CONF-9009266--9

UCRL-JC--104647

DE91 007343

Hydrogen-like Recombination X-Ray Laser Experiments Using a 20 Picosecond Laser Pulse at the Nova Facility

R. Shepherd. D. Fields, L. DaSilva, C. Keane, B. MacGowan, D. Matthews, G. Shimkaveg, G. Stone, D. Eder, A. Osterheld, R. Walling, B. Young, A. Fry, M. Eckart, W. Goldstein, R. Stewart, G. Charatis, and G. Busch

This paper was prepared for submittal to the
York Proceedings
York, England, September 17-21, 1990

January 7, 1991

DISCLAIMER

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Lawrence Livermore National Laboratory, Livermore, California, 94550.
*KMS Fusion, Inc., Ann Arbor Mi., 48104

ABSTRACT: Hydrogen-like recombination X-ray lasers are currently under investigation as an alternative candidate to collisional pumped soft X-ray amplifiers. Efforts are being concentrated on the n=3 to n=2 transitions in H-like Mg and NaF.

1. INTRODUCTION

Recombination X-ray lasers hold the promise of relatively high gain lengths (5 to 15 cm^{-1}) while possibly allowing the reduction in the size of the heating laser. Our study of short wavelength, recombining systems began with a series of experiments designed to understand the ionization balance of MgF_2 and Al when heated with a 0.53 µm, 20 picosecond laser pulse. Once information had been gathered on the ionization balance of these elements, targets were chosen and X-ray laser experiments proceeded at the Nova Two-Beam facility. Although the data have been encouraging, the preliminary results are inconclusive in showing gain in the X-ray laser targets. Experiments are continuing to understand the physics of these systems.

2. IONIZATION BALANCE EXPERIMENTS

The ionization balance experiments were performed at KMS Fusion, Inc., using the Chroma laser in the 20 picosecond configuration (Charatis, 1989). The targets were heated with two laser beams (180° between their angles of incidence) each focussed with an f/6 lens in a spot focus geometry. The beams were temporally and spatially synchronized to within 2 ps and 10 µm, respectively. The target layout consisted of 2000 Å aluminum sandwiched between 500 Å Lexan (CH_x), MgF_2 sandwiched between 500 Å of Lexan, 600 Å, 1100 Å, and 2200 Å of aluminum with 300 Å of formvar ($C_2H_7O_2$) on one side, 1100 Å of free standing aluminum, and aluminum slabs. The laser intensity was varied from 3×10^{14} Watts/cm^2 to 2×10^{15} Watts/cm^2. The plasmas were diagnosed using time resolved x-ray streaked spectroscopy (27 ps temporal resolution and spectral resolution of $E/\Delta E$=300), holographic interferometry with 20 ps temporal resolution, and x-ray and visible diodes.

Using the free-bound continuum (to determine the electron temperature) and the high-n lines from the K-shell spectra (to reduce opacity effects), the quasi-steady state method (Osterheld, 1991) was applied to the time resolved x-ray spectra and the ionization balance was determined for the various target types and laser intensities. Typical ionization balance data is displayed in figure 1a. Opacity of the Al XIII 1s-2p transition was taken into account by assuming a Doppler broadened line shape and applying (Osterbrock, 1974)

$$\tau = 1.5 \times 10^{-32} (N_A / kT)^{1/2} N_l \lambda^3 A_{ul} (g_u / g_l) L,$$

where, N_A is the atomic number, N_l is the ground state ion density, λ is the line wavelength, A_{ul} is the radiative rate, and g_u and g_l are the upper and lower level degeneracies, respectively. Population inversions were observed between the high and low n quantum states of the H-like species (see figure 1b). Calculation of the atomic rates for the range of densities (measured using holographic interferometry) and temperatures imply that the plasmas are in a regime where the three-body recombination rate, which preferentially populate states with large principal quantum number and obital angular momentum, is the dominant level-populating mechanism.

