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High Resolution Two-dimensional Near Field Images of Neon-like Soft X-ray Lasers

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Abstract. We discuss high resolution two-dimensional near-field images of the neon-like nickel and germanium x-ray laser. The Asterix iodine laser, using a prepulse 5.23 ns before the main pulse, was used to irradiate slab targets. Our imaging diagnostic consisted of a concave multilayer mirror that imaged the x-ray laser line (with a magnification of ten) onto a backside illuminated x-ray CCD detector. A great deal of structure was observed in the near field images, particularly in the J=0-1 emission. We observed a large difference in the spatial dependence of the J=0-1 and J=2-1 lines of germanium, with the J=2-1 emission peaking farther away from the original target surface. The prepulse level was varied and observed to have a significant effect on the spatial dependence of the germanium and nickel laser lines. A larger prepulse moved the peak emission farther away from the target surface. These measurements are generally consistent with hydrodynamic simulations coupled with atomic kinetics.

1. Experimental Results

Recent experiments have demonstrated that the J=0-1 line becomes the dominant line for low-Z Ne-like x-ray lasers when a prepulse is applied before the main driving laser pulse[1-4]. Numerical simulations have indicated that using the prepulse creates a more uniform, larger scale length plasma which allows the J=0-1 line to propagate better. The J=0-1 line is predicted to appear in a higher density region than the J=2-1 lines since its upper level is populated primarily by collisional excitation from the ground state, while the J=2-1 lines on the other hand are significantly affected by recombination. Here we present two-dimensional near field images of the J=0-1 and J=2-1 laser lines of Ne-like germanium and the J=0-1 line of Ne-like nickel from slab irradiated targets. These results are compared to hydrodynamic simulations coupled with atomic kinetics.

The experiments were performed using the Asterix laser. Typically a 320 J, 450 ps main pulse with a prepulse (5.23ns earlier) of varying energy was focused to a 3 cm long by 150 μm wide line focus. A thin 25 μm wire was positioned at one end of the target at a measured distance (~310 μm) off the target surface in order to provide a spatial fiducial.

Our imaging diagnostic consisted of a concave multilayer mirror (MoSi) which imaged the x-ray laser line (with a magnification of ten) onto a backside illuminated x-ray CCD detector. Two sets of mirrors were coated, one with a peak wavelength at 19.6 nm corresponding to the Ge J=0-1 line and the other set had a peak wavelength at 23.4 nm for the pair of Ge J=2-1 lines at 23.2 nm and 23.6 nm as well as the Ni J=0-1 line at 23.1 nm. These mirrors have a peak reflectivity of approximately 50 % and a bandpass of around 1.5

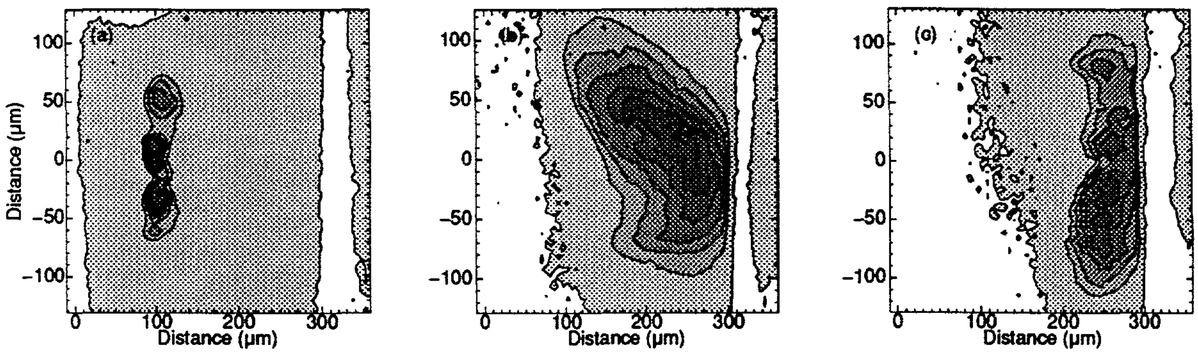

Fig. 1. Contours of 2-dimensional near field images (a) Ge J=0-1 (b) Ge J=2-1 (c) Ni J=0-1

nm. The proper choice of filtering was essential to decrease the background emission and scattered light. For the experiments at 19.6 nm, a 2.6 μm thick Al filter was used to eliminate short wavelength radiation below 17 nm, while a filter consisting of a 50 nm thick layer of Ti coated on a 100 nm thick Al and 188 nm thick lexan substrate was used to cutoff the long wavelength radiation above 25 nm. For the experiments at 23.4 nm, a 0.6 μm Al filter was used to eliminate the short wavelength radiation, while a 75 nm Co on 280 nm polyimide filter was used to suppress the 19.6 nm line by two orders of magnitude and reduce the long wavelength radiation.

Figure 1 shows contour plots of Ge and Ni near-field images obtained using a 15% prepulse. The laser blow-off (radial) direction is the horizontal axis in the figures with zero corresponding to the original target surface. The wire fiducial is clearly evident at 310 μm from the target surface. We observe significant variations in brightness along both the radial and the transverse direction. We believe this is partly due to the prepulse and non-uniformities in the laser focal spot which in turn produces an inhomogeneous plasma. The line focus arrangement used with the Asterix laser actually consists of six overlapping lines (due to the six section cylindrical lens array) of which two are used for the prepulse.

