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Preferentially Accelerating Heavy Ions over Protons using Petawatt class femtosecond lasers

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Understanding and controlling a highly charged, high density and high temperature extreme plasma produced by high intensity short laser pulses interacting with solid targets can provide novel insights into high energy physics, nuclear physics, and others. These plasmas also provide a platform for transforming the electromagnetic laser fields into quasi-electrostatic which can be used to accelerate particles. In particular, there has been a lot of recent interest in the acceleration of high atomic number (high-Z) ions. Although conventional sources of low-Z ions are already relatively compact, high-Z sources cannot achieve high energies and charge states, resulting in heavy ion accelerator complexes being extremely large with unavoidable beam emittance growth. Laser-accelerated heavy ions can provide, in a compact space both high charge states and moderately high energies (> 10 MeV/nucleon) with good emittance, making them an attractive replacement for the drift tube linacs typically used as the front end of conventional heavy ion accelerator systems. Most of the previous studies have focused on low-Z ion generation at intensities < 10^{21} W/cm^2, with maximum energies observed up to 48 MeV/nucleon and 80 MeV/nucleon for 10 J class and 100 J class laser systems respectively [1,2]. For high-Z ions, the generation of highly charged low energy (< 10 MeV/nucleon) beams have been demonstrated using lasers with intensities < 10^{21} W/cm^2. In order to realize applications, even higher-Z, and higher energy beams are required. Even though highly charged high energy Fe ions were reported [3,4], unfortunately, the ionization dynamics and the interplay with the acceleration mechanisms is far from being fully understood.

Here we present an experimental, analytical and numerical investigation of the ionization and acceleration dynamics of highly charged silver ions from foils driven by a femtosecond PW-class laser pulse focused to a peak intensity of 5×10^{21} W/cm^2 [5]. By varying the silver foil thickness from 50 to 800 nm, we demonstrate the suppression of the maximum proton energy with thinner targets while simultaneously increasing the charge state and the maximum energies of the silver ions, unambiguously detected using a novel detector configuration. With optimum target thickness of 500 nm high flux highly charged ~40 and ~10 MeV/nucleon energy ions are observed, while at the thinnest target of 50 nm, maximum charge state and energy increased up to ~45 and ~26 MeV/nucleon. Combining analytical considerations with numerical hydrodynamic and particle-in-cell (PIC) simulations we show that the surface contaminant at the rear surface is pre-accelerated and effectively blown off during the intrinsic relativistic rising edge in PW-class laser pulses, resulting in reduced contaminant ion energies but enhanced acceleration of bulk target ions. The bulk electron temperature in the target reached ~10 keV, resulting in significant ionization of the silver M-shell and L-shell by collisions. These highly charged silver ions could subsequently be extracted by strong sheath fields of ~40 to 80 TV/m at the target rear, without being shielded by surface contaminants. Simulations show that the increase in charge state from the thinnest targets is due to additional field ionization by the intense field of the laser as it bores through the target. Therefore, by careful observation of the ion charge state, we have been able to investigate the transition between collisional and field ionized heavy ion acceleration. Our investigation of the ionization and acceleration mechanisms of highly charged ions therefore provides a path for improving the control and capabilities of laser driven heavy ion sources, a key component for next-generation heavy ion accelerators.

References

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