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Abstract. We have imaged laser-accelerated foils and exploding foils on the few-micron scale using an yttrium x-ray laser (155 Å, 80 eV, ~ 200 ps duration) and a multilayer mirror imaging system. At the maximum magnification of 30, resolution was of order one micron. The images were side-on radiographs of the foils. Accelerated foils showed significant filamentation on the rear-side (away from the driving laser) of the foil, although the laser beam was smoothed. In addition to the narrow rear-side filamentation, some shots revealed larger-scale plume-like structures on the front (driven) side of the Al foil. These plumes seem to be little-affected by beam smoothing and are likely a consequence of Rayleigh-Taylor instability. The experiments were carried out at the Nova two-beam facility.

INTRODUCTION

Production of laboratory x-ray lasers (XRL) is robust enough that the special features of the XRL can now be confidently exploited. One such feature is high brightness, which makes XRLs especially well-suited for imaging other bright sources such as laser plasmas, where the XRL can actually dominate much of the plasma self-emission. We have utilized an imaging system (1), shown in Fig. 1, which operates in the soft x-ray spectral region to obtain high resolution images of laser accelerated and x-ray heated aluminum foils.

The x-ray laser is produced from an exploding yttrium target by one 600 ps long, 0.53 μm wavelength, 2 kilojoule beam of the Nova laser; the other Nova beam is used to create the plasma target. The XRL (2) has a wavelength of 155 Å, a duration of about 200 ps and an energy of about 8 mJ. The collimated XRL in the imaging system has a diameter of approximately 5 mm, which is sufficient to image

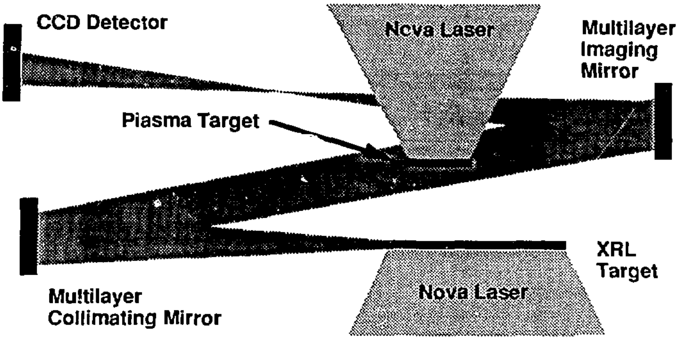

FIGURE 1. Experimental setup for plasma imaging using an x-ray laser on the Nova two-beam facility.

an entire plasma target. The bandpass of the entire system is of about 8 Å. Images were recorded on a 1024x1024 pixel CCD detector.

HIGH RESOLUTION PLASMA IMAGES

Figure 2 shows an image of a laser accelerated foil backlit by the yttrium (Y) XRL halfway through a high energy 1 ns drive. The foil, which was 10 μm of CH on 3 μm Al, was irradiated on the CH side. Horizontal spatial resolution is better than 2 μm. Vertical resolution is limited by the XRL duration to ~ 10^7 cm/s x 200 ps = 20 μm. Although the Nova drive beam was smoothed with steering wedges and a random phase plate, small-scale, 5-6 μm, structure is evident on the rear (Al) side. Larger-scale structure can also be observed. Some of the structure may be an artifact due to refraction of the XRL beam along extreme density gradients in the foil plasma, thus the actual extent of the plasma cannot be quantified from the image. However, the XRL beam is spatially quite smooth so the nonuniformities observed in the image are indeed produced by density variations within the plasma.

Further experiments with these foils have revealed structure on the front (CH) side of an accelerated foil. As before, the plasma is backlit with the Y XRL, but because of higher frontside temperatures, self-emission is very strong. In addition to steering wedges and phase plate, the drive beam was also smoothed by adding 17 Å of frequency dispersion to the beam. In spite of this additional beam smoothing, the front side of the foil shows tens-of-micron size plumes coming off the foil. These are likely a consequence of Rayleigh-Taylor instability.

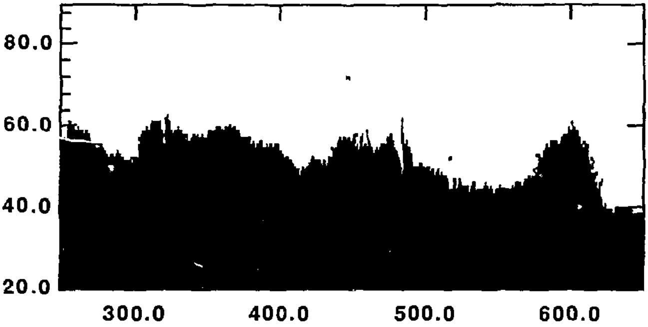

FIGURE 2. X-ray laser backlit image of a foil (10 μm CH on 3 μm Al) accelerated by a 1 ns Nova pulse taken at 0.5 ns. The picture shows an enlarged view of the central region of the foil plasma, which is being driven upward in the picture. The scale is in microns; the 700 μm diameter foil was originally located at zero on the vertical scale. The Nova beam was smoothed, but there are the spatial nonuniformities in the plasma.

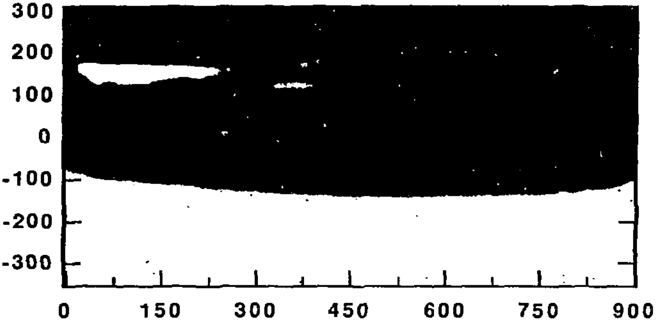

FIGURE 3. X-ray laser backlit image of an exploding foil 1 ns after the end of a 1 ns heating pulse. Zero marks the original foil position. The drive is incident through the support above in the picture. The scale is in microns.

Figure 3 displays an XRL backlit image of an exploding foil. The foil in this case is 3 μm of aluminum. The heating mechanism was indirect absorption of gold M-band radiation (about 2 keV) which was produced by illuminating a 300 μm spot with the remaining Nova beam on one side (away from the exploding foil) of a 1500 Å gold burnthrough disk located 1 mm from the Al foil. X-rays < 2 keV passing through the Au foil were removed by a 50 μm plastic filter. The higher energy x-rays were absorbed volumetrically in the aluminum and the aluminum expanded nearly symmetrically. The Nova drive pulse was 1 ns; the XRL backlight occurred 1 ns after the end of the drive pulse. The image shows the foil expanded to about 200 μm, almost filling the 200 μm gap between the foil and a plastic support above. A single "fringe" can be seen below the plasma. This is believed to be caused by XRL rays, which have been refracted by 1-3 μm in the expanding plasma, re-positioned by the multilayer imaging mirror to a new spot in the image plane. Note that there is sufficient coherence in the XRL to produce circular diffraction patterns in the image plane around small imperfections (dust or oil droplets) on the collimating mirror.

CONCLUSIONS

The high brightness of x-ray lasers makes them ideal for studying plasmas. Some examples of high spatial resolution radiography using an XRL have been discussed here. All are 200 ps snapshots of fast-evolving plasmas. They reveal unexpected structure in the plasma, which may be due to drive beam nonuniformity or initial, undetected imperfections in the targets. More quantitative measurements can be made by combining the XRL's brightness with its property of coherence in deflectometry or interferometry. (1)

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