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PREPRINT

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Time-Resolved X-Ray Line Diagnostics of Laser-Produced Plasmas*

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Abstract

We have examined the underdense plasma conditions of laser irradiated disks using K x-rays from highly ionized ions. A 900 ps laser pulse of 0.532 μm light is used to irradiate various Z disks which have been doped with low concentrations of tracer materials. The tracers whose Z's range from 13 to 22 are chosen so that their K x-ray spectrum is sensitive to typical underdense plasma temperatures and densities. Spectra are measured using a time-resolved crystal spectrograph recording the time history of the x-ray spectrum. A spatially-resolved, time-integrated crystal spectrograph also monitors the x-ray lines. Large differences in Al spectra are observed when the host plasma is changed from SiO_2 to PbO or In. Spectra will be presented along with preliminary analysis of the data.

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Discussion

We have performed a series of measurements to investigate the usefulness of x-ray line intensities as electron density and temperature diagnostics. Line intensities from highly stripped ions have been used successfully in diagnosing high temperature astrophysical and magnetically confined plasmas[1,2]. Line intensities of He-like and H-like species from laser-produced plasmas have also been used by various researchers to estimate electron temperature and densities in the coronal plasma region[3]. In general, these measurements have been compromised due to the relatively dense, transient nature of laser-produced plasmas. Large temperature and density gradients can also complicate the analysis in determining a unique temperature and density. In our experiment we have begun studying these effects to assess their importance and begin to use line diagnostics to predict temperature and densities of underdense plasmas.

The experiments were performed in the single beam interaction chamber at the Center Laser Facility of Rutherford Laboratory[4]. A single beam of 0.532 μm light is focussed using an f/1 lens onto planar targets of various Z materials. The average intensity on target is $\sim 10^{15}$ W/cm^2. The target normal is tilted 10° with respect to the beam.

The targets are discs of CH, SiO_2 and high Z materials which have been doped with low concentrations of elements whose lines are to be used as diagnostics. Typically, the dopant levels are less than ten atomic percent; although for some high Z targets larger concentrations are needed. In all cases the dopant levels should not change significantly the $\bar{Z}$ or hydrodynamics of the plasma.

Two crystal spectrographs measure the x-ray spectra. A spectrograph located at 80° to the disc normal measures the time-integrated spectra. A 50 μm slit is placed in front of the spectrograph to spatially resolve the plasma along the incident beam direction. In general, line emission is observed to extend away from the absorption region which shows a large

continuum emission into the coronal region where only line emission is observed. Examples of the data are shown in the figures. An x-ray crystal streak camera located on the opposite side of the target time resolves the line emission with 80 psec resolution[5]. For the lower Z targets the x-ray line emission lasts significantly longer than the contimuun emission. For the high Z targets the x-ray lines tend to follow the laser pulse.

The data is still being analysed but examples of the data are presented here. Most of the time-integrated spectra have not been corrected for film response or spectrograph dispersion although approximate corrections are made in the analysis[6]. Time-resolved spectra have been corrected for the film response.

Figure 1

Example of a spatially resolved spectrum from the time integrated spectrograph. A slit in front of the spectrograph provides about 50 μm resolution at the target. This particular target is an aluminosilicate glass target which is about 8% aluminum. Both aluminum and silicon lines are observed. The resonance lines are seen to extend away from the interaction region where continuum emission is observed toward the direction of laser irradiation.

Figure 2

Example of a time-resolved spectrum from the x ray crystal streak camera. Al and Si intercombination lines are clearly resolved from the resonance line. From such data time-resolved temperature and density data can be derived. Line emission can be seen over 1 ns past the peak of the laser pulse which is defined by the continuum emission.

Figure 3

Low concentrations of seed materials are used to reduce opacity effects on resonance line intensities. Ratios of intensities for successive lines in the He-like series are plotted in the figure. The ratios agree with the ratios of their gf values, or oscillator strengths, as predicted for optically thin plasmas. Opacity effects would preferentially reduce the lower n state transitions since they have larger oscillator strengths. The ratios in the figure would be lower than their gf value ratios if opacity effects are large.