Figure 2a: Line Focus Magnesium X-ray Streak Data Time Average from 210-280 ps

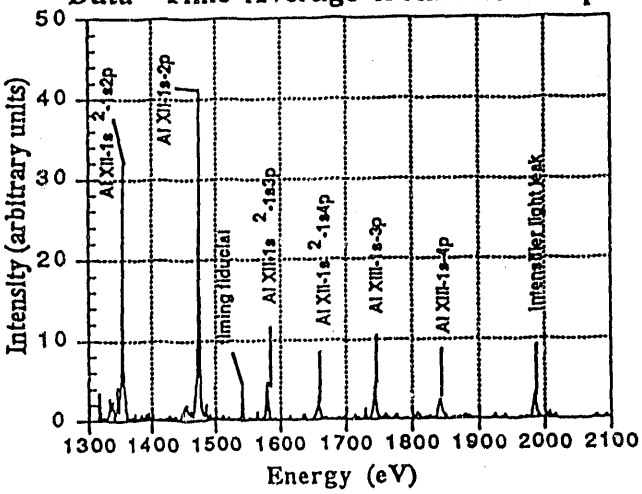
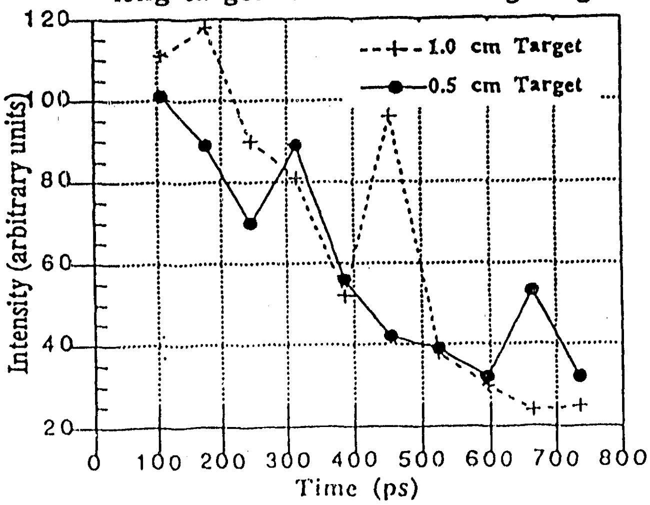


Figure 2b: Comparison of 1.0 cm long target to a 0.5 cm long target



3. GAIN LENGTH EXPERIMENTS

The Nova Two Beam facility was used to study gain H-like and He-like Mg. The experiments were designed to study gain in the n=3-2 (45 Å H-like Mg and 50 Å He-like Mg), and n=5-3 (89 Å H-like manifolds.Two beams of the Nova laser were configured to produce 100 J of 0.53 μm laser light in 20 ± 4 ps. Each laser beam is focussed using two cylindrical lenses, with a 'best focus' of 100 μm along the width of each beam. The targets consisted of 0.5 and 1.0 cm long, 33 μg/cm2 thick Mg supported on 500 Å of Lexan (CH_x). Two types of diagnostics were fielded: 1) diagnostics for gain measurement and 2) diagnostics for ionization balance determination (for a detailed description of the diagnostics the reader is referred to Shimkaveg, 1991). The diagnostics used for the gain measurement consisted of two 1 meter microchannel plate intensified grazing incidence spectrographs (McPIGS) (one on the axis of the lasing medium to measure the time integrated gain and one at 30° to the lasing medium to measure the spontaneous emission), and a streaked flat field spectrograph (SFFS) (on the axis of the lasing medium to
measure the time dependent

gain). The ionization balance measurements were performed using two streaked crystal spectrographs to observe the time-dependent K-shell emission from the target, one looking normal to both the gain medium axis and the heating laser axis approximately 8 cm away from the target, the other slightly off both normals about 50 cm from the target. Two time integrated spectrographs were also used at 30° to the gain medium, in the plane of the gain medium and the heating laser. The focal quality and pulse width was monitored using two time-integrated pinhole cameras and a visible streak camera, respectively.

