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Effect of Radiation Process in Relativistic High Energy Electron Transfer
相対論的高エネルギー電子輸送における輻射過程の影響

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In cone-guiding fast ignition, an Au-cone is used to introduce heating laser close to a compressed core. In such a high *Z* material, not only collisions with bulk plasma particles, but radiation dumping will be important for transport of relativistic fast electrons generated by irradiation of ultra-intense laser. We analyse the effects of collision and radiation on the energy transport of fast electrons in a cone by assuming various material on the basis of Particle-In-Cell simulations.

1. Introduction

Fast Ignition Realization Experiment program (FIREX) [1] is advanced in Institute of Laser Engineering , Osaka university. In this project, a dense fuel core imploded by low-intensity and long-pulse GEKKO XII laser is heated by a ultra-high-intensity and short-pulse LFEX laser. The aim of this project is demonstrate fast heating of fusion fuel up to the ignition temperature (5keV).

Generally, low density plasma ablated by implosion laser irradiation exists in the surrounding of a dense core. It prevents the heating laser from reaching close to the core. Kodama et al. [2] proposed a cone-shell target that an Au cone is pickled in fuel shell to introduce the heating laser near the core. Using the cone-shell target, 20% heating efficiency was attained in the integrated experiments.

On the other hand, in recent integrated experiments using Au cone attached shell targets, it was observed that the grate amount of γ-ray is generated by irradiation of heating laser, and the γ-ray affects measuring instruments directly, as well as measurement of fusion neutron yields via the (γ,*n*) reactions in chamber structure materials.

Additionally, for transport of relativistic fast electron in a high *Z* material such as Au, not only collisions with bulk plasma particles but also radiation dumping can not be neglected. For instance, in the room-temperature solid-density Au, the contribution of radiation to the stopping power for fast electron (shown in Fig.1) becomes larger with increasing energy of fast electrons, *e.g,* the contribution is 11% for 1-MeV electron and is 50% for 10-MeV electron. Hence, we should consider the radiation dumping in the fast electron transport in the cone material especially for in the high Z material.

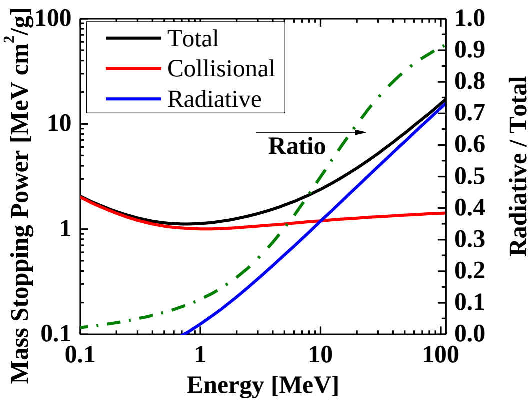

Fig. 1 .Energy dependence of the stopping power to the high energy electron in room-temperature solid-density Au.

In this work, we examine the effect of radiation dumping on energy transport of fast electron in various materials on the basis of the Particle-In-Cell (PIC) code including collision and radiation processes.

2. Simulation method

We use relativistic electromagnetic PIC code of which the typical cycle in one time step is shown in Fig.2. In the conventional PIC code, the equations of charged particle motion and time development of electromagnetic field are simultaneously solved (Fig.2 blue line). Since the aim of this work is analyze of energy transport in high density material, we have to consider both collision and radiation processes (Fig.2 red line).

Related to generated γ-ray, assuming its stopping range is large enough to the cone and implosion core size, so we don't consider radiation transport process. We assume that γ-ray freely escape from the cone and the core with keeping its direction and energy at emission. For extract of fundamental properties, one dimensional simulation is preferable since the PIC simulations for the target with wide density scale (from laser critical density to the solid one) are very expensive. So, we carried out simulations in one dimensional real space and three-dimensional velocity space in the view of both developing and computation execution.

