§5. Ion Energization during Coulomb Explosion of Laser-irradiated Hydrogen Pellets

Murakami, M. (ILE, Osaka Univ.),
Tanaka, M.

Plasma expansion into vacuum and ion acceleration during Coulomb explosion of laser-irradiated hydrogen pellets have been studied extensively in the past decade. In the phenomena, hot electrons expand rapidly outward leaving massive cold ions (protons) behind, resulting in large radial electrostatic field between the electron front and the ion core. The energy transfer rate from hot electrons to ions and the maximum energy attained by ions are practically important issues of laser fusion engineering.

Theories traditionally assumed unrealistic charge quasi-neutrality condition, until a self-similar solution without such constraint was found with the two-fluid equations coupled with the Poisson equation [1]. The self-similar solution is characterized by a single constant parameter

$$\Lambda_s = \frac{R(t)}{\lambda_D(t)} = \frac{R_0}{\lambda_{D0}} = R_0\left(\frac{4\pi n_{e0}e^2}{T_{e0}}\right)^{1/2}$$

which is the ratio of the plasma size R and the Debye length λ_D. The solution exists only for a specific parameter value γ=4/3 with

$$T_e(t) \propto n_e(t, r=0)^{\gamma-1}$$

where T_e and n_e are the electron temperature and density, respectively. Thus, the solution requires verification by another method.

Recently we have shown using molecular dynamics simulation [2] that the self-similar solution is the relevant solution of the Coulomb explosion process [3]. Our molecular dynamics code exactly treats a charged N-body system with the Coulomb and core-exclusion forces (without spatial grids) [2]

$$m_i \frac{d\mathbf{v}_i}{dt} = \sum_j \frac{q_i q_j}{|\mathbf{r}_i - \mathbf{r}_j|} + 48\varepsilon_{ij}\left[\left(\sigma/r_{ij}\right)^{12} - \left(\sigma/r_{ij}\right)^{6}\right],$$

$$\frac{d\mathbf{r}_i}{dt} = \mathbf{v}_i$$

Here, $\mathbf{r}_i$ and $\mathbf{v}_i$ are the position and velocity of i-th particle, respectively, m_i and q_i are its mass and charge, respectively, $r_{ij}=|\mathbf{r}_i\mathbf{r}_j|$ is the distance between i-th and j-th particles,σ is the sum of radii of i-th and j-th particles, and ε_{ij} is the Lennard-Jones interaction energy for these particles.

Figure 1 shows the maximum ion kinetic energy $\varepsilon_{i,max}$ normalized by $2T_{e0}$ against the initial radius of the hydrogen pellet. Circles and squares denote the simulation value for the initial electron density 10^{23}/cm^3 and 10^{21}/cm^3, respectively, and the solid curve corresponds to analytical value. The value $\varepsilon_{i,max}/2T_{e0}$ increases with the initial radius, and theory and simulation values agree quite well. The energy transfer efficiency from electrons to ions is shown in Figure 2; the notation is the same as for Figure 1. The energy transfer efficiency to ions increases monotonically with the initial pellet radius; again theory and simulation values are in excellent agreement. Therefore, we conclude that the analytical formula of the self-similar solution can be used for robustly for engineering design. We propose the operational window $1<\Lambda_u<10$ for the design of target pellets in laser fusion.

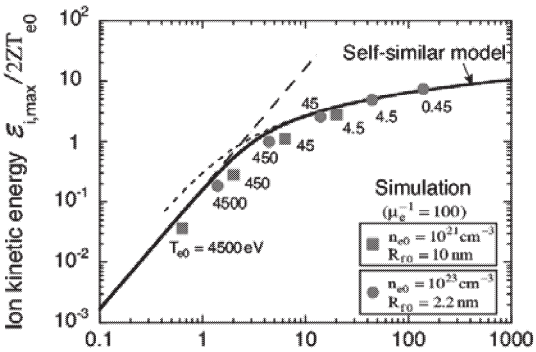

Fig.1 The maximum ion kinetic energy $\varepsilon_{i,max}$ normalized by $2T_{e0}$ against the initial radius of the hydrogen pellet.

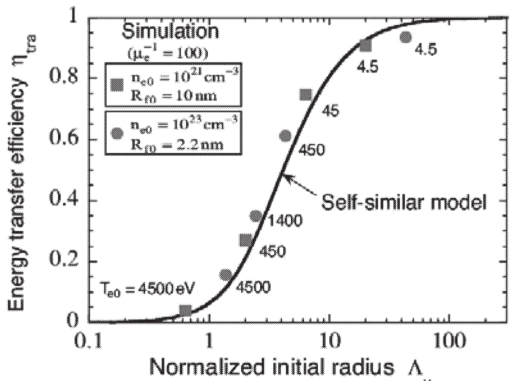

Fig.2 The energy transfer effciency from electrons to ions as the function of initial radius.

References
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