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Deuteron acceleration from buried layers in Petawatt laser-matter interactions.

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The aim of this experimental campaign was to investigate electron transport in to the target bulk and the subsequent heating of buried layers. Thick plastic targets were constructed with a buried 'active' deuterated layer. By burying the deuterated layer, the front and rear sheath acceleration, bulk plasma motion (blow off), and hole boring on the front surface will not be responsible for deuteron acceleration in these interactions. The measurement should in theory be a snapshot of possible acceleration mechanisms within the bulk of the target.

The VULCAN Petawatt facility delivered on target ~240J, 1.05μm, 700fs pulse with intensities of 10^{20} Wcm^{-2}. The beam was focused on to target at an angle of 43° to a spot size of 6x7μm with an F/3 off axis parabola. The targets consisted of solid CD slabs 136μm thick, and CH-CD-CH layered targets. The thickness of the buried CD layer was 168μm and the front and back CH thickness was adjusted to keep the total thickness of target constant whilst varying the position of the buried layer. The thickness of the front CH layer ranged from 7μm to 200μm, and total target thickness ~400μm. Plain CH targets, of thickness 136μm, were also used to give an estimate of the CH background.

Current mode time of flight (TOF) diagnostics consisting of plastic scintillator coupled to photo-multiplier tubes via conical light guides were placed at 137, and 208 degrees with respect to target normal in the forward direction. All angles in this section are defined from target normal in the forward hemisphere.

Neutron time of flight spectra were recorded using an oscilloscope. The scattering of neutrons from concrete, lead and plastic shielding was accounted for using MCNP. The VULCAN Petawatt target area was modelled using MCNP, a code that relies on the Monte Carlo method to track particles through user specified geometries.

Figure 1a shows raw time of flight spectra for plain CH slabs, plain CD slabs, and CH-CD-CH layer targets. Neutron scattering and multiple, neutron producing reactions broaden the signal such that there are no resolvable peaks. The basic analysis of the neutron spectra was to integrate under the neutron time of flight signal and normalise by the laser energy. In figure 1b the signal appears to decrease with increasing depth of buried layer. This indicates that the mechanisms that produce the neutrons depends on the depth of the buried layer. The buried layer at 200 μm is below the signal obtained from plain CH slabs (dotted line) and so cannot be reliably counted as significant.

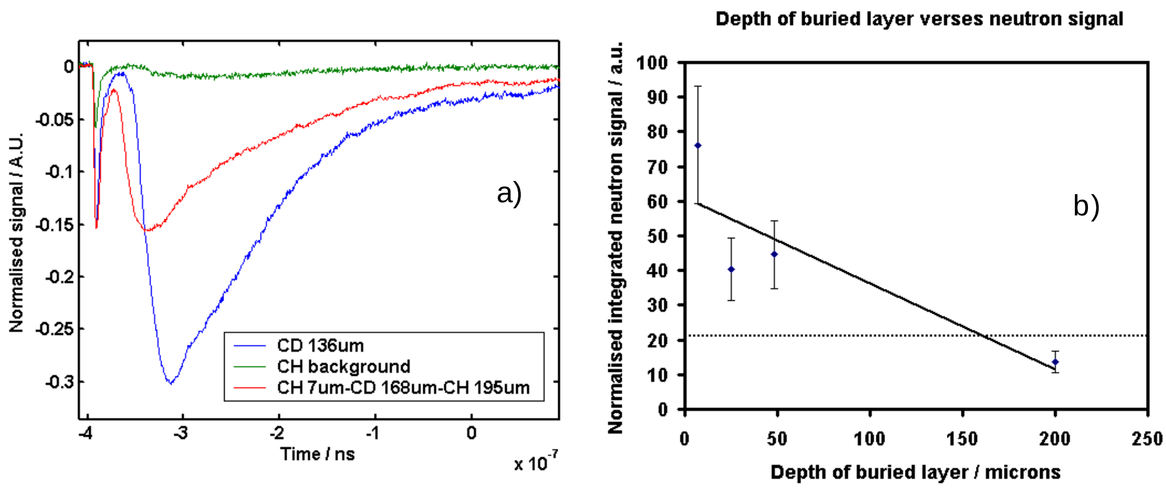

Figure 1 – a) Raw time of flight signals b)Plot of depth of buried layer against normalised, integrated signal, dotted line represents signal from plain CH targets.

In general the signals obtained from plain CD slabs were larger than obtained from buried layer targets. Transforming from time of flight to energy and unfolding the scattering revealed no more information about signal shape, i.e. revealed no hidden structure in the spectra.

There are many possible reactions that could be happening to build the total neutron signal. Reactions include d(d,n)He, C(d,n)N, d(d,pn)d, d(p,np)p, photo and electro-disintegration of deuterium and X(p,n)Y and X(γ,n)Y reactions in surrounding material. The signal from plain

CH targets would be a reasonable estimate of any X(p,n)Y and X(γ,n)Y reactions in plastic and the surrounding materials.