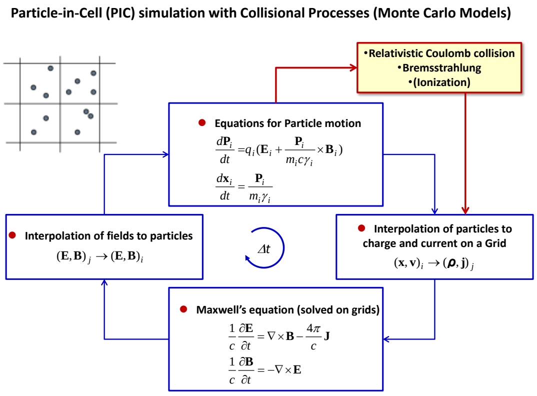

Fig. 2. Typical cycle in one time step in relativistic electromagnetic particle simulation considering collision and radiation processes.

3. Relativistic Binary Collision

We briefly present the relativistic binary collision model. The collisional model is based on Ref. [4] (basic concept) and Ref.[5] (relativistic binary collision between different weighted particles).

After choosing two particles, the calculation of collision is done in center of mass (COM) flame. The coordinate system of momentum space is rotated to the system in which the p_z-axis is aligned with the momentum vector $\boldsymbol{p}_1$ of the first particle. This transformation is represented by

$$\begin{pmatrix} cos\theta cos\varphi & cos\theta sin\varphi & -sin\theta \\ -sin\theta & cos\varphi & 0 \\ sin\theta cos\varphi & sin\theta sin\varphi & cos\theta \end{pmatrix} \begin{pmatrix} p_x \\ p_y \\ p_z \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ p \end{pmatrix} \quad (1)$$

The relativistic collisional frequency is given by

$$\nu_{12} = \frac{4\pi (e_1 e_2)^2 n_L \Lambda}{{p_{rel}}^2 v_{rel}} \quad (2)$$

where, Λ is the Coulomb logarithm, n_L is the lower density among the first particle density n_1 and the second one n_2, p_{rel} and v_{rel} are the relative momentum and velocity between two particles. The scattering angle Θ is chosen randomly from distribution of Θ that has the zero mean value and the variance of

$$\langle \tan^2(\Theta/2) \rangle = \nu_{12} \Delta t \quad (3)$$

where Δt is time step duration of simulation. The magnitude of the momentum p is unchanged in the binary collision process, but only the direction is changed. Once the scattering angle is determined, we can get the change in momentum of the particle in the collision $\Delta\boldsymbol{P}$. Using both $\Delta\boldsymbol{P}$ and the conservation of the total momentum through the collision process, we get the momenta for two particles after the collision.

$$\boldsymbol{P'}_1 = \boldsymbol{P}_1 + \Delta\boldsymbol{P} \quad (4)$$

$$\boldsymbol{P'}_2 = \boldsymbol{P}_2 - \Delta\boldsymbol{P} \quad (5)$$

Finally, the momenta in COM frame are transformed to those in laboratory frame. These calculations are done for all particles in every step.

4. Radiation process

When the high energy electrons pass through the high density plasmas, the large angle scattering by bulk ions occurs and the high energy photons are emitted via the bremsstrahlung process. The emitted γ-ray has the energy from hundreds keV to several tens MeV. The energy of emitted photons becomes impossible to ignore in the kinetics in the large angle scattering of high energy electrons.

The treatment of large angle scattering is basically the same as that for the small angle binary collision noted above except for the collision cross-section. In addition, we calculate the radiation emission due to the bremsstrahlung. The radiation probability of bremsstrahlung is calculated by quantum electrodynamics [**6**]. The energy and momentum losses of fast electrons are also calculated to keep the energy and the momentum balances between electrons and photons.

5. Concluding Remarks

We simulated the transport of fast electrons in dense plasmas by assuming various materials for plasma with PIC code including collision and radiation process. We will discuss the contribution of radiation emission to energy loss of fast electrons.

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