Conf-940592--8

UCRL-JC-116774
PREPRINT

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This paper was prepared for submittal to the
Conference Proceedings of the 4th International
Colloquium on X-ray Lasers
Williamsburg, Virginia
May 16-20, 1994

July 1994

Lawrence
Livermore
National
Laboratory

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Observation of Strong Emission from Ne IX and NeX Transitions in a Laser-Driven Plasma

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Abstract. We observe strong emission from the $1s^2$ - $1snp$ Rydberg series in He-like neon and from the Lyman- α transition in H-like neon. These emissions are observed when $1.05\text{ }\mu\text{m}$ light from a 650 femtosecond laser is focussed into the dense, localized output of a pulsed, supersonic nozzle. The maximum focal irradiance of our laser was measured at full power in a vacuum to be $2 \times 10^{18}\text{ W/cm}^2$. Although emissions from lower charge states such as Ne^{6+} and Ne^{7+} closely follow rates predicted by tunneling theory, emissions from Ne^{8+} and Ne^{9+} are observed at irradiances two orders of magnitude below tunneling theory estimates (e.g. the He- α line appears at $2 \times 10^{17}\text{ W/cm}^2$). We discuss the origins of these anomalously high charge states and the implications to recombination-pumped x-ray lasers.

INTRODUCTION

Recently McPherson et al.¹ reported strong, energetic emission (greater than 1 keV) from laser excited, krypton atoms in a pulsed gas source. Audebert et al.² observed $K\alpha$ emission from argon in the interaction between a subpicosecond laser and the output of a gas jet. In both cases the emissions are anomalous in the sense that they derive from ions stripped to a higher charge state than predicted by tunneling theory. McPherson et al. postulate that this anomalous emission results from a new type of absorption in the clusters of Kr atoms, formed in the supersonic expansion of the gas nozzle. Other mechanisms that may cause sufficient excitation to produce these emissions include collisional ionization from the field-driven free electrons, or from the hot electrons produced by stimulated Raman scattering in the plasma. In any case the observation of such strong anomalous emission of a collisional origin will affect the design of ultrashort pulse, recombination pumped XUV lasers that depend on the existence of cold electron temperatures at electron densities of $\sim 10^{19}\text{ cm}^{-3}$. In this paper we present our observations of fluorescence from He-like and H-like neon. We compare our results with a model that combines a laser-driven collisional excitation term with tunneling ionization.

DESCRIPTION

The laser system used in our experiments is a Nd:glass system that can generate up to 10 Joules at a wavelength, $\lambda=1.053\text{ }\mu\text{m}$.³ The system employs chirped pulse amplification to produce high contrast, time-bandwidth limited pulses that are 650 femtoseconds in duration at a power level of 15 TW. To determine the focussed irradiance of the laser in vacuum we simultaneously measure the pulse duration, pulse energy and the spatial beam profile at the focus at full laser power. To make x-ray emitting plasmas we focus the laser at the output of a pulsed gas jet that is equipped with a supersonic nozzle designed for Mach 8 flow. To determine the

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FIGURE 2. Ionization probability versus laser irradiance for higher charge states in neon.

To account for an enhanced rate of ionization necessary to yield x-ray line emission from transitions in Ne^{8+} and Ne^{9+} , we have considered laser field-driven collisional ionization. The number of ions of each charge species produced with the passage of the focused laser pulse is calculated by solving the coupled series of equations for sequential ionization as a function of both space and time. Laser assisted collisional ionization is modeled by including in the rate equations a cycle averaged collisional ionization rate. Only the quiver velocity of the free electrons is considered; all thermal motion is considered negligible compared to the very large quiver motion. If the classical expression for the collisional ionization of a bound electron is used, the cycle averaged collisional ionization rate for the i^{th} charge species is given by:

$$\left\langle \frac{dn_{i+1}}{dt} \right\rangle_{\text{coll}} = \frac{q_i e^4 n_e n_i}{\sqrt{m} U_p} \left[\left(\frac{1}{I_p} + \frac{1}{4U_p} \right) \ln \left(\frac{1 + \sqrt{1 - I_p/2U_p}}{1 - \sqrt{1 - I_p/2U_p}} \right) - \frac{\sqrt{1 - I_p/2U_p}}{I_p} \right]$$

As can be seen in comparing the model results with the emission data, Ne VII and NeVIII emissions are accurately simulated by the model, however the deviation of the model predictions from the observed emissions for the Ne IX and Ne X transitions is significant- these emissions are much stronger than what our simple collisional model would indicate. Recent work at Rutherford⁷, where similar observations of H-like and He-like emissions in Ne are seen, suggests that Raman heating may produce the necessary density of sufficiently energetic electrons to yield the strong emissions that we observe. We also see strong Raman backscattering in our experiments and are currently developing a similar Raman heating model for use in understanding our results. Alternatively, similar anomalous emissions have been reported by McPherson in Kr and Xe and are attributed to collective electron effects in the large clusters that are generated by their supersonic nozzle. Under the conditions of operation of our pulsed supersonic nozzle (Mach 8 flow) we are also likely to be producing large clusters of neon atoms⁸, however, until we can obtain more quantitative evidence for a cluster-based mechanism to explain our results we will continue to focus our attention on the Raman-based mechanism for producing anomalous x-ray emission.

SUMMARY

We observe anomalous x-ray emission from He and H-like transitions in neon plasmas produced from a gas jet. We see these emissions at focal irradiances that are two-orders of magnitude below the values that would be predicted by a purely field ionization mechanism. Although preliminary estimates for collisional excitation from field driven electrons yield a substantial enhancement of the rates over a pure tunneling mechanism they fail to predict the large yields that we observe experimentally. We continue to investigate other mechanisms to explain the bright line emissions from NeIX and NeX transitions in laser driven plasmas produced from gaseous targets.

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This work was performed under the auspices of the United States Department of Energy by the Lawrence Livermore National Laboratory under contract no. W-7405-Eng-48.