Figure 4

Examples of Si spectra from CH and PbO targets. Prominent Si features are identified. These traces are taken through the region of maximum continuum emission. The broad band feature about 5.5 Å in the PbO is M-shell emission from ionized lead. The $L\alpha/2^1P_1$ ratio is much larger for PbO than for CH implying a much higher electron

temperature for PbO. The reduction of the intensity of the Li-like line (the feature adjacent to the $^3P_1$ line) for PbO also is consistent with the PbO being hotter. This trend is consistent with increases in absorption for higher Z plasmas.

Figure 5

Comparison of Si spectra from CH and PbO plasmas in the coronal regions. The continuum emission is reduced to film fogging levels and the Pb M band emission has disappeared. In both spectra the $^1P_1/^3P_1$ ratio is about one indicating a low density plasma. The $L\alpha/^1P_1$ ratio is higher in PbO than in CH as observed near the interaction region. The lines in the CH plasma are broader than in PbO. The broadening is probably Doppler broadening indicating a much higher expansion velocity for CH plasma.

Figure 6

The Si $Ly\alpha/2\,^1P_1$ ratio as a function of time through the pulse is plotted for CH and PbO. The line ratios have about the same time history as the incident laser pulse which has a 900 ps gaussian shape. It is seen that the line ratios peak at a somewhat higher value than the time integrated value. The right hand scale is the electron temperature derived assuming coronal equilibrium. Density effects may change these values. Peak electron temperatures for PbO are 1.5 keV while for CH are 0.8 keV. These are somewhat lower than predicted by codes, or inferred from Raman data. Similar low electron temperatures have been inferred from ionization balance by Galanti and Peacock for carbon[7].

Figure 7

Various dopants have been seeded into CH targets and their x-ray spectra have been measured. The $^1P_1/^3P_1$ line ratios are plotted in the figure comparing with predicted line ratios from Boiko et al.[8]. New calculations are presently in progress using improved collisional rates[1]. For the seed targets the line ratios indicate emission is from near critical density implying the seeds are sampling the same region of the target.

