§17. Effective Parallelization of PIC Simulation for the Calculation of Laser Plasma Interaction

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In fast ignition scheme of laser inertial fusion, a compressed core plasma whose electron density exceeds 1000 times of solid density is irradiated by an ultra intense laser beam to heat the core for ignition of the thermonuclear reactions. However, because the ultra intense laser beam can be propagated only up to its critical density (=1/100 of solid density), the fast electrons are usually created at this point and then propagate for several 100 μm to the core. These processes should involve a board range of non-linear effects such as relativistic laser self-focusing, horsing and snaking instability, and Weibel instability of high current beam propagation in the plasma. In order to reproduce the whole physics during the laser and beam propagation, a particle-in-cell (PIC) calculation is widely used. The simulation treats individual particle motions via Lorenz force, so that the system size will be proportion in the particle numbers. This makes difficult to calculate large size plasma (~mm) as used in the experiment. For this purpose, so many parallelization methods have been developed to minimize the calculation resources. The most popular method divides the calculation region into several sub-regions equally. However, when the particle population is not uniform in each sub-region, the parallelization efficiency easily saturates with the number of calculation nodes.

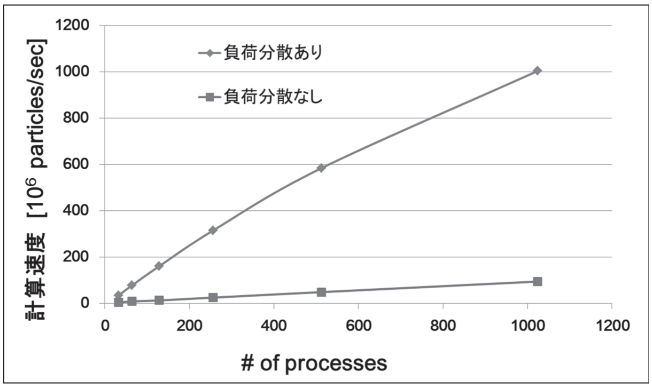

FIG. 1. The calculation speed per one particle with (blue) and without (red) Oh!Help! as a function of processes.

In order to improve the calculation efficiency, we applied Oh!Help[1)] library to our PIC code. This library enables to have a primary and secondary domain in each node. The domain with light load helps the calculation of other primary domain having heavy load (secondary domain), resulting in load balance among the domains. In order to validity of this library, we conducted a calculation for laser plasma interactions changing the domain number. The total grid size of this simulation is 2400 x 2400 (corresponding to the size of 35μm x 35μm). A dense plasma is located around left middle side with 24μm(v) x 4μm(h), in which electron density is $10n_c$ (particle number: $2.2x10^7$). The ultra intense laser light (focal intensity of 10^{20}W/cm^2) irradiates the plasma from the left side. The laser wavelength is 1μm and the pulse duration is 100fs. Figure 1 shows the calculated results as a function of domain (process) number. The vertical axis indicates the calculation speed per one particle. The blue and red lines represent the results for the cases with and without the library. In the result, the calculation speed with library linearly increases and the speed is nearly 10 times of the speed without the library.

Using this code, we conducted a real scale PIC simulation in the Plasma Simulator, NIFS. We fixed the number of processors as 8192 through the calculation. The size of plasma is 616μm(h) x 70μm(v), and the plasma has an exponential density ramp from $0.05n_c$ to $1.2n_c$ with the scale length of 194μm. The intense laser light irradiates from the left boundary with 10^{19}W/cm^2 focal intensity with F7 focusing cone. The pulse length is 2ps and the calculation ends at 5ps. In the calculation, the focused position is changed. Figure 2 shows the calculated magnetic field intensity for 0.06, 0.15, and $0.47n_c$ focusing conditions detected at 2.5ps. It is clear that when the focus position becomes deeper region, the intense laser light suffers more beam breakup (filamentation). In any cases, the calculation time was about 9.5 hours. This fact indicates that we can conduct the real scale calculation for fast ignition in the realistic time scale using this library.

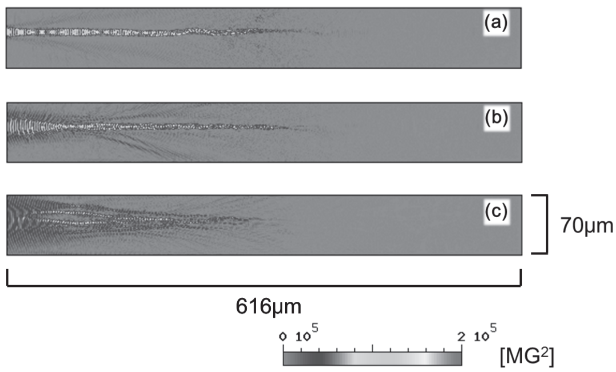

FIG. 2. Calculated magnetic field intensity for (a) $0.06n_c$, (b) $0.15n_c$, and (c) $0.47n_c$ focusing conditions detected at 2.5ps from the laser injection.

1) H.Nakashima *et al.*, ICS'09 (2009) 90-99.