MeV Ion Jets from Shortpulse-Laser-Plasma Interaction with Thin Foils ◇

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Irradiating thin foils with femtosecond laser pulses at focal intensities exceeding 10^{19}W/cm^2, proton beams with new features [1,2,3] are reported: (i) $10^{11}-10^{13}$ protons with energies between 5 and 50 MeV are generated within an angle of 20°, (ii) leaving the *rear surface* of the thin foil target ($\sim 50\mu$m) in laser direction, and (iii) forming a dense, charge-neutralized bunch of ~ 1 ps duration. We attribute this to the so-called target-normal sheath acceleration (TNSA) mechanism [4]. It assumes that relativistic electrons which are created at the target front side penetrate the foil, and, extending past the rear surface, produce a strong space charge field $E_{stat} \approx kT_{hot}/e\lambda_D$ with $\lambda_D = (\epsilon_0 kT_{hot}/e^2 n_{e,hot})^{1/2}$. Typical values of $T_{hot} \sim 3MeV$ and $n_{e,hot} \sim 3 \cdot 10^{19} cm^{-3}$ yield $\lambda_D \sim \mu$m and thus $E_{stat} > 10^{12}$V/m. A few monolayers of atoms at the rear surface are field-ionized and accelerated normal to the surface by E_{stat}, with the most energetic electrons always extending further out into vacuum, maintaining the accelerating field.

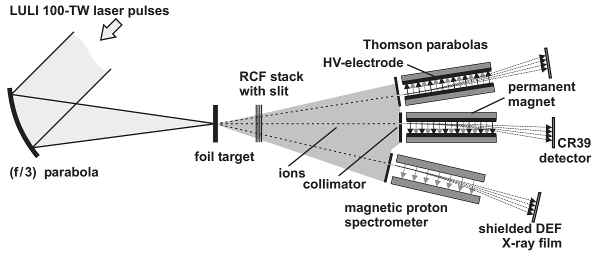

Fig. 1: Setup for laser-acceleration and probing of fast ions from the rear surface of thin foils.

At the LULI 100TW laser we recently demonstrated that also heavy ion beams can be accelerated from the *rear surface* of thin foils. The pulses ($\sim 30J, \sim 300fs, 1.05\mu m$) were focused at normal incidence on target to an intensity of up to 5×10^{19}W/cm^2. As targets we used 50μm thick Al and W foils coated on the rear side with 1μm carbon or 0.3μm CaF_2. The diagnostics consisted of two Thomson parabola spectrometers ($B = 0.65$ T, $E = 1.3$ MV/m) with CR-39 track detectors supplemented by stacked RCF and a magnetic proton spectrometer (Fig.1). We find that heavy ions are effectively accelerated, provided the hydrogenous surface contaminants are removed by resistively heating the substrates up to ~ 600 K and ~ 1200 K. This procedure increases the energy gain of heavier ions by more than an order of magnitude to more than 5 MeV/nucleon. The energy conversion efficiency was increased by three orders of magnitude to 5%. Fig. 2 depicts the observed energy spectra of different ion species which provide unprecedented information about the ionization mechanisms, the spatio-temporal evolution of the accelerating field and the origin of the energetic ions.

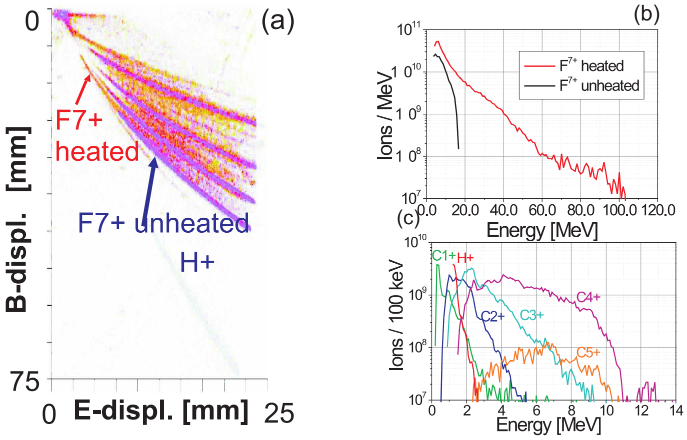

Fig. 2: (a) Overlayed signals of heated (orange) and unheated (blue) W|CaF_2 targets: The proton signal vanishes for heated targets, the Fluorine signals (especially F^{7+}) increase. (b) Corresponding F^{7+}-spectra: More than 100 MeV (5 MeV/nucleon) are observed for F^{7+}-ions. (d) Ion spectra from heated Al|C-targets. $C^{4+}$is the dominant species. The cutoff energy depends on the charge state.

An ongoing controversy exists whether these energetic ions are accelerated from the rear surface by TNSA or from the front side plasma and driven through the target [5]. In contrast to energetic protons, which may stem from the contaminants on both sides, the ions in the present experiments all originate from the coating at the rear surface. An estimate of the effects of collisional ionization by the hot electron component (2MeV), by a warm return current (50eV), and 3-body recombination analytically as well as numerically (FLY-code by R.W. Lee with time dependent ion and electron densities, and electron temperature), Barrier Suppression Ionization (BSI) can be identified as the dominant ionization mechanism. Our simulations also show that the basic TNSA model is too static to explain the low charge state distributions. Further modelling should include the initial dynamics of the electron distribution on a timescale $t \ll \tau_{laser}$, as well as the late expansion and cooling dynamics after the pulse at $t \gg \tau_{laser}$.

References

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