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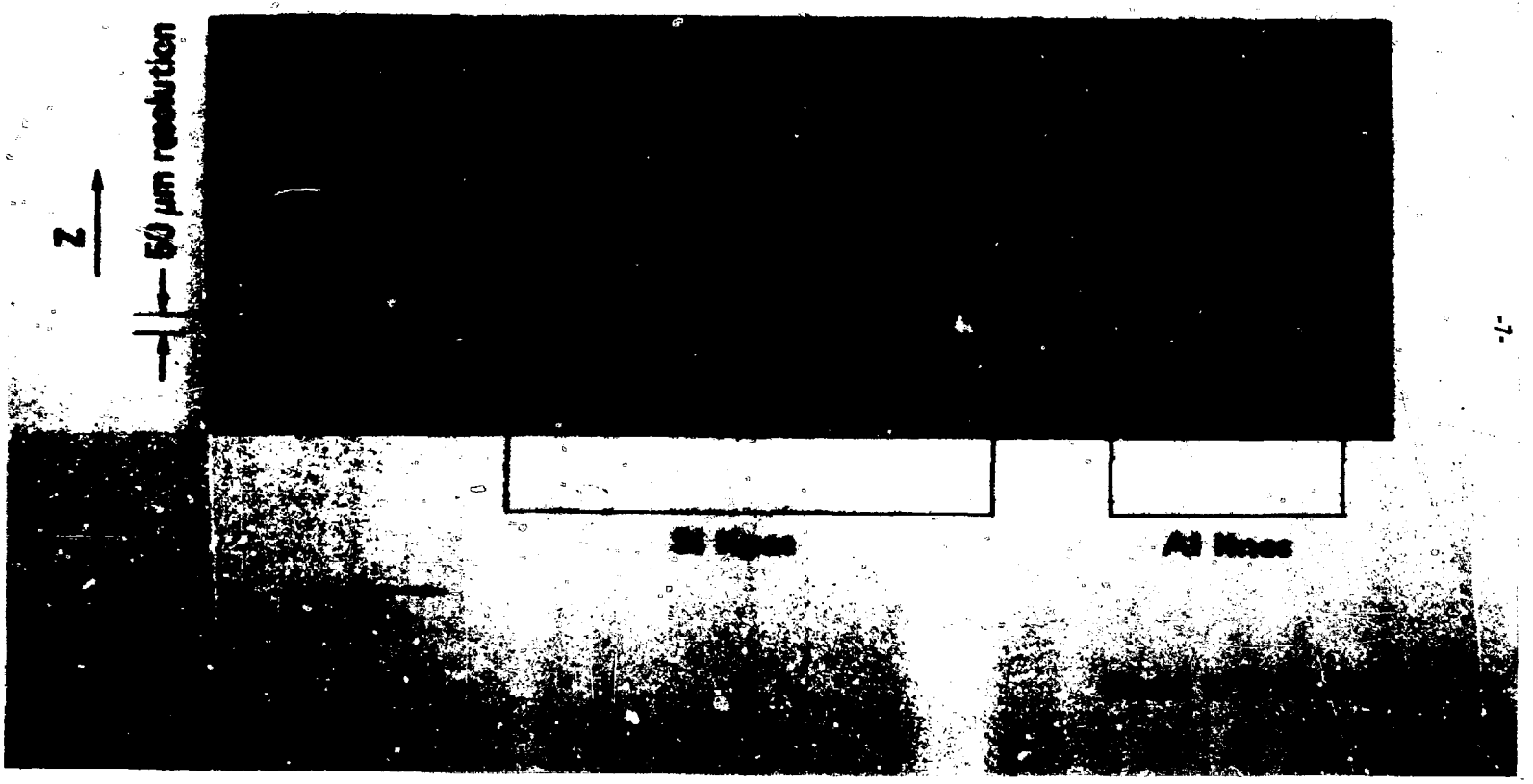
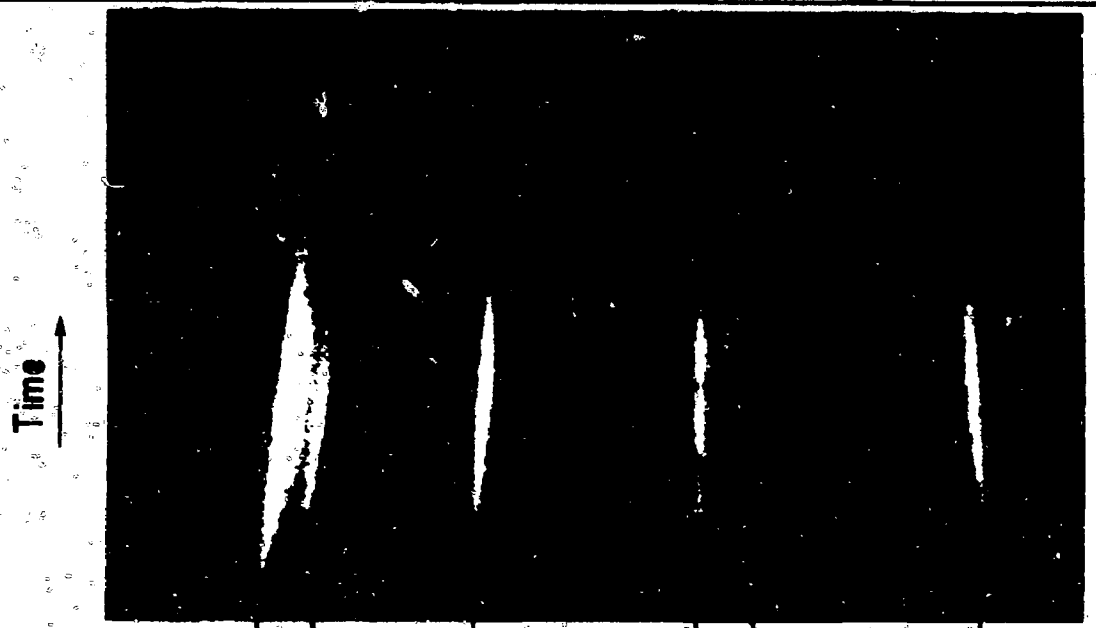
EXAMPLE OF A SPACIALLY RESOLVED SPECTRUM FROM AN Al-DOPED GLASS TARGET



