Optimizing Deuterated Metal Foils to Generate a Quasi-Monoenergetic Deuteron Beam on the Multi-Terawatt Laser

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The Multi-Terawatt (MTW) Laser System at LLE was used to study the target normal sheath acceleration (TNSA) mechanism in deuterated metal foils at intensities close to 10^{19} W/cm^2. Deuteron beams were previously generated with this mechanism using either plastic[1] or heavy-water[2,3] targets. While plastic targets promise simple handling, they offer poor beam quality; on the other hand, heavy-water targets yield higher beam quality but require careful handling. Deuterated metal foils provide a reasonable compromise between ease of handling and beam quality. In addition, certain metals such as titanium have a high capacity for storing hydrogen in the form of hydrides.[4]

A first batch of targets was prepared by exposing 500 × 500 × 25-μm^3 titanium foils to 1 mTorr of atomic deuterium (D^0) generated by a glowing tungsten filament in a deuterium atmosphere for varying amounts of time. The second batch was formed by depositing titanium onto titanium substrates in a deuterium atmosphere.

A total of 50 deuterated metal targets were shot to create a survey of deuteron beam characteristics as a function of surface loading. The spectra of all emitted ions were measured using the Thomson parabola ion spectrometer.[5] Remarkably, the deuterons had a quasi-monoenergetic spectrum well approximated by a Gaussian (see Fig. 1). This unusual TNSA spectrum was predicted in literature[6] for heavy target substrates. Heavy atoms remain almost stationary during the TNSA process, generating a nearly static electric field that uniformly accelerates light ions. All fielded targets produced this Gaussian energy spectrum, regardless of loading type, with a very consistent mean beam energy and width of 0.8±0.6 MeV.

Total yields ranged from low-10^{10} to mid-10^{11} deuterons per shot, depending critically on the surface loading. Figure 2 shows that there is an increase in deuterium yield with titanium thickness for targets onto which titanium was evaporated under a D^0 atmosphere. On the other hand, there was no increase in yield with D^0 exposure time for targets that were simply exposed to D^0. Comparing yields across the batches, simple D^0 exposure for 22 h proved more effective than condensing 1 μm of titanium on titanium in the presence of D^0. Consequently, the total deuterium yield of an evaporatively loaded target increases with TiD thickness, but diffusively loaded targets always produce higher yields within the parameter space evaluated. However, this higher yield cannot be increased further by longer exposure times. In future experiments, titanium targets will be exposed to atomic tritium (T^0) for 24 h to produce a tritium beam that will be used to study nuclear reaction rates relevant for stellar nucleosynthesis.

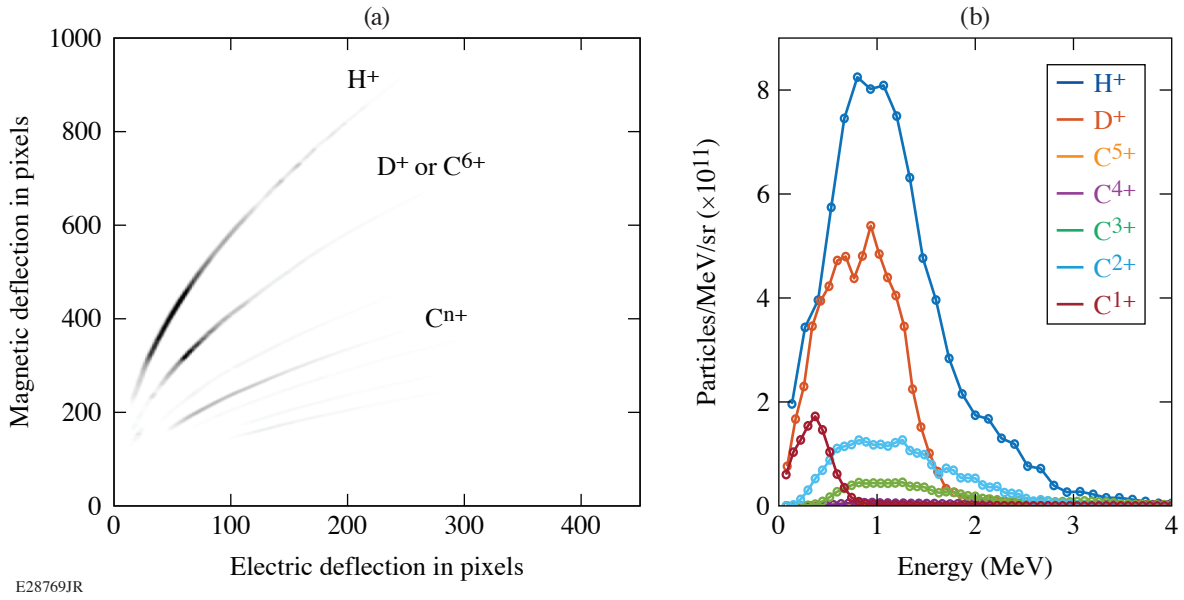

Figure 1
Data for one shot using a Ti-backed target exposed to D^0 for 98 h: (a) the digitized image plate and (b) the corresponding Thomson parabola spectra for each trace. Note the peaked deuteron spectrum.

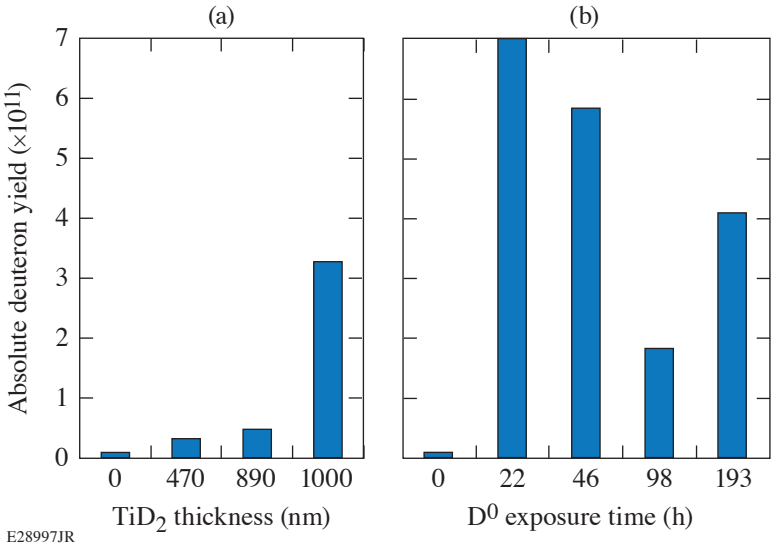

Figure 2
The absolute deuteron yields for the two different batches. (a) Targets onto which Ti was evaporated under a D^0 atmosphere. An increase of yield with thickness is evident. (b) Targets exposed to a D^0 atmosphere. Since there is no increase in yield with exposure time, it is concluded that saturation occurs quickly. Atomic deuterium exposure is clearly the more-effective loading method.

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