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Theory and simulation of the acceleration of high charge-state heavy ion by an ultrahigh intense laser

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These days cancer therapy using heavy ion beam such as carbon ion has had successful results. Generally, linear or synchrotron particle accelerators are used to get energetic heavy ion beams, but the size of such accelerators is too large to distribute it widely to medical institutions. So, the realization of a compact accelerator is demanded. A laser particle accelerator is one candidate for a future compact accelerator. With the progress of laser technology, the energy of ion beams has increased day by day. A recent report has shown that an ultra-intense laser of 10^{21} W/cm^2 accelerated almost fully stripped iron ions up to 0.9 GeV [1].

When an ultra-intense laser with an intensity greater than 10^{18} W/cm^2, irradiates a solid, a low-Z material, i.e. hydrogen, carbon, is easily fully ionized, however it is hard to fully strip electrons from high-Z atoms such as iron, copper, silver, gold and so on. The degree of high ionization is critical for efficient acceleration. Therefore, understanding the dynamics of ionization in a target during the intense laser-matter interaction is a key to realizing high-Z ion acceleration by a laser.

In the case of the ideal situation, a laser system has no prepulse or pedestal components and the target consists of pure material, namely no contaminants. The ultrahigh intense laser will be able to accelerate heavy ions efficiently in this case, but actually the laser has some prepulse or pedestal components and the target has contaminants. We here propose that the prepulse plays a role in blowing off contaminants so that the main pulse accelerates purely the material. We demonstrate this scheme by an integrated simulation.

Prepulse parameters are carefully determined to remove contaminants from target using a self-similar expansion model. To simulate overall laser-matter-interactions from the low intensity of 10^{10} W/cm^2 to high intensity of 10^{21} W/cm^2, a relativistic Particle-In-Cell (PICLS [2]) simulation, which incorporates atomic processes, such as Coulomb collisions, field ionization and impact ionization, is combined with hydrodynamic simulation (FLASH2D [3]). The laser parameters are set to the real parameters of the J-KAREN-P laser system at KPSI, QST, Japan. The target consists of silver and the contaminants are assumed to consist of hydrogen and deuterium, which has the same charge-to-mass ratio of carbon for the condition of full ionization.

Contaminant detachment before the main pulse arrival is clearly seen in the simulation. Rapid progress of ionization is observed right after the main pulse irradiation. The charge-state of efficiently accelerated silver ions is around +38 and is mostly determined by the strength of the rear surface sheath field. We conclude that the tuned prepulse blows off contaminants from the target, and then the main pulse-induced sheath field ionizes silver up to high-charge-states and simultaneously accelerates the silver ions.

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