EXAMPLE OF A TIME-RESOLVED SPECTRUM FROM AN Al DOPED GLASS TARGET



Shot 1/7/82

Figure 2

RATIO OF SUCCESSIVE LINES IN He SERIES AGREE WITH THEORETICAL VALUES FOR OPTICALLY THIN LINES

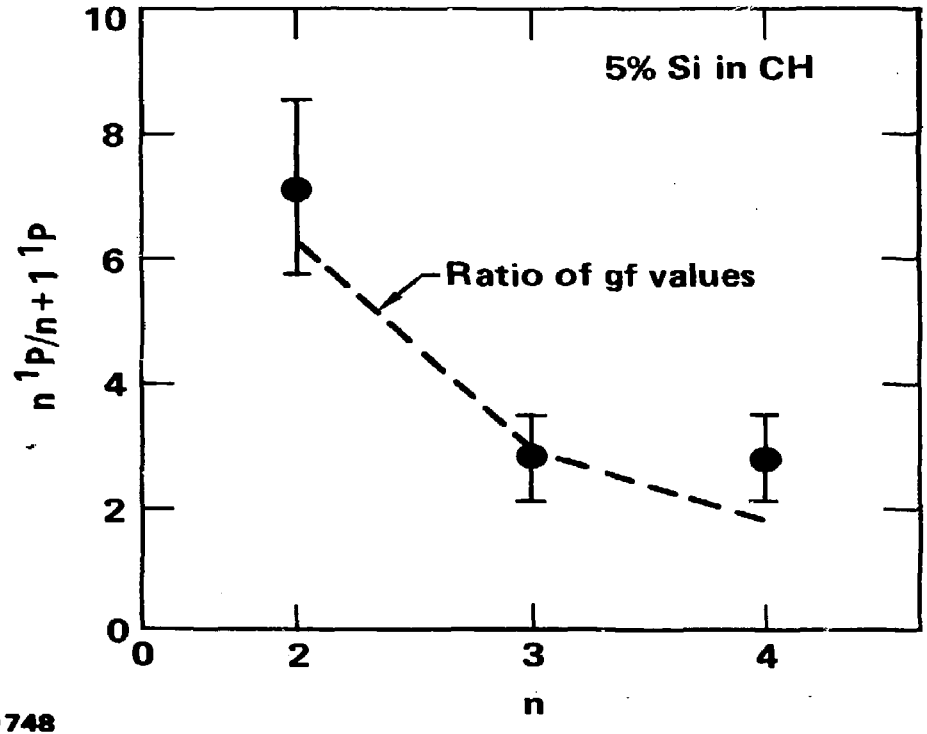


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Figure 3

COMPARISON OF Si SPECTRA FROM THE INTERACTION REGION FOR CH AND PbO FOR $2\omega_o$ ILLUMINATION

