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2D Spatial Gain Profiles in Multiple-pulse Driven Ne-like Ge Lasers

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2D spatial gain profiles in multiple-pulse driven Ne-like Ge lasers

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Abstract. In this paper, we present the direct spatial measurement of the two-dimensional gain profiles for the Ne-like Ge 196 Å laser line using a slab target illuminated by the multiple pulse technique. To understand the spatial dependence for Ge plasmas driven by a series of 100 ps pulses 400 ps apart we did a series of Nova experiments backlighting short Ge amplifiers. Two-dimensional, high-resolution, spatial images of the 196 Å laser emission from the output aperture of the amplifiers were measured to determine the spatial position of the gain. The amplifier lengths were chosen to be short enough to avoid the significant refraction effects which have dominated the analysis of previous near field imaging experiments. To assure good temporal overlap, the traveling wave geometry was used to illuminate both the amplifier and backlighter. The amplifier design included a wire fiducial that provided an absolute spatial reference and avoided the usual difficulty of determining the location of the target surface. We compare the measured spatial gain profiles with simulations done using LASNEX, which calculates the hydrodynamic evolution of the plasma, and XRASER, which uses the temperatures and densities from LASNEX to do the gain and kinetics calculations. These experiments are the last X-ray laser experiments done on Nova and represent the end of an era.

1. Introduction

With most researchers now using some variant of the prepulse or multiple pulse technique [1,2], the Ne-like 3p $^1S_0 \rightarrow$ 3s $^1P_1$ laser line now dominates the laser output. To understand why this line now lases so well, imaging experiments have been done to measure the near field spatial dependence of the laser output under various illumination conditions. However, those experiments [3-5] were unable to measure the spatial position of the gain directly because the spatial distribution of the laser emission was determined primarily by refraction for the long lasers used. In this work we overcome the refraction limitation by imaging the near field output of short Ne-like Ge amplifiers which are backlit with output from a long Ne-like Ge laser. These measurements are compared with calculations.

2. Experimental Setup and Results

The experiments were conducted on the Nova 2 beam laser facility at LLNL. The Nova laser produced a series of three 100 ps pulses which were 400 ps apart. Each pulse produced 400 J of energy at 0.53 μm in a 120 μm wide by 4.5-cm long line focus, resulting in a peak intensity of 74 TW/cm^2. Figure 1 shows a schematic of the experiment.

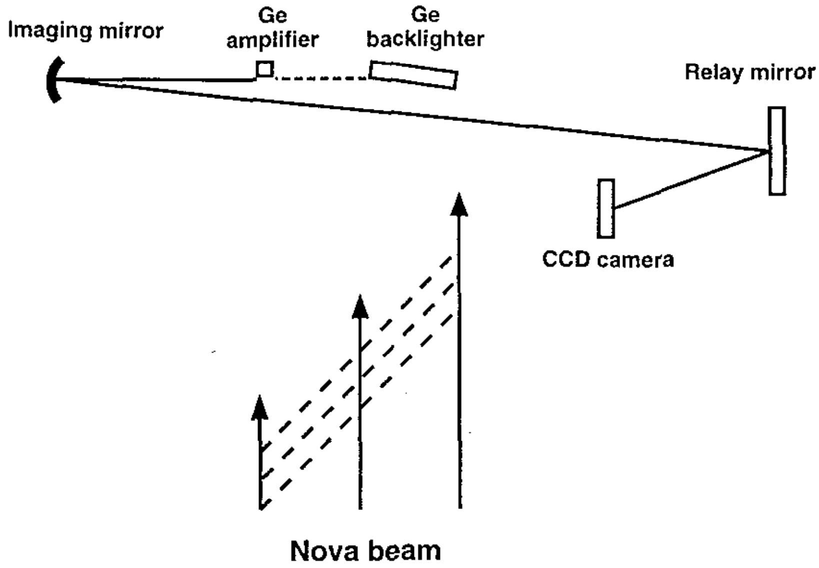

Fig. 1. Schematic of the experimental setup.

