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Multiple Pulse Traveling Wave Excitation of Neon-like Germanium

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Abstract. Traveling wave excitation has been shown to significantly increase the output intensity of the neon-like germanium x-ray laser. The driving laser pulse consisted of three 100 ps Gaussian laser pulses separated by 400 ps. Traveling wave excitation was employed by tilting the wave front of the driving laser by 45 degrees to match the propagation speed of the x-ray laser photons along the length of the target. We show results of experiments with the traveling wave, with no traveling wave, and against the traveling wave and comparisons to a numerical model. Gain was inferred from line intensity measurements at two lengths.

INTRODUCTION

Tilting the wave front of the driving laser to match the propagation velocity of the x-ray laser can be an effective method of increasing the effective gain length to extract the maximum energy out of the x-ray laser. This technique for exciting the plasma, usually called traveling wave excitation, is particularly useful and important when the duration of the driving laser divided by the length of gain medium is ≤ 33 ps/cm (the propagation time of x-ray laser photons). It is expected that a table-top x-ray laser will most likely require a short duration, high intensity driving laser to produce the plasma gain medium. A short duration x-ray laser has many potential applications, such as probing a high density, laser-produced plasma or imaging a biological sample.

The traveling wave technique has been employed in various short pulse lasers to shorten the pulse duration and increase the amplification (1-5). Traveling wave excitation of an x-ray laser has been demonstrated for the Ne-like yttrium exploding foil laser at 155 Å (6). In these experiments we demonstrate the application of the traveling wave technique to the Ne-like Ge x-ray laser using slab targets. We observe a factor of ten increase in x-ray laser line intensity compared to no traveling wave and a factor of seventy increase compared to having the traveling wave go the opposite direction. Transit time effects are included in a numerical model that agrees well with the experiments.

EXPERIMENT AND DISCUSSION

Experiments were performed using the Nova laser at Lawrence Livermore National Laboratory. The laser pulse consisted of three 100 ps Gaussian pulses separated by 400 ps peak to peak. Each pulse had an intensity on target of 1.1×10^{14} W/cm² at a laser wavelength of 0.53 μ m. A 3 cm long line focus of width 120 μ m was used. Targets consisted of a 1 μ m thick layer of Ge deposited on a 125 μ m thick foil of Ni. Because of a 16% gap in the laser beam, the effective length of the target was 2.52 cm. We also used half length targets for gain measurements. Our diagnostics consisted of a 1-meter grazing incidence spectrograph (McPigs) with a microchannel plate detector viewing one end of the x-ray laser axis and a flat field spectrograph (SFFS) using a varied line space grating and a streak camera detector viewing the opposite end of the x-ray laser.

The traveling wave was implemented by inserting a diffraction grating along with additional mirrors in the path of the driving laser (Nova), before the main amplifiers and KDP frequency doubling crystal. First order diffraction from the grating produces the tilted wave front due to a varying path length. The angle ϕ of the tilted wave front is given by $\tan(\phi) = \lambda_L/D \cos(\vartheta_0)$, where λ_L is the laser wavelength (1.06 μ m), D is the groove spacing and ϑ_0 is the diffraction angle. The grating groove spacing and incident angle ϑ_i , was selected in this case so that the wave front was tilted to ~ 45 degrees to match the transit time of photons along the laser medium.

Germanium spectra taken from multiple pulse irradiated targets show a very strong J=0-1 line unlike earlier experiments with a single pulse (7). In Fig. 1 we show a comparison between a multiple pulse spectrum and a single longer (600 ps) pulse spectrum. For the 600 ps Gaussian pulse experiment we observe the J=2-1 lines at 232 $\text{\AA}$ and 236 $\text{\AA}$ but do not clearly see the J=0-1 line. Other recent experiments of Ne-like Ge with a slab target have also exhibited stronger lasing in the J=2-1 lines (8,9). Lasnex hydrocode simulations indicate that the multiple pulses are acting similar to the prepulse in that a larger more uniform density plasma is created compared to the standard single pulse (10). Streaked spectra of the plasmas show that the x-ray laser lines do not show up during the first pulse, but only appear during the second and third pulse of the driving laser. The first pulse ionizes the plasma but the conditions are unsuitable for gain. The second and third pulse create a

FIGURE 1. Comparison of Ne-like Ge x-ray laser spectrum for two pump laser conditions.

somewhat hotter plasma with more gradual density gradients that are better suited for good amplification. The J=0-1 line appears earlier in time than the J=2-1 lines and has a somewhat shorter time duration.

We compared laser irradiation of Ge slab targets for three different wave front angles: first with the traveling wave going toward the detector ($\phi = 45$ degrees); second with no traveling wave ($\phi = 0$ degrees); and third with the traveling wave going away from the detector ($\phi = -45$ degrees). A simple numerical model was developed to simulate the effect of the transit time of the x-ray laser photons on the integrated output line intensity. In Fig. 2 we compare the measured integrated intensities of the J=0-1 line at 196 Å, taken with the McPigs spectrograph, to this numerical model. The points show the measured data while the lines are from the numerical model. We measured a gain of 4.1 cm^{-1} for the 196 Å line on data taken at two different lengths for the case with the traveling wave going toward the detector since there is no transit time effect for this case. For cases with no traveling wave or the traveling wave going in the opposite direction, there is a fall-off in the increase of intensity as the length of the plasma column is increased.

Our simulation assumed the time history of the emissivity and gain was Gaussian with a full-width at half-maximum (FWHM) of 85 ps for the J=0-1 line at 196 Å. This emissivity time duration gave the best fit to our data for the x-ray laser going against the traveling wave. Experimental data in Fig. 2, for the case with no traveling wave, falls slightly below the expected values. This may be due to inhomogeneous plasma effects and imperfect matching of the traveling wave pump to the propagation speed of the x-ray laser photons as well as approximations in the model. It should be noted that our model includes the 16% gap in the middle of the target since the propagation time across the gap is non-negligible.

The J=2-1 line at 236 Å was also measured for the three cases and exhibited a similar change in intensity due to the traveling wave. Again we adjusted the FWHM of the emissivity and gain time history in order to agree with the experimental data for the traveling wave going against the direction of the x-ray laser photon. In this case we have a somewhat longer duration (FWHM = 115 ps) in our model consistent with the longer measured duration of the 236 Å laser compared to the 196 Å laser. The time duration of the J=2-1 laser line at 236 Å was measured for the three traveling wave configurations (at a plasma length of 2.52 cm) and compared to the numerical model using the measured gain of 4.3

FIGURE 2. Intensity of the J=0-1 line plotted vs length. The curves are from the numerical model while the points are experimental data.

cm^{-1} . Our measurements give a laser duration (FWHM) of 55 and 77 ps for the cases with and against the traveling wave as compared to model predictions of 36 and 64 ps, respectively. Agreement with our model is reasonable given the approximations in our model and the uncertainties in the plasma conditions.

CONCLUSION

We have compared x-ray laser experiments with, without and against the traveling wave. An order of magnitude enhancement of the Ne-like Ge x-ray laser intensity is observed when the traveling wave technique is used to compensate for the short gain duration of these plasmas. Gains of 4.1 cm^{-1} for the 196 Å line and 4.3 cm^{-1} for the 236 Å line were inferred from integrated line intensity measurements at two lengths. These measurements for the various traveling wave configurations and plasma lengths agree well with a numerical model including transit time effects. This technique can be important for applications of x-ray lasers where a short pulse laser is required.

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