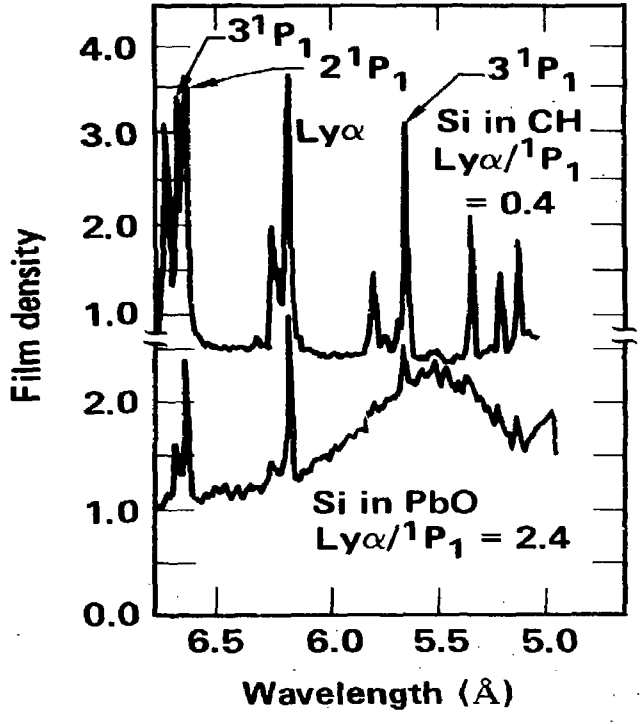

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Figure 4

COMPARISON OF Si SPECTRA FROM THE CORONAL REGION FOR CH AND PbO FOR $2\omega_o$ ILLUMINATION

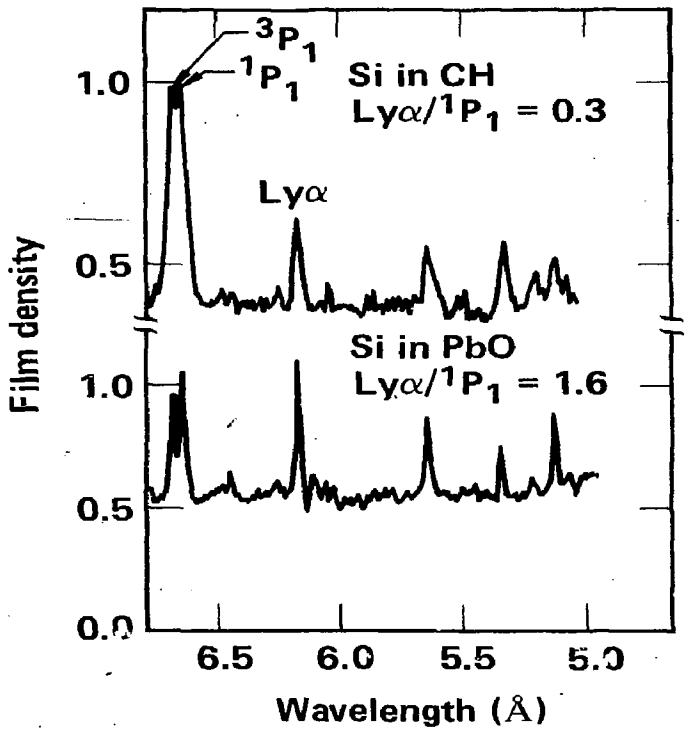

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Figure 5

TIME DEPENDENT LINE RATIOS OF Si CAN BE USED TO DERIVE TIME DEPENDENT ELECTRON TEMPERATURES

