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Highly charged heavy ion acceleration from a high temperature solid heated by J-KAREN laser system

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The interaction of relativistically intense short pulse (~few tens of fs) laser pulse with solid material generates quasi-static electric fields with strengths of > TV/m are produced within a short distance of less than μm [1]. Thanks to the very strong field gradient, the field can accelerate ions beyond MeV within a micron. Unlike the acceleration of low-Z ions, acceleration of the high-Z ion is more complicated because charge state distribution should be controlled for pursuing higher acceleration efficiency or for manipulating a spectral shape of the ions. However, all the proposed laser-driven acceleration mechanisms, including the most investigated and easy to implement mechanism, Target Normal Sheath Acceleration (TNSA) [2], are far from being fully understood in the sense of ionization mechanisms. To address this issue, we investigate the ionization mechanisms in HED plasma produced by a laser pulse of peak intensity ~5x10^{21} Wcm^{-2} interacting with a silver 500 nm target by using J-KAREN laser system KPSI, QST [3]. Even the J-KAREN laser is high contrast laser system the pulses show not completely ideal (Gaussian-like) temporal shape. The existence of the rising edge is an inherent feature of high power laser systems based on highly non-linear processes and eliminating this rising edge is challenging, even when applying pulse cleaning techniques such as plasma mirrors and/or a plasma shutter. The rising edge interacts with target in advance to the main pulse and can prematurely expand the target resulting in reduction of proton cutoff energies. This is a serious barrier for not only proton acceleration, however we found this temporal shape can be a beneficial effect on heavy ion acceleration from the bulk of the target. In the experiment we observed that silver ions with a charge state of ~ +40 are accelerated up to ~15 MeV/u with the particle number of (2±1)x10^6 ion/shot within an energy range of 10-15 MeV/u. With the help of hydrodynamic, particle-in-cell (PIC) simulations and analytical estimates, we find out that the ions in the contaminant layer pre-expands and effectively detaches from the target, still keeping the target material intact, so that the bulk ions are exposed to stronger sheath fields and accelerated to higher energies. The highly charged energetic silver ions are generated via electron collisions in the hot (~6 keV electron temperature) solid plasma. The reported heavy ion acceleration mechanism is in unexplored physical regime, which has been generated for the first time via interaction with a laser with an ultra-high intensity using the state-of-the-art laser system J-KAREN.

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[2] Clark et. al., Energetic Heavy-Ion and Proton Generation from Ultraintense Laser-Plasma Interactions with Solids, PRL 86 1654 (2000)
[3] Kiriyama, H., et. al., High-contrast high-intensity repetitive petawatt laser. Opt. Lett., 43 2595-2598 (2018); Pirozhkov, A.S., Approaching the diffraction-limited, bandwidth-limited Petawatt. Optics Express 25, 20486 (2017).

Working group

Laser-driven ion acceleration

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