# §21. Collisional Effects on Fast Electron Generation and Transport in Fast Ignition

Sakagami, H.,
Kaseda, Y. (Dept. Phys., Nagoya Univ.),
Taguchi, T. (Dept. Elect. Eng., Setsunan Univ.),
Johzaki, T. (Inst. of Laser Eng., Osaka Univ.)

We have been promoting the Fast Ignition Integrated Interconnecting code ($FI^3$) project to boldly explore fast ignition frontiers. Under this project, interaction between ultrahigh-intense laser and Au cone plasma is computed by PIC code. As the Au plasma is extremely overdense, collisional effects (drag and scattering) within the cone would be important. According to 1D collisional PIC code PICLS1d,[1] relatively low energy fast electrons, which are expected to mainly heat the core, suffer from strong scattering by highly ionized ions, and lose their kinetic energies through collisional interactions with background electrons and a resistive field. In addition the return current carried by background electrons is significantly damped by the increased resistivity.[2]

A PIC code introduces a spatial mesh on which fields are defined and the field value for a particle is determined by interpolating field values on neighboring mesh points. This algorithm can greatly reduce calculations, but forces of the direct interaction between two particles, i.e. collisions, are automatically filtered out. So PIC codes are widely used for modeling plasmas where collisions are not important in physical processes. When the plasma density is as high as solid density, binary collisions cannot be ignored in determining physical processes such as heat conduction and energy relaxation. Collisional effects can be calculated by the binary collision process, where the collision frequency depends on the relative velocity of pairing particles. Installing the binary collision model into PIC code, however, requires very long computation time. Thus we have developed the statistical collision model that is based on modified Langevin equation[3] for electron-electron collisions to reduce computations. The modified Langevin equation is given by

$$\frac{d\mathrm{v}}{dt} = -(\nu_S + \nu_D)\mathrm{v} + R(t) \quad . \qquad (1)$$

In our model, the velocity change of each electron by collisions is computed with two components. First one describes a slowing down term with the electron-electron slowing down rate $\nu_S$ by Coulomb collisions and an additional term $\nu_D$ given by

$$\nu_S = \frac{8\pi e^4 n_e \ln\Lambda}{m_e^2 \mathrm{v}^3}\mu(x), \quad \mu(x) = \frac{2}{\sqrt{\pi}}\int_0^x t^{1/2}e^{-t}dt, \quad x = \frac{m_e \mathrm{v}^2}{2k_B T_e} \qquad (2)$$

and

$$\nu_D = -\frac{k_B T_e}{m_e \mathrm{v}}\frac{\partial \nu_S}{\partial \mathrm{v}} \quad . \qquad (3)$$

Second component represents a fluctuation term, which is calculated as a random force *R(t)* and *R(t)* satisfies following equations:

$$\begin{cases} \langle R(t) \rangle = 0 \\ \langle R(t)R(t') \rangle = 2D\delta(t-t') \end{cases} \qquad (4)$$

and

$$D = \frac{k_B T_e}{m_e}\nu_S \quad . \qquad (5)$$

Once we define $T_e$ as a target state, we can compute time evolution of velocity of electrons, and the velocity distribution function is relaxed to Maxwellian distribution with Te regardless of initial distributions. These computations have the order of number of particles and CPU time can be saved.

In the fast ignition scheme, fast electrons are generated by ultrahigh-intense laser and propagate toward the core through the dense plasma. Thus collisions between fast (beam) and background electrons should be important. Our statistical collision model is extended to Maxwellian distribution with the drift velocity, and the thermal and drift velocities of the target state are determined as an equilibrium state to conserve total energy and momentum of electrons. In this situation, beam and background electrons are independently relaxed to the target state, where the total energy and momentum of electrons are the same as those of the initial state. As an averaged velocity of background electrons is lower than that of beam electrons, background electrons are relaxed much faster than beam electrons because $\nu_S$ is inversely proportional to the cube of electron velocity. Thus the background electron energy quickly increases, but the beam electron energy slowly decreases without conserving the total energy in early stage. To conserve the total energy and momentum of electrons at any time, we improve algorithm of our statistical collision model as follows: 1) discriminate between background and beam electrons, 2) measure thermal and drift velocities of background electrons as the target state, 3) compute collisions of beam electrons with the target state and calculate momentum and energy losses, 4) compute collisions of background electrons with the target state, and 5) correct background electron velocity to conserve the total energy and momentum.

Finally we investigated collisional effects on fast electron generation and transport in fast ignition using 1D PIC code with our statistical collision model. In the collisional case, the pressure of electrons in the x-direction decreases by the isotropic process due to scattering by collisions. Consequently, the density profile steepening at the laser front is enhanced, and then the low energy component (<8 MeV) of fast electrons is generated much less than that of the collisionless case. Under current parameters, collision has little effects and more researches are needed to investigate collisional effects on fast electron generation and transport in fast ignition.

This work was partially supported by JSPS Grant-in-Aid for Scientific Research (C)(19540528).

1) Sentoku, Y., et al.:J. Comput. Phys. **227** (2008) 6846.
2) Johzaki, T., et al.:Plasma Phys. Control Fusion **51** (2009) 014002.
3) Taguchi, T., et al.:Optics Express **18** (2010) 2389.