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Enhanced Output of Soft X-ray Lasers using Double Slab Targets

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Abstract. Double slab neon-like niobium soft x-ray laser experiments have been performed using the Nova laser. The two slabs have their front surfaces facing in opposite directions with either a 300 μm or 600 μm planar separation between them. Separate laser beams irradiate each slab with an intensity on target of $1.3 \times 10^{14} \text{ W/cm}^2$. Best coupling was observed using a 300 μm separation. The angular divergence of the laser is measured for single slab and double slab configurations. Comparisons to numerical models are discussed.

INTRODUCTION

Neon-like collisional x-ray lasers have typically used either thin foils irradiated from both sides with a driving laser or massive slab targets irradiated on only one side (1). While thin foil targets have produced impressive results for both Ne-like and Ni-like x-ray laser systems, there are several advantages to using massive slab targets. Slab targets are generally easier to manufacture and can be more efficient due to a larger gain region. However at longer lengths refraction becomes a problem which limits the gain-length product. This can be compensated for by using double slab target configurations which couple the rays from one plasma into another. The planar separation of the two slabs with respect to each other must be optimized for best coupling. This type of double target configuration has been used effectively for Ne-like Ge to produce large gain-length products and recently has produced a saturated laser at 236 $\text{\AA}$ using a multilayer mirror for double-pass amplification (2-4).

Here we have used single and double targets of niobium. The intensity of the J=2-1 lines increased approximately four orders of magnitude by going from a single slab target of length 2.52 cm to a double slab target of 5.04 cm. Our strongest line, the J=2-1 line at 138.6 $\text{\AA}$ is most likely in the saturated laser regime for the double length targets. We have also measured a shift in the angular divergence of the x-ray laser lines when changing the planar separation between the slabs, in qualitative agreement with our numerical simulation codes.

EXPERIMENTAL RESULTS AND DISCUSSION

The double slab configuration is illustrated in Fig. 1. Two beams from the Nova laser pointed in opposite directions irradiate the two sides of the double slab target. The slabs are premounted on a rigid frame with the front surfaces all parallel to each other. There is a 5 mm gap between the two opposing slab targets and a planar separation d between the slabs to compensate for refraction. We used separations of $d = 300 \mu\text{m}$ and $600 \mu\text{m}$. A single 600 ps square pulse irradiated each slab target with an intensity of $1.3 \times 10^{14} \text{ W/cm}^2$. Note that each single slab target actually consists of two slabs with a 16% gap between the slabs because of the corresponding gap in the laser beam. The effective length of each 3 cm target was therefore 2.52 cm. We also employed combination double slab targets in which one slab was Nb and the other slab was Zr. This allowed us to measure and compare the intensity of two single slab lasers on a single shot with the same irradiance. The Nb x-ray laser is an interesting case to study because of the strong hyperfine effect that is observed in several lasing transitions (5,6).

FIGURE 1. Schematic showing the double slab configuration and the refracted ray path.

Spectra containing the two $J=2-1$ lines at $138.6 \text{ \AA}$ and $140.4 \text{ \AA}$ of Ne-like Nb are shown in Fig. 2 for single slab and double slab configurations. These are time-integrated spectra obtained from a 1-meter grazing incidence spectrograph with a microchannel plate detector (McPigs). There is roughly four orders of magnitude increase in the intensity of these two lines when the length is doubled to 5.04 cm using a double slab target with a $300 \mu\text{m}$ planar

FIGURE 2. Comparison of Ne-like Nb spectra from single slab (dashed curve) and double slab (solid curve) targets with $d = 300 \mu\text{m}$.

separation. This separation gave better coupling and produced a brighter x-ray laser than using a 600 μm separation. Using the relative intensities and neglecting saturation effects we obtain a gain-length product of $GL \approx 17.5$ ($G=3.5 \text{ cm}^{-1}$) for the J=2-1 line at 138.6 $\text{\AA}$, $GL \approx 19.1$ ($G=3.8 \text{ cm}^{-1}$) for the J=2-1 line at 140.4 $\text{\AA}$, and $GL \approx 16.1$ ($G=3.2 \text{ cm}^{-1}$) for the J=1-1 line at 147.6 $\text{\AA}$. These gain values are actually a lower limit on the small signal gain since it is expected that the measured intensities for the double slab targets are at or approaching the saturation regime. Comparing these values to earlier measured gains from Nb foils (6), one finds generally good agreement except for the 138.6 $\text{\AA}$ line which has a lower measured gain here. However this is the strongest line and assuming it is saturated at the double target length, as would be expected theoretically, then one would expect to measure a lower effective gain. More measurements at shorter lengths are needed to accurately measure the gain.

Time resolved spectral measurements were made using a flat field spectrograph with a streak camera detector (SFFS). The duration of the J=2-1 laser lines was measured to be $< 200 \text{ psec}$ for the 5.04 cm length double slab targets.

ANGULAR DIVERGENCE

The entrance slit of the McPigs spectrograph was aligned perpendicular to the target surface so that the angular distribution of the x-ray lines in the expansion direction could be measured. A comparison of the angular divergence of the 138.6 $\text{\AA}$ line for the two double slab cases is shown in Fig. 3a. We see that $d = 300 \mu\text{m}$ gives the best coupling. The 600 μm separation is too large and allows mainly the large angle rays to couple between the two plasmas from each slab.

A Lagrangian hydrodynamics code (LASNEX) was used to model the plasma

FIGURE 3. (a) Experimental measurement of angular divergence of 138.6 $\text{\AA}$ line for 300 μm separation (solid curve) and 600 μm separation (dashed curve). (b) Numerical simulation of angular divergence.

produced by line focus irradiation of Nb slab targets. We then used a post processor to model the gain profiles of the lasing transitions. Finally, the gain and electron density profiles were input into a 3-dimensional laser transport code (Beam3). A simulation of the angular distribution of the 138.6 Å Nb line is shown in Fig. 3b. We find good qualitative agreement with experimentally measured values. These results are also consistent with Ge double slab experiments in which the optimum separation was found to be $\sim 200 - 300 \mu\text{m}$ (2,3).

CONCLUSION

The effects of refraction have been reduced by using a double slab configuration and we have significantly enhanced the brightness of Ne-like Nb x-ray lasers. We have measured $GL \geq 17$ for the two $J=2-1$ lines at 138.6 Å and 140.4 Å and $GL \approx 16$ for the $J=1-1$ line at 147.6 Å. Two separations were tried for the double slabs and the best coupling was observed for a 300 μm separation between the slabs. The angular distribution of the laser lines is observed to change with the separation. While we observe good qualitative agreement with our numerical codes, future experiments and more detailed analysis are planned to improve our understanding of these double slab x-ray lasers.

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