The Ge slab target consisted of two parts; a 1.89 cm long Ge laser which served as the backlighter and a short Ge amplifier which was varied in length from 0 to 0.6 cm. The overall length of the target from the back end of the long backlighter to the output end of the short amplifier was held fixed at 4.5 cm. The 1.89 cm long Ge laser was tilted by 9 mrad so that it would more uniformly illuminate the amplifier. The output end of the Ge amplifier had a 25-μm diameter Al wire positioned above the target surface to serve as an absolute spatial fiducial. The target was illuminated using the traveling wave setup so that the Nova beam would illuminate the target from end to end at a phase velocity equal to the speed of light with the Nova beam first illuminating the 1.89-cm long section which would simultaneously backlight the amplifier as it was being driven by the Nova laser.

The two-dimensional (2D), high-resolution, spatial imaging diagnostic consisted of a 25 cm focal length Mo/Si multilayer mirror which imaged the output aperture of the short Ge amplifier onto an X-ray CCD camera which was placed 720 cm from the mirror. The magnification was 27.8. The mirror had a peak reflectivity of approximately 40% and bandwidth of 15 Å for 196 Å radiation. A second flat Mo/Si multilayer mirror was used between the imaging mirror and CCD to relay the image and block additional background. Al filters with 3-μm total thickness were used to attenuate the signal and to eliminate shorter and longer wavelength signals which could be reflected off the mirror.

From previous experiments we know that lasing occurs during the 2nd and 3rd Nova drive pulse with pulse durations of 50 ps and that lasing during the 3rd pulse is an order of magnitude brighter than during the 2nd pulse. For that reason, the time integrated data recorded by the CCD camera is primarily a snapshot at the time of the 3rd Nova drive pulse with the 1.89 cm Ge laser acting as a 50 ps gate for the CCD camera.

Figure 2 shows a 2D image of the near field emission from a backlit 0.3-cm long amplifier. The Nova laser is incident from above with the target surface at zero on the vertical axis. The plasma is expanding upwards in the vertical direction. The fiducial wire is centered 202 μm above the target surface. The black area is the position of the laser emission at 196 Å from the Ge amplifier. The lasing peaks about 45 μm from the target surface and has a horizontal width of approximately 130 μm, which corresponds closely to the width of the Nova line focus. In previous experiments with 3-cm long lasers, the laser emission peaked 160 μm from the target surface and calculations showed that refraction was bending the beam away from the surface, making it impossible to measure the actual

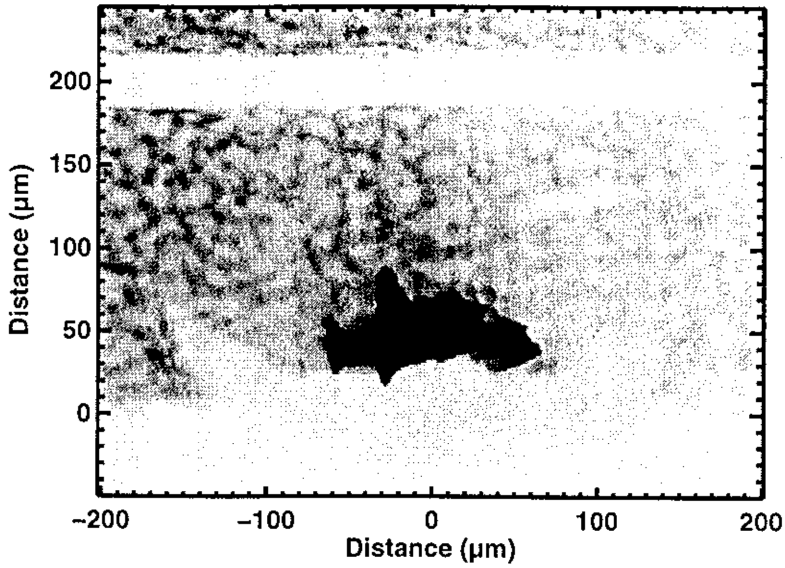

Fig. 2. 2D image of the near field 196 Å laser emission from a backlit 0.3-cm long amplifier.

position of the gain region. In this experiment, the amplifier is an order of magnitude shorter and refraction should be a very small effect since refraction is proportional to the propagation distance squared. The laser emission in Fig. 2 is a measurement of the location of the gain region with some small corrections.

