Two-dimensional near-field images of the neonlike germanium soft-x-ray laser

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We present what are believed to be the first two-dimensional near-field images of the neonlike germanium x-ray laser obtained with multilayer imaging mirrors. The Asterix iodine laser, with a low-intensity prepulse 5.23 ns before the main pulse, was used to irradiate germanium slab targets. We observe 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 target surface. The prepulse level is also observed to have a significant effect on the spatial dependence of the germanium laser lines. A great deal of structure is observed in the near-field images, particularly in the $J = 0-1$ emission. © 1996 Optical Society of America

Recently much progress has been made in extending the range of the Ne-like x-ray laser system.[1] By use of the prepulse technique it has been possible to achieve lasing in low-Z to moderate-Z elements from Cl ($Z = 17$) to Se ($Z = 34$).[2–7] It has been observed 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. Modeling and experiments have indicated that using the prepulse creates a more uniform, larger-scale-length plasma that allows the $J = 0-1$ line to propagate better.[8] The $J = 0-1$ line is predicted to appear in a higher-density region than the $J = 2-1$ lines because its upper level is populated primarily by collisional excitation from the ground state, whereas the $J = 2-1$ lines are significantly affected by recombination.[9] Here we present two-dimensional near-field images of the $J = 0-1$ and $J = 2-1$ laser lines of Ge from slab irradiated targets that show, for the first time to our knowledge, the spatial variation of the emission of a Ne-like collisional x-ray laser in both the plasma blow-off direction and the transverse line-focus direction. A near-field image of a carbon fiber recombination laser at 18.2 nm was measured recently.[10]

These experiments were performed with the Asterix laser, with a prepulse 5.23 ns before the main pulse.[4] Typically a 320-J, 450-ps main pulse was focused to a 3-cm-long by 150-μm-wide line focus. We used slab targets consisting of 1 μm of Ge coated onto a machined flat copper substrate. A thin 25-μm wire was positioned at one end of the target at a measured distance (~310 μm) off the target surface to provide a spatial fiducial.

Our imaging diagnostic consisted of a concave multilayer mirror that imaged the x-ray laser line (with a magnification of 10) onto a backside-illuminated x-ray CCD detector as shown in Fig. 1. The multilayer mirrors consist of superpolished (<0.1-nm rms roughness) concave fused-silica blanks with a 50-cm radius of curvature and coated with alternating layers of Mo and Si. 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 with a peak wavelength at 23.4 nm for the pair of Ge $J = 2-1$ lines at 23.2 and 23.6 nm. These mirrors have a peak reflectivity of approximately 50% and a bandpass of ~1.5 nm. The proper choice of filtering was essential for decreasing 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, and a filter consisting of a 50-nm-thick layer of Ti coated upon a 100-nm-thick Al and a 188-nm-thick lexan substrate was used to cut off the long-wavelength radiation above 25 nm. For the

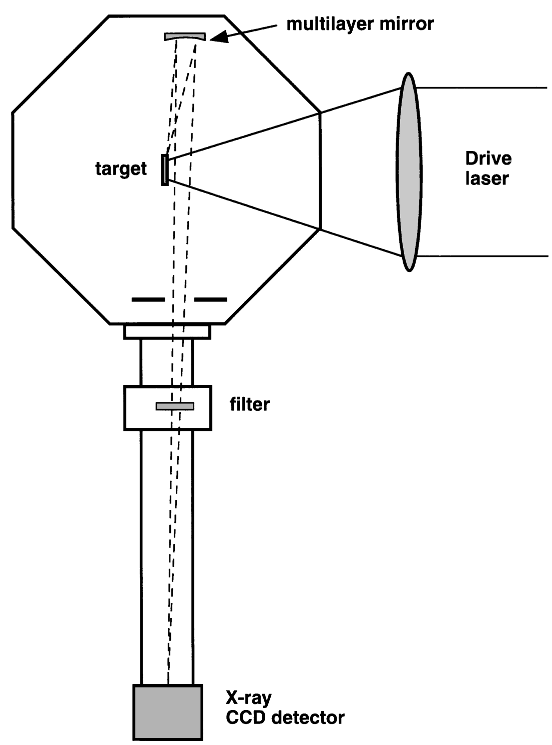

Fig. 1. Schematic showing the experimental arrangement.

