Spectroscopy of laser-generated ions and neutrons

S. Karsch[1,2], M. Hegelich[1,2], G. Pretzler[1,2], M. Roth[3], M. Geissel[3], A. Blaszevic[3], T. Schlegel[3], T. Cowan[4], M. Allen[4], P. Audebert[5], J. Fuchs[5], J.C. Gauthier[5], D. Habs[1] K.J. Witte[2], A. Pukhov[2], J. Meyer-ter-Vehn[2]

[1]LMU München, [2]MPQ Garching, [3]GSI Darmstadt, [4]General Atomics San Diego, [5]LULI Palaiseau

In recent laser plasma experiments, an intense and collimated beam of highly energetic protons was found to be emitted from the rear side of foil targets [1, 2, 3]. For example, using the Petawatt laser in Livermore, up to several percent of the laser energy was transferred into 2×10^{13} protons of energies $> 10\,\mathrm{MeV}$, with maximum energies above 58 MeV [4]. This effect is explained by an ultra-strong space charge field due to a relativistic electron cloud created by the laser pulse and located the backside of the target (TNSA mechanism [5]).

In previous experiments protons from surface contamination were found to be the dominant species to be accelerated independent of the target material.

In this experiment we tried to accelerate other ions as well by removing the contaminating layer. This was done embedded in a large experimental campaign at the 100-TW single shot laser at the Laboratoire pour l'Utilisation des Lasers Intenses (LULI) in Paris. The setup of our special experiment is shown in Fig. 1. Two Thomson parabola spectrometers distribute ions of one charge-to-mass ratio (q/m) on a parabolic trace according to their energy in the detector plane. CR39 nuclear track detectors recorded the traces.

We used 50μm aluminum targets with a rear-side 1μm carbon layer. Resistive heating led to a strong reduction of protons and an enhancement of carbon ions as obvious from Fig. 2. For quantitative analysis, single ion tracks on the CR39 films were counted by a scanning optical microscope [6]. First results suggest that C^4+ ions are dominantly accelerated with higher temperature and maximum energy than expected from linear interpolation. The full evaluation is under way and is expected to yield rich information on the dynamics of the ion acceleration mechanism.

In another experiment, targets with an amorphous CD-layer on the backside were used to produce a beam of accelerated deuterons. A CD_2 catcher target was positioned in this beam and $\sim 3 \times 10^7$ neutrons were generated, mainly by deuterium fusion.

At the MPQ ATLAS-10 laser facility, an adaptive optics system has been installed which consists of two deformable mirrors, wavefront and beam-profile diagnostics, and automatic closed-loop alignment. The modifications now allow for reproducible high-intensity experiments up to $I > 2 \times 10^{19}$ W/cm^2. In ongoing fusion neutron generation experiments with solid CD_2-targets, a clear dependence of neutron yield on laser intensity has been found (Fig. 3). TOF spectroscopy of these neutrons allows to deduce the directional characteristics of the deuterons accelerated in the laser plasma, and a few different regimes were identified, with different angular deuteron distribution and probably with different acceleration mechanisms. (sup. by DFG Ha 1101/7-1, GSI F/E LM/HABP and EU Large Scale Facility Access Program)

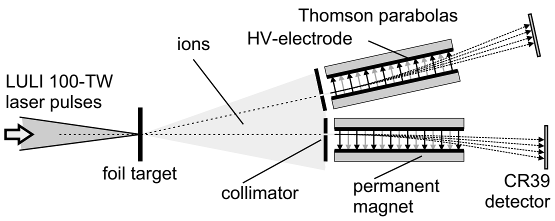

Figure 1: Setup for accelerating and diagnosing fast ions from the rear side of solid foils. Two Thomson parabolas were used at angles of 0° and 13° to the target normal.

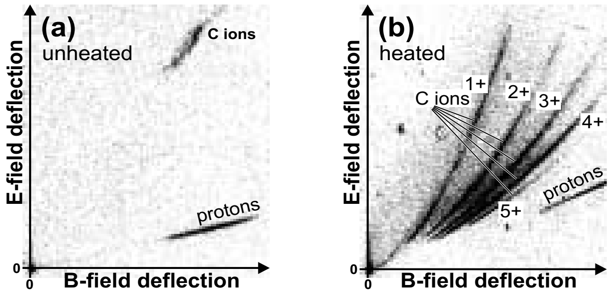

Figure 2: Thomson parabola spectra of laser accelerated ions. **(a)** Unheated target of 50 μm Al with a 1-μm layer of carbon at the rear surface. **(b)** Same target, but resistively heated for removing contaminating layers from the surface. The electric field in the Thomson parabola was different for the two shots.

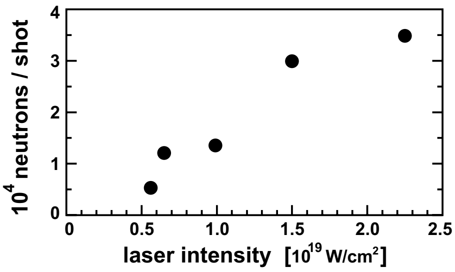

Figure 3: Dependence of the fusion neutron yield on laser intensity with solid CD_2 targets.

References

[1] S.P. Hatchett et al., Phys. Plasmas **7**, 2076 (2000).

[2] E.L. Clark et al., Phys. Rev. Lett. **84**, 670 (2000).

[3] A. Maksimchuk et al., Phys. Rev. Lett. **84**, 4108 (2000).

[4] R.A. Snavely et al., Phys. Rev. Lett. **85**, 2945 (2000).

[5] S.C. Wilks et al., Phys. Plasmas **8**, 542 (2001).

[6] W. Rusch et al., Nucl. Tracks Radiat. Meas. 19, 261 266 (1991).