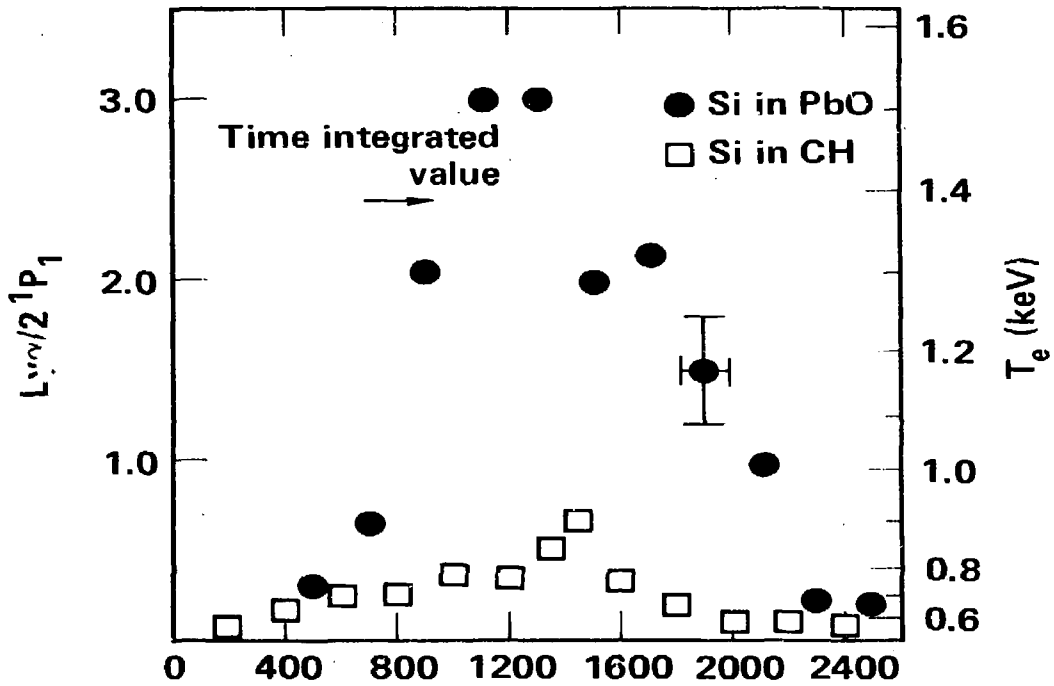

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Figure 6

SIMPLE ANALYSIS OF $^1P_1/^3P_1$ RATIO SHOWS THAT DOPANT EMISSION IN CH OCCURS AROUND CRITICAL DENSITY FOR 0.532 nm LIGHT

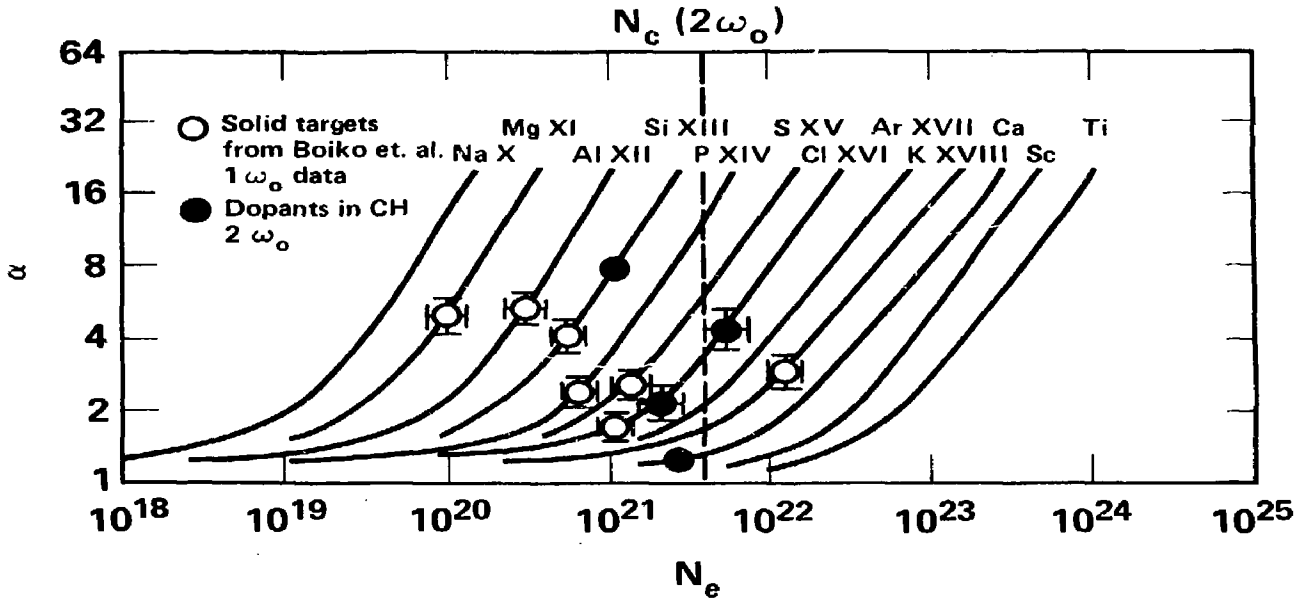

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Figure 7