Because of the concern for the optics in the laser amplifiers, the total power output was severely limited.With the 0.5 cm targets, the total intensity on target was very nearly matched to that of the previous spot focus experiments. The laser intensity of 1.0 cm targets was about a factor of two smaller. In both cases, the K-shell emission indicates an ionization state comparable to the state achieved in the spot focus experiments. Typical K-shell data is displayed in figure 2a. The time history of the H-like and the He-like emission is noticeably different from data taken at a comparable time in the spot focus. The K-shell emission shows little indication of inversions between the high and low n quantum states in the H-like or He-like series. The analysis of the time resolved SFFS data shows some possible enhancement at 450 ps. However, more shots are required to show conclusive evidence of gain in the n=3-2 manifold (see figure 2b) when increasing the length of the target from 1.0 cm to 0.5 cm. No evidence of gain was observed for the n=5-3 manifold. Likewise, the McPIGS data showed a possible indication of gain when increasing the target length. Currently it is believed that the line focus targets do not cool as rapidly due to their geometrically slower expansion. The result is a higher temperature (which can lead to collisional population of the lower levels) and/or a higher electron density plasma which can lead to collisional de-population of the high n states). Further experiments must be done to understand the differences between the relevant kinetics of the target geometries.

Figure 1a: Relative Time Dependent Bare and H-like Ion Fractions

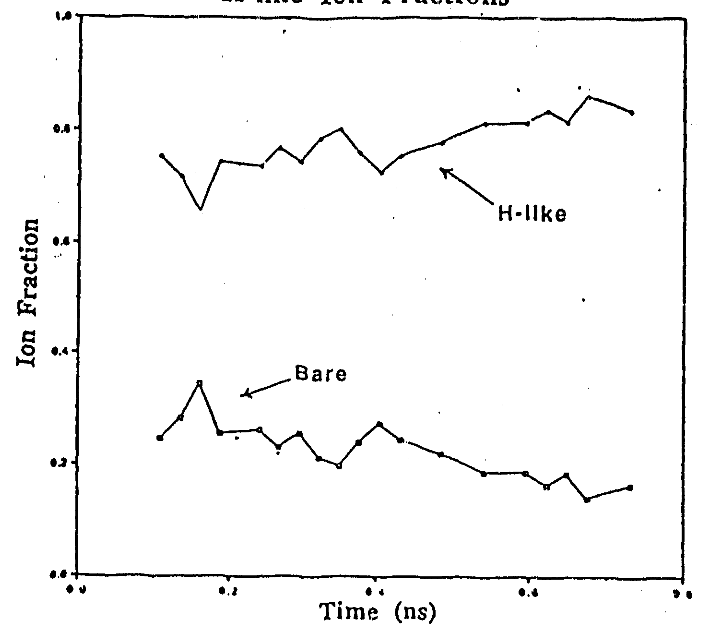
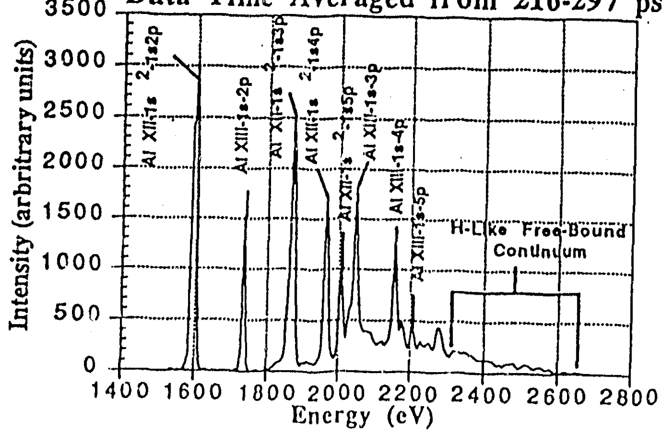


Figure 1b: Spot Focus Aluminum X-ray Streak Data Time Averaged from 216-297 ps



4. CONCLUSIONS

Ionization balance and X-ray laser experiments are being conducted on H-like and He-like Mg at Lawrence Livermore National Laboratory. The spot focus experiments suggest that large population inversions are attainable using 20 ps laser pulses with modest (1×10^{15} Watts/cm^2) laser intensities. At present, however, only a few sparce encouraging results have been seen. No conclusive evidence of gain has been observed in the line focus experiments at the Nova facility. The interpretation of the experiments are speculative at this point, however the data suggest the hydrodynamic expansion of the line focus targets is insufficient to cool the targets rapidly enough to produce population inversions. Further experimentation and modeling is needed to understand the atomic kinetics and the hydrodynamics of short -pulse, laser produced, recombining plasmas.

5. REFERENCES

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*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

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DATE FILMED

03 / 04 / 91