The d(d,n)He, C(d,n)N, d(d,pn)d reactions would indicate that energy has been deposited into the buried layer since they involve accelerated deuterons. The contribution from (p,n) and (γ,n) reactions in CH and surrounding material can be eliminated using the CH background measurements obtained from the plain CH slabs. Energies from the d(γ,n)p reaction are lower than 1 MeV and therefore these neutrons will be in the very low energy end of the spectrum, especially after scattering. The contribution of neutrons from electro-disintegration of deuterium is two orders of magnitude lower than the d-d reaction (in plain CD) according to Toupin *et al* [1].

The d(p,np)p reaction is not as significant in CD as it may be in the buried layer targets as the cross sections are equal, but less protons are accelerated from the front as they are boiled off by the prepulse. However in buried layer targets there are many protons accelerated from the front CH layer and the significance of the d(p,np)p reaction will increase compared to the 'trace' mechanisms accelerating deuterons in the buried layer.

To try and gain a greater understanding of the possible ion acceleration mechanisms simulations were run using the 2D particle in cell framework, OSIRIS. A realistic density profile was used to describe a fully ionised deuterium plasma slab of thickness 8.3 μm and maximum density $100n_c$. The simulation box was a 640 x 512 grid with 8 x 8 particles per cell. The laser was incident from the left, with wavelength $1\mu m$, with a $7\mu m$ spot size and an $a_0 = 20$.

At 318 fs there is a shock forming in the ion distribution. This can be seen in figure 2a, a plot of ion momentum in the forward and backward (negative) directions against the position along the laser axis (x). At this time the shock has propagated approximately 1.75 μm into the target. Maximum ion momentum here is $0.04M_dc$, which corresponds to an ion energy of 186 KeV.

Figure 2b shows a plot of ion momentum in the transverse plane against x. This shows some lateral ion transport in the region of the shock, the maximum ion momentum here is ~0.01 M_dc which corresponds to an ion energy of 46.7 KeV. These ion energies are above the Q value for d-d fusion but this may not be an appropriate mechanism for deuteron acceleration in the buried layer.

We can calculate the shock speed from the ion speed obtained in these simulations using $v_{ion}=2v_{shock}$ (Silva et al[2]) and this indicates for the shock to penetrate even $7\mu m$ (the thinnest CH front layer thickness) the laser must drive for a duration > 2.3ps. This will be an efficient mechanism for the plain CD slabs but will *not* be responsible for deuteron acceleration in the buried layer targets.

Another possibility is that filamentary structures observed in the early stages of the OSIRIS simulation (fig.2c) in the electron beam are penetrating the buried layer and transferring a significant amount of energy to the ions here. A possible mechanism has been described by Honda *et al* [3] by which current filaments are observed to coalesce and produce radial ion expulsion using a 2D PIC code.

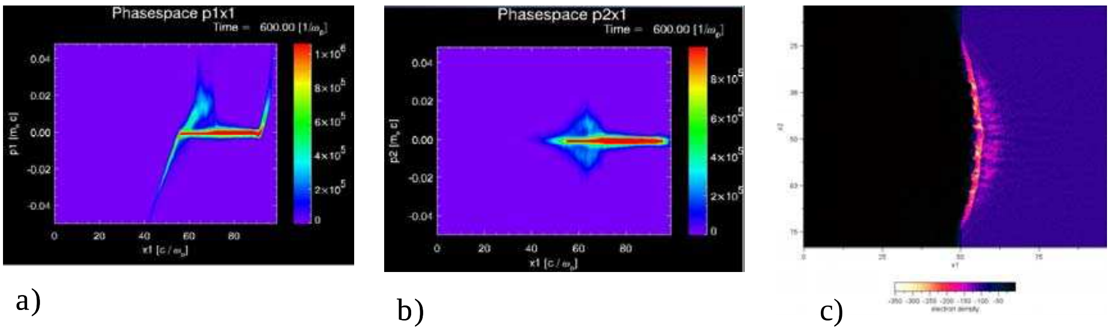

Figure 2 a) Ion phase space for forward and backward direction, b) Ion phase space for transverse direction

He predicts that the ions reach energies in excess of 100KeV (for 20KA current, and sub micron spatial scale). In experiments using petawatt lasers we have ~40 MA currents and so one may expect ion energies to be higher than 100 KeV. The targets used were thick but the electron filaments should penetrate into the buried layer. Gremillet *et al* [4] have observed electron filaments penetrating to a depth up to ~100 μm using the PARIS hybrid code. This method may therefore reasonable for plastic layers on the front of less that this thickness.

This mechanism is required to explain the neutron numbers as opposed to background plasma heating to a few KeV via the return current. More simulations are required to understand this mechanism and the LSP code will be used for this However, it is difficult to separate out the d(d,n)He (and other reactions relying on accelerated deuterons) from the d(p,np)p reaction at present.

References

[1] C. Toupin et al., Phys. Plasmas 8 3 2001

[2] L. Silva et al., Phys. Rev. Lett. 92 1 2004

[3] M.Honda et al., Phys. Rev. Lett. 85 10 2000

[4] L. Gremillet et al., Phys. Plasmas 9 3 2002