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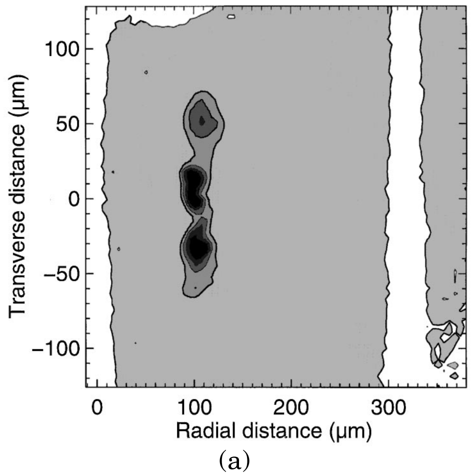


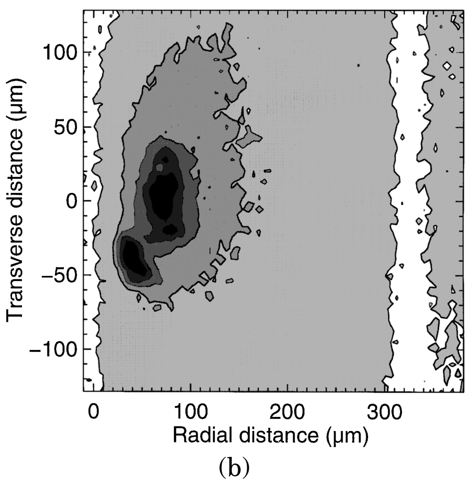
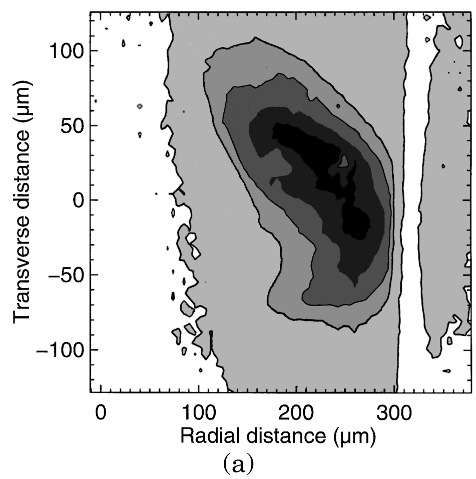


Fig. 2. Contour images of Ne-like Ge $J = 0-1$ x-ray laser near-field emission: (a) 15% prepulse, (b) 1.65% prepulse.

experiments at 23.4 nm, a 0.6-μm Al filter was used to eliminate the short-wavelength radiation, and a 75-nm Co on 280-nm polyimide filter was used to suppress the 19.6-nm line by 2 orders of magnitude and reduce the long-wavelength radiation.

In our first set of experiments we used the 19.6-nm multilayer mirror to image the Ge $J = 0-1$ line for different prepulse levels. Figure 2 shows contour plots of images obtained with 15% and 1.65% prepulse levels. The laser blow-off (radial) direction is the horizontal axis in the figures, with 0 corresponding to the original target surface. The wire fiducial is clearly evident at 310 μm from the target surface. Our brightest signal is obtained with a 15% prepulse; however, for this case we also observe large variations in brightness along the transverse direction. We believe that this is partly due to the prepulse and to the nonuniformities in the laser focal spot, which in turn produce an inhomogeneous plasma. In addition, the exponential amplification and high gain (~ 4) of the Ge $J = 0-1$ line will enhance the effect of nonuniformities on the x-ray laser output. The line-focus arrangement used with the Asterix laser actually consists of six overlapping lines (because of the six-section cylindrical lens array), of which two are used for the prepulse. There may be some transverse nonuniformity from the prepulse since it has a narrower width than the main pulse. With a 1.65% prepulse we observe a more-uniform near-field emission region for the Ge $J = 0-1$ line, as shown in Fig. 2(b). With no prepulse this line was too weak to be observed. Using an absolute calibration for the backside-illuminated CCD detector,[11] we determine 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. This is consistent with earlier measurements performed on the Asterix laser in which time-integrated spectra of the Ge x-ray laser were measured for these prepulse conditions by use of both flat and curved slab targets.[12]

