Ion Acceleration in Shortpulse-Laser-Plasma Interaction ◇

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We report on systematic studies on proton and heavy ion acceleration from thin metal foils irradiated by ultrashort (100 fs) high-intensity (10^{19} W/cm^2) laser pulses. Intense ion pulses are found to be mainly accelerated from the target rear side normal to its surface. This observation is explained by the target normal sheath acceleration (TNSA) mechanism [1], where the ions are accelerated in the quasi-static electric field that builds up when electrons are driven through the foil forming a charged cloud with gradients in the range of MV/μm behind the foil. In recent experiments efficient ion acceleration up to 5 MeV/u could be demonstrated. As the presence of protons in the heavy ion beam leads to a shielding of the accelerating fields the targets had to be heated for the removal of hydrocarbon contaminants [2]. Still, the full dynamics of the acceleration process, the dependence on laser parameters and the origin of the different charge states and their energy distribution are not fully understood up to now, yet crucial for anticipated applications.

In experiments performed at the LULI 100 TW laser in 2003 we used sandwich-targets (few Beryllium monolayers sputtered on 25μm tungsten substrates and buried with pure tungsten layers of varying thickness) to characterize the acceleration fields longitudinally. Water and hydrocarbon contaminants were successfully removed by resistive heating (1200°C). Still, oxygen and argon ions were observed to be accelerated most effectively, presumably originating from buried oxide layers in the tungsten foil and from the sputtering process where Ar-gas was used for surface passivation. Astonishingly, the different charge states of these ions show distinct maxima in the energy spectra (Fig. 1) which resemble an equilibrium distribution corresponding to the transmission through a thin stripper foil [3], indicating that deeper layers are involved in the acceleration process.

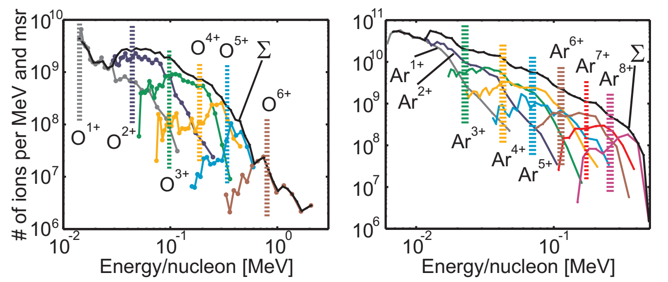

Fig. 1: Oxygen and Argon ion spectra measured at the LULI laser. The vertical lines correspond to the kinetic energy necessary to produce the respective charge state by electron exchange reactions in a carbon stripper foil [3].

Furthermore, experiments were performed at the the 10-Hz-TW laser system ATLAS 10, MPQ Garching. Although operated in single shot mode, the flexibility of the system enabled the systematic study of the influence of different laser parameters on the acceleration mechanism for the case of protons and carbon ions (contaminations on aluminum foil targets). First, the foil thickness and the duration of the intrinsic pre-pulse (ASE) of the laser was varied. The maximum proton energy was found to strongly depend on these parameters resulting in an optimal foil thickness for each ASE-duration [4], close to the value where the rear side is affected by the ASE pre-pulse prior to the arrival of the main pulse.

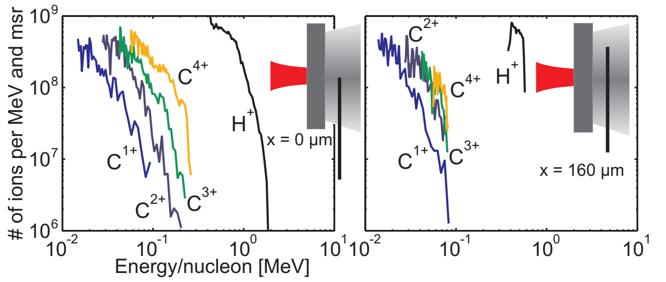

Fig. 2: Scraper method to determine the spatial source size for the different charge states.

Second, the spatial origin of the different charge states of the heavy ions is of concern. Field ionization at the surface is the dominant ionization mechanism and recombination is unlikely on the 100 fs time scale. At an early stage the acceleration field reaches values exceeding 1 MV/μm, sufficient to ionize carbon to C^{4+}. From this central maximum the field decreases radially and temporally. Assuming that a certain charge state can only be produced when the field exceeds the field ionization threshold a simple experiment was performed. A mechanical scraper was placed 1 cm behind the target and moved through the ion beam. In a distance of 1 m the ion spectra for each scraper position were recorded (pinhole-∅ 300μm). The results (Fig. 2) demonstrate that the lower charge states originate from an extended source being 100× larger than the laser spot size. Thus also their divergence due to the radial gradient of the accelerating field is expected to be reduced as it has been observed in independent experiments at ATLAS.

The latter method is promising for addressing the question of the origin of different charge states which is of great importance in understanding the underlaying physics. More detailed measurements are scheduled and prepared to be performed at the PHELIX laser (GSI Darmstadt).

References

[1] S.C. Wilks, *et al.*, Phys. Plasm. **8** (2001) 542
[2] M. Hegelich, *et al.*, Phys. Rev. Lett. **89** (2002) 085002
[3] K. Shima, *et al.*, At. Data Nucl. Data Tabl. **51** (1992) 174
[4] M. Kaluza *et al.*, submitted to Phys. Rev. Lett. (2003)

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