§33. Research on Target Heating Processes Using PW-Laser-Driven Intense Proton Beams

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Stopping power of hot and dense matter for heavy ions is predicted to be larger than that of cold equivalent, resulting in the range shortening of projectiles. This effect, called as “plasma effect”, is very important for target design of heavy-ion-driven inertial confinement fusion. By using z-pinch-discharge plasmas or laser-produced plasmas as targets for beam-plasma interaction experiments, many scientists have so far examined the enhancement of stopping power due to the plasma effect. However, no experiment using beam-heated plasma has been conducted. Thus, the purpose of this study is to examine the feasibility of the interaction experiments using plasma targets heated by PW-laser-driven intense proton beams. We estimate the energy loss of the protons in a carbon foil using a simple simulation code and survey the optimum experimental parameters.

Kodama *et al.* have measured the energy spectra of converging proton beams from a concave thin foil target backward irradiated by a PW laser at ILE. We used one of the spectra obtained by them for our estimation, which was integrated with incident angles from 0º to 30º. By neglecting space charge effects, here we assumed that the front surface of the carbon foil was located at the geometrical focal point of the converging proton beam. Because the incident protons penetrate the foil with diverging, the beam-heated volume in the foil had a conical shape as shown in Fig. 1. We evaluated the amount of beam energy deposition on this volume by integrating the total energy loss of protons. The energy loss calculation used the Bethe’s stopping formula extended to plasma media. To obtain temperature from the internal energy of the target, we used a SESAME equation-of-state library. By assuming that high-energy protons were generated at the moment of PW-laser irradiation, the arriving time of each proton was determined from its velocity and the distance between the foils (300 μm). Figure 2 shows the time evolution of foil temperature for various foil thicknesses from 10 μm to 500 μm. From the figure one can see rapid increases in the foil temperature due to the energy deposition by penetrating protons. Here, we neglected the expansion of the plasma and assumed that the plasma had the same density as solid because the heating time (~10 ps) was much smaller than the time scale of hydrodynamic motion. For the case of a 100-μm foil, a plasma with a temperature of 100 eV and a mean ion charge of 4 was finally obtained after heating, which means that the condition for measuring the plasma effects on the stopping power is satisfied. In Fig. 2 we plotted the energy spectra of incident and outgoing protons. Solid lines for outgoing protons are in the case of plasma target with beam heating, while dashed lines are in the case of cold target without beam heating. For high-energy protons with kinetic energies above 10 MeV, spectrum shifts to lower energy were very small because of low stopping power for such high-energy protons. No plasma effect was detectable because the foil target was not heated enough when the high-enegy protons interacted with the target. On the other hand, because relatively low-energy protons with energies around 1 MeV lost large amount of their energy in the foil, spectrum shifts to lower energy were observable. In addition, the enhancement of energy loss due to the plasma effect could be observed, particularly in the cases using a foil of 50 μm and 100 μm.

In conclusion, to observe plasma effects in actual experiments, a novel method for high-resolution energy spectrum measurement will be needed.

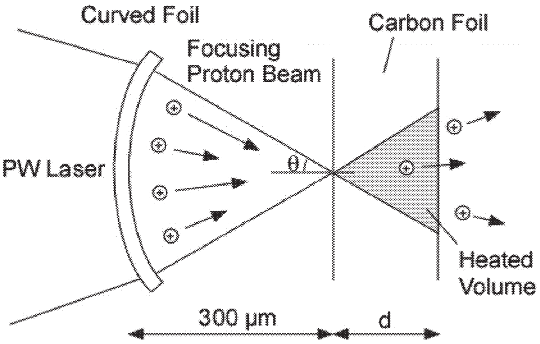

Fig. 1. A schematic of beam-heated foil plasma interacting with intense protons.

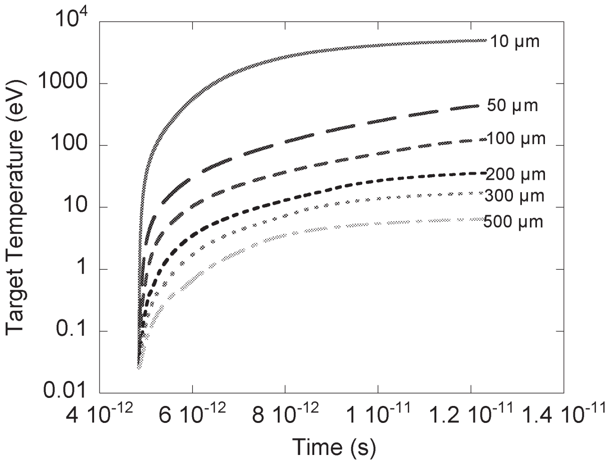

Fig. 2 Time evolutions of target temperature for various foil thickness.

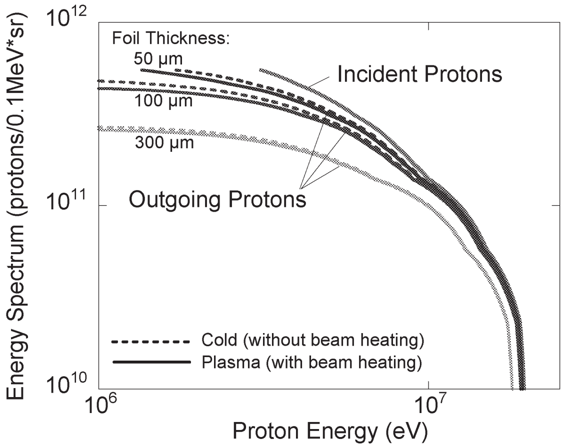

Fig. 3. Energy spectra of protons outgoing from carbon foils of 50 μm, 100 μm, and 300 μm thick.