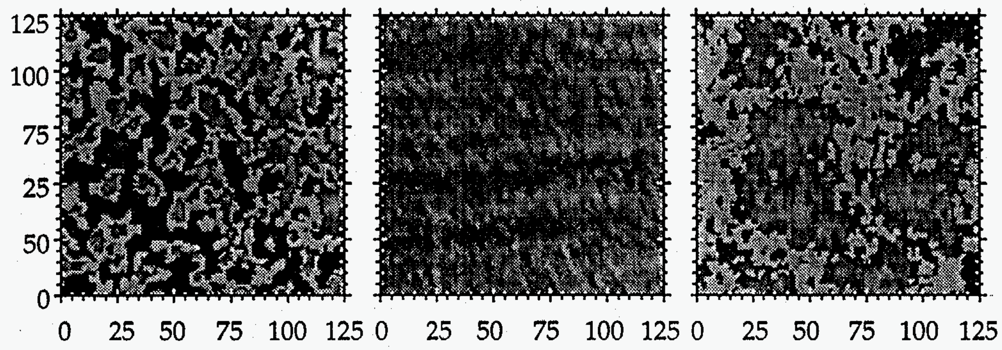
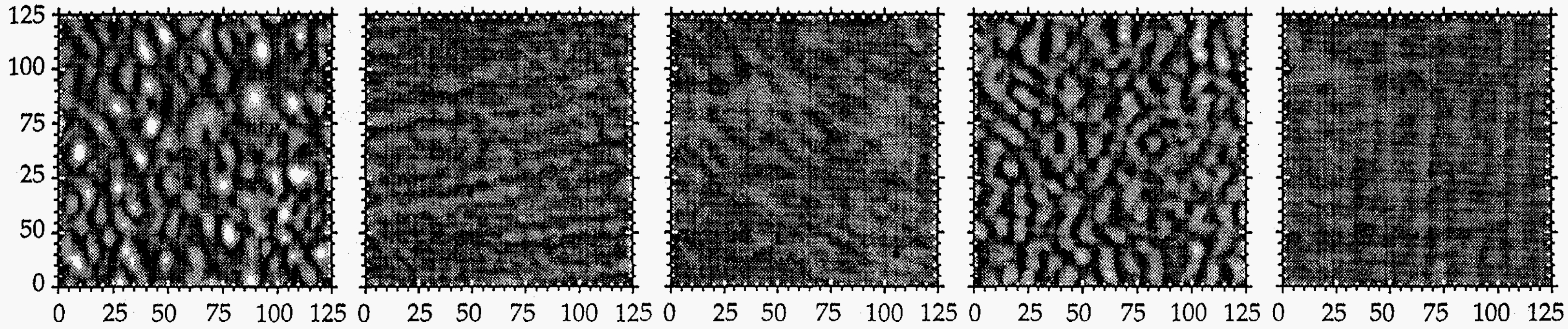


Figure 3: Modulation transfer function of the XUV imaging optics used for these experiments.



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

Figure 4: Far field images of the laser speckle pattern used to imprint modulations in the 2 μm Al foils. We show a) the static speckle pattern, b) an SSD smoothed speckle pattern, and c) an ISI smoothed speckle pattern. The scales are microns at the focal plane of the imprint beam.



a) Static speckle b) SSD smoothed speckle c) ISI smoothed speckle d) Overlapped static e) Overlapped SSD

Figure 5: XUV radiographs of Al foils imprinted by direct drive irradiation with a single 0.53 μm beam (a-c) and two overlapping 0.53 μm beams (d-e). The scales are in microns at the target plane.

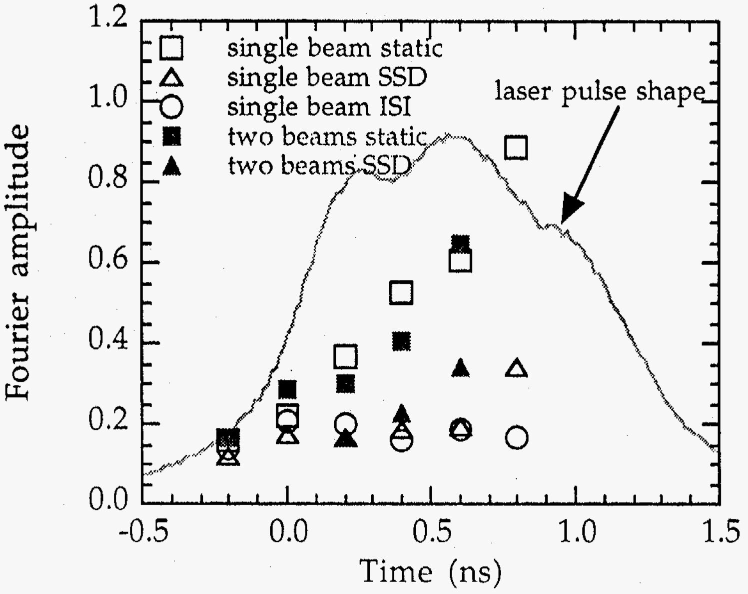


Figure 6: RMS modulation of the Al foil as a function of time. The imprint beam pulse shape is overlaid for timing.

Technical Information Department • Lawrence Livermore National Laboratory
University of California • Livermore, California 94551