To determine a gain from this data we need to know the intensity of the backlighter, the self-emission of the amplifier, and other backgrounds. The non uniformity of the backlighter, the uncertainty in the background subtraction of the self emission and other background, as well as slight saturation of the CCD make it difficult to determine the actual gain from the data. However, from the 0.2 and 0.3 cm amplifier experiments we can put a lower bound of 8 to 12 cm^{-1} on the peak gain.

3. Plasma Modeling

We modeled these experiments using LASNEX 1D and 2D simulations. The densities and temperatures calculated by LASNEX were used as input to the XRASER code, which calculated the gains of the laser lines including radiation trapping effects. For the 2D LASNEX calculation we used a 1D slice from the middle of the line focus as input to the 1D XRASER calculation. Figure 3 shows a lineout (solid line) of the intensity of the laser emission for the 0.3-cm long amplifier which is averaged over an 86 μm stripe through the middle of the amplifier versus distance in the plasma expansion direction. The sharp drop in intensity centered at 202 μm clearly shows the position of the 25-μm diameter Al wire. This experimental data is compared with the calculated gain (dotted lines) for the 196 Å line at the time of peak gain for the 3rd Nova drive pulse versus distance from the target surface in the plasma expansion direction as calculated by XRASER using the 1D and 2D LASNEX calculations as input. The gain peaks at 60 μm for the 1D case and 50 μm for the 2D case. One sees that the laser emission is closer to the surface than either calculation and points out the need for more detailed calculations which have finer spatial zones near the critical

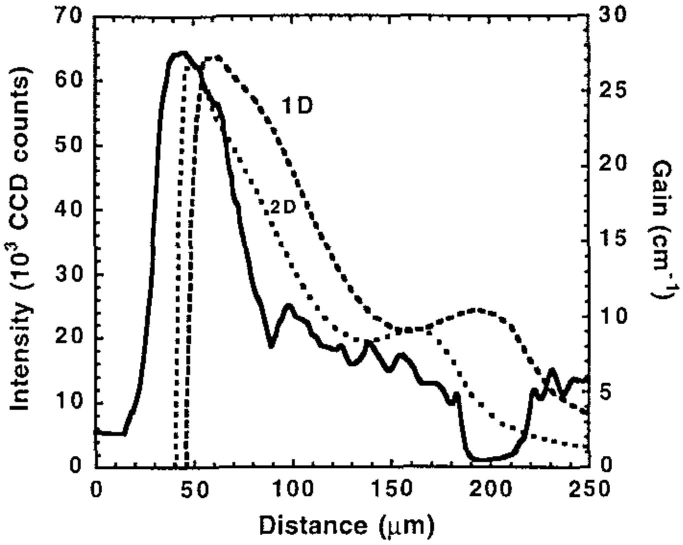

Fig. 3. Spatial dependence of the 196 Å laser emission (solid line) from the 0.3-cm long amplifier versus distance in the plasma expansion direction. This is compared with the gain (dotted lines) calculated by XRASER using the 1D and 2D LASNEX calculations as input.

density surface and better temporal resolution. More complete 2D calculations are also needed to see how the gain varies transversely across the line focus. More details of the experiments and calculations can be found in Ref. 6.

4. Conclusions

In conclusion, we present high-resolution, two-dimensional, spatial images of the 196 Å Ne-like Ge laser emission at the output aperture of short amplifiers backlit by longer Ge lasers. The backlighter and amplifier are both created by illuminating the targets by a series of 100 ps pulses from the Nova laser. The images show the peak of the laser emission, which corresponds to the gain region, to occur about 45 μm from the target surface. The simulations show the gain peaking 50 to 60 μm from the surface This is an important first step in understanding where the gain is originating in these plasmas and more experiments are needed to quantitatively map out the gain profiles and to measure other plasma parameters such as the temperature and density to compare with calculations.

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