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Ionization-stabilized Laser Ion Radiation Pressure Acceleration

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Laser-driven ion acceleration has aroused great interest during the past decades, since ion beams have potential for many groundbreaking applications [1,2]. However, the currently obtained ion beams are always characterized by low energies, broad energy spectra and large angular spreads. How to generate high-quality energetic ion beams is of great significance for the realization of laser-based applications. Previous studies have focused on target normal sheath acceleration (TNSA) and radiation pressure acceleration (RPA) [3]. TNSA is very robust and easily accessible in experiments, but typically with poor beam quality. On the other hand, RPA is convinced to be able to generate ion beams with super high energy and narrow energy spread, but has rigorous requirements on experimental conditions and is very susceptible to transverse instabilities. Thus, the acceleration always ends prematurely and the beam qualities deteriorate seriously.

To achieve stable RPA and improve beam qualities, in this talk, a novel scheme of ions from laser-irradiated ultrathin foils is proposed [4,5], where a high-Z material coating in front is used. The coated high-Z material, acting as a moving electron repository, continuously replenishes the accelerating ion foil with comoving electrons in the light-sail acceleration stage due to its successive ionization under laser fields with Gaussian temporal profile. As a result, the detrimental effects such as foil deformation and electron loss induced by the Rayleigh-Taylor-like and other instabilities in RPA are significantly offset and suppressed so that stable acceleration of heavy ions are maintained. Two- and three-dimensional particle-in-cell simulations show that a monoenergetic Al^{13+} beam with peak energy 3.8 GeV and particle number 10^{10} (charge > 20nC) can be obtained at intensity 10^{22} W/cm^2.

Meanwhile, I will also present our recent progresses on laser-driven ion acceleration. First, a new acceleration mechanism named "electrostatic capacitance-type acceleration" [6] is proposed, which is suitable for a multi-species nanofoil target irradiated by an intense few-cycle laser pulse. With this mechanism, 100MeV proton beams with energy spread less than 10% can be obtained with a laser energy less than 10J. Then, through theoretical analysis and numerical simulations, scaling laws for laser-driven ion acceleration from nanometer-scale ultrathin foils are derived [7], which are consistent with relevant experimental data on different facilities over a large range of laser and target parameters. This is the first experimentally-validated scaling law for ion acceleration from laser-irradiated nanometer-scale foils.

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