Figure 3 shows the Ge $J = 2-1$ near-field emission for the two prepulse conditions. In this case we observe some nonuniformity for the 15% prepulse case and very little for the 1.65% prepulse. With the 1.65% prepulse the near-field image is more symmetric and appears to be split into a characteristic two-lobe structure that is due to a more-symmetric transverse expansion.[13] The total output energy of the $J = 2-1$ lines ($\sim$10 μJ) is comparable for the two prepulse cases, indicating that the prepulse has less of an effect on the gain for this transition. This is again consistent with previous spectral measurements.[12] With no prepulse our signal is not strong enough to permit us to observe the $J = 2-1$ lines. Note that the Ge $J = 2-1$ emission



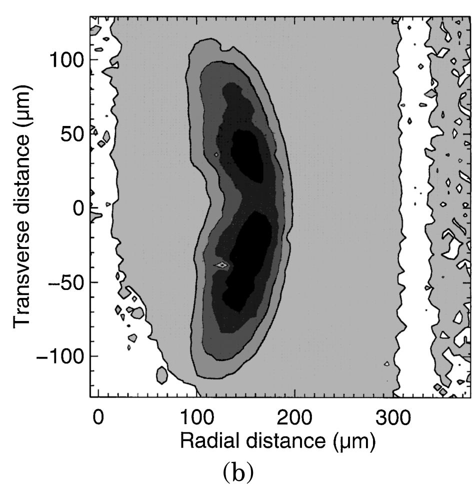


Fig. 3. Contour images of Ne-like Ge $J = 2-1$ x-ray laser near-field emission: (a) 15% prepulse, (b) 1.65% prepulse.

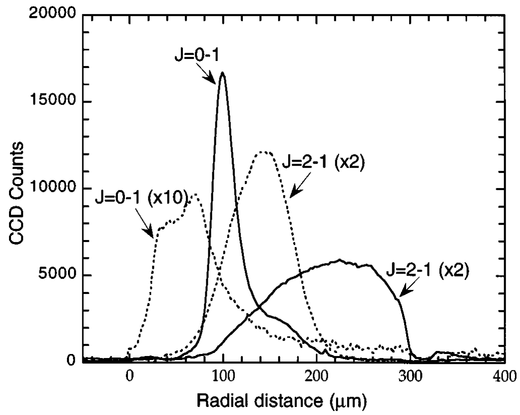


Fig. 4. Measured intensities (CCD counts) of the Ge $J = 0-1$ and $J = 2-1$ lines averaged over the transverse direction and plotted as a function of radial position. The solid curves are for a 15% prepulse, and the dotted curves are for a 1.65% prepulse. The $J = 2-1$ line intensities are multiplied by 2 and the $J = 0-1$ (1.65% prepulse) line intensity is multiplied by 10 for these plots.

peaks much farther from the target surface than does the $J = 0-1$ line and is spread out over a larger region.

We observe 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 Fig. 4 we have plotted the intensity averaged over the transverse position as a function of the radial distance from the target surface. We observe in all cases that with a larger prepulse the plasma expands more and the peak of the x-ray laser emission occurs farther from the target surface. For the Ge $J = 0-1$ line the peak shifts from 70 to 90 μm when going from a 1.65% prepulse level to a 15% prepulse, and the Ge $J = 2-1$ emission peaks are at 150 and 250 μm for the 1.65% and 15% prepulse cases, respectively. This is due to recombination's playing a much larger role in populating the $J = 2-1$ upper level. Numerical codes predict that the $J = 2-1$ emission will peak later in time and farther from the target surface than the $J = 0-1$ emission.[7,13] Large electron density gradients will lead to refraction of the signal away from the higher-gain region. The emission, particularly the $J = 0-1$ line, therefore peaks somewhat farther from the target surface than does the peak gain.[13] The broader spatial extent that is measured for the $J = 2-1$ emission is also consistent with numerical models. The sharply peaked radial profile of the $J = 0-1$ line with a 15% prepulse is indicative of a larger density gradient that limits the gain region.

In summary, we have obtained high-resolution two-dimensional near-field images of both the Ge $J = 0-1$ and $J = 2-1$ lines. These images show the spatial extent and dependence of the Ge laser lines. The $J = 0-1$ line has more structure and peaks closer to the target surface than do the $J = 2-1$ lines. A larger prepulse shifts the peak outward from the target surface. The large intensity variation in the transverse direction shows that Ne-like x-ray laser measurements in which a horizontal slice of the plasma is viewed may vary greatly from shot to shot, depending on the transverse position that is viewed. Drive laser nonuniformity needs more investigation and may play a significant role in the development of a more coherent and more efficient x-ray laser.

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