There is a significant difference in the radial dependence of the x-ray laser depending on the element and the transition. The Ge J=0-1 line peaks at ~ 90 μm while both the Ge J=2-1 lines and the Ni J=0-1 line peak at ~ 250 μm, although the Ni J=0-1 line has a somewhat sharper peak. This is consistent with numerical simulations.

With a 1.65% prepulse we observed a more uniform near field emission region for all cases and in addition we observed that the peak of the emission moved radially closer to the target surface. With no prepulse our signal was not strong enough to observe these lines. Using an absolute calibration for the backside illuminated CCD detector we determined the output energy of the 19.6 nm line to be ~10 μJ for the 15% prepulse case and ~ 1 μJ for the 1.65% prepulse case, while the Ge J=2-1 energy was ~10 μJ for these two conditions[5].

2. Discussion

We observed a large change in the peak of the x-ray laser emission in the radial blow-off direction depending on the prepulse level and transition. In all cases with a larger prepulse the plasma expanded more and the peak of the x-ray laser emission moved farther from the target surface. For the Ge J=0-1 line the peak shifts from 70 μm to 90 μm when going from a 1.65% prepulse level to a 15% prepulse, while the Ge J=2-1 emission peaks are at 150 μm and 250 μm for the 1.65% prepulse and 15% prepulse cases respectively[6]. This is due to recombination playing a much larger role in populating the J=2-1 upper level. In Fig. 2 we show calculated contour plots of gain as a function of both time and radial distance from the target for the 15% prepulse and no prepulse conditions[4]. We used a 1-D hydrodynamic

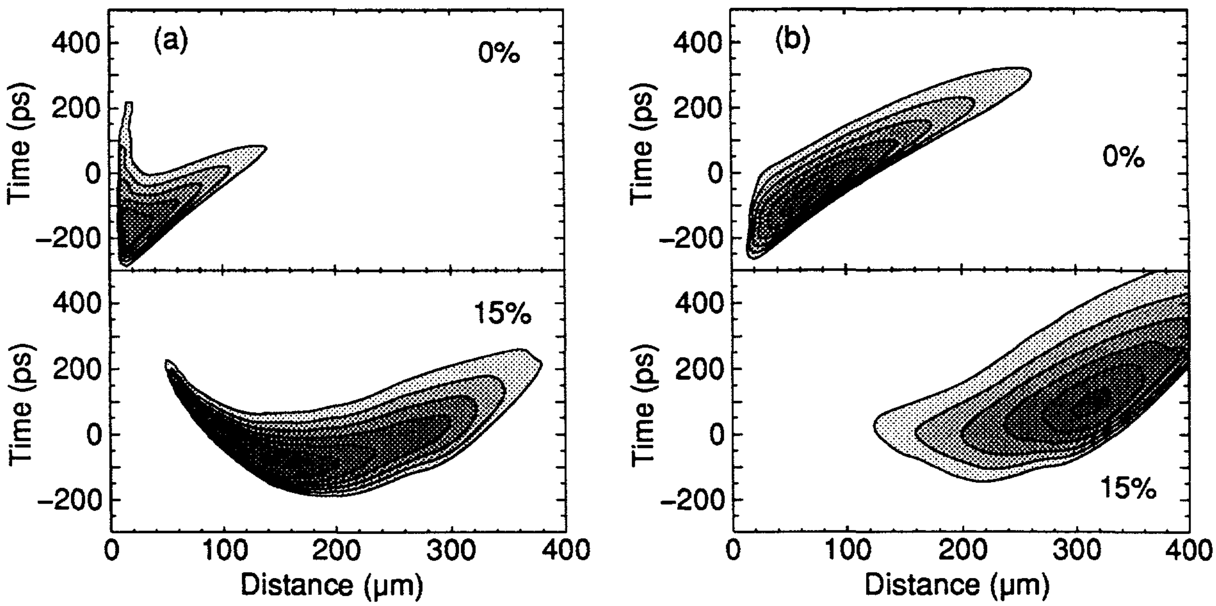

Fig. 2. Numerical simulation of gain for Ne-like Ge. (a) Ge J=0-1 (b) Ge J=2-1

model and calculated the gain using a postprocessor. Our numerical results show the J=2-1 emission peaking later in time and farther from the target surface than the J=0-1 emission, similar to other models[7-8]. The addition of a prepulse allows more plasma expansion and moves the peak emission region farther from the target surface in agreement with our observations. Also note the broader spatial extent of the J=2-1 emission, consistent with our results. Although this model is in qualitative agreement with our experiment, more detailed 2-D modeling with ray tracing is required to accurately model these experimental results.

3. Conclusion

In summary we have obtained high resolution two-dimensional near-field images of the both the Ge J=0-1 and J=2-1 lines and the Ni J=0-1 line. These images show the spatial extent and dependence of the Ge and Ni laser lines. The J=0-1 line has more structure and peaks closer to the target surface than the J=2-1 lines. A larger prepulse shifts the peak outward from the target surface. Non-uniformities in both the drive laser and x-ray laser needs more investigation and may play a significant role in the development of a more coherent and efficient x-ray laser.

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