Thermal Neutron Generation in PW Laser Experiments at the Rutherford Appleton Laboratory

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Electron and ion energy transport in dense plasmas is an extremely important topic for the fast ignitor research for inertial fusion energy [1]. Recent experiments indicate that the hot electrons generated at the plasma surface carry about 50% of the laser energy into the over-dense plasma. However, the fast electron current propagation involves very complex processes that arise from the strong electric and magnetic fields that are induced and that significantly affect its propagation. Particle-in-cell (PIC) simulations show that electron filaments (that are generated from the Weibel instability) coalesce with each other and result in a significant energy loss in the plasma [2]. The merged single filament induces anomalous stopping due to the electromagnetic turbulence that arises from the interaction of the strong fields with the cold electron return current [3].

Recent experiments have shown electron heating of the bulk material to 200-350eV by resonance line emission from buried Al signature layers inside a solid plastic target [4]. However, the heating there may have been affected by resistivity mismatching between plastic and metal layers [5]. We report here observations of thermal neutron production using a single PW-class laser beam. The experiment was conducted using the new PW laser facility at Rutherford Appleton Laboratory. The PW laser irradiated sandwich targets that consisted of a variable thickness front plastic (CH) layer, a fixed thickness deuterated plastic (CD) layer, followed by a rear plastic layer (CH). The targets were designed to remove any boundary layer heating processes due to density and Z mismatches and were sufficiently thick to reduce heating due to refluxing electrons from the rear surface. The laser pulse was incident at an angle of 45 from the target normal, the focused intensity was 5×10^{20} W/cm^2 and had a good intensity contrast ratio (10^{-8}). The neutron signals were observed using the multi-channel neutron detector system, LaNSA [6] that has been reconstituted in the VULCAN PW target area for this purpose.

