§21. X-ray Spectroscopy of Photoionized Plasma with Laser-Plasma Radiation

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Quantitative descriptions of emission and absorption of radiation are of great importance in the study of energy transport and hydrodynamic behavior of hot dense matters such as laser produced plasma or celestial objects. Numerous radiation hydrodynamic codes including sophisticated atomic models have been developed and they have been validated mainly with absorption spectroscopy of relatively low-temperature dense plasmas in local thermodynamic equilibrium (LTE) created with intense thermal radiation [1]. With decease in density, plasma becomes collision-less and photo-excitation and ionization processes become important particularly in the materials exposed to intense radiation sources. Such a photoionized plasma has been observed in the interstellar medium surrounding x-ray binary stars [2]. To investigate formation of such plasmas, atomic codes developed mainly for the analysis of photoionization have been used [3], but little of them have been benchmarked with laboratory experiments.

We have started a new spectroscopic research in order to provide an experimental database extended to a plasma region dominated by the radiation processes. A rate-equation including heating by external radiation was developed. In addition a preliminary experiment was made by using a new GXII irradiation system named HIPER (High Intensity Plasma Experimental Research). Low-density hydrocarbon plasma was heated with laser-plasma thermal radiation, and x-ray spectra were observed with a time-resolved spectrograph.

The ionic and excitation states are determined by competition of radiation heating and ionization with collision-initiated cooling and recombination. Temperature of the matter (which is less-collisional due to low density), and ionization equilibrium are strongly dependent on a scale value called ionization parameter defined as [4], $\xi = P_x / nR^2$ where P_x [erg/s] is the luminosity of radiation source, n [cm^{-3}] is the density, and R [cm] is the distance between the matter and the source. If the ionization process is governed by photoionization due to relatively lower density, the ionization parameter provides a scaling factor for plasmas of different densities and distances.

The rate equation was solved to investigate how photoionization influences on the population of ionic and excitation states of carbon plasma. Details of the model are described elsewhere [5]. A dilution factor f is introduced so as to provide a common photoionization parameter ξ=10 to compare with the experimental condition. It is noted from these calculations that higher ionization stages can be attained when scarce carbon plasma is heated with intense radiation.

In the experiment two identical gold cylinders were irradiated with a frequency-tripled Nd:glass laser pulse to generate a quasi-Planck radiation of 80 eV. Separately, a parylene foil of 0.2 μm coated with a 10 nm gold was irradiated with a shorter laser pulse to create a low density plasma. Density and temperature of the CH plasma were estimated with one dimensional radiation hydro-code ILESTA-1D. The ionization parameter calculated for these conditions was 13. To obtain absorption spectrum of the CH plasma, an x-ray backlight source was generated with a gold foil and the third laser pulse. As seen in Fig. 1, soon after the onset of the main drive, self-emission of C $1s^2 1snp$ (n=2-4) lines and their satellites were observed. Until then no self-emissions nor absorption spectra were observed. This infers that the hot CH plasma was generated with thermal x rays from the twin cavity and ionized at least up to the He-like stage. This is consistent with the model prediction.

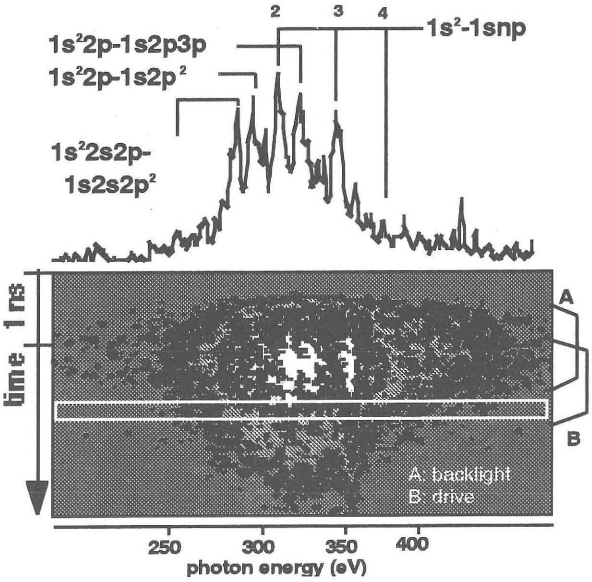

Fig.1 X-ray streak spectrum from the low density CH plasma heate with thermal radiation.

In this study, the rate equation was solved assuming the steady state case but this is not adequate to compare with the experiment. Then, as a next step, the equation will be solved for the non-steady state to predict time-dependent ionization processes in a more realistic manner. In addition, further experimental study is necessary to demonstrate the dominance of radiation-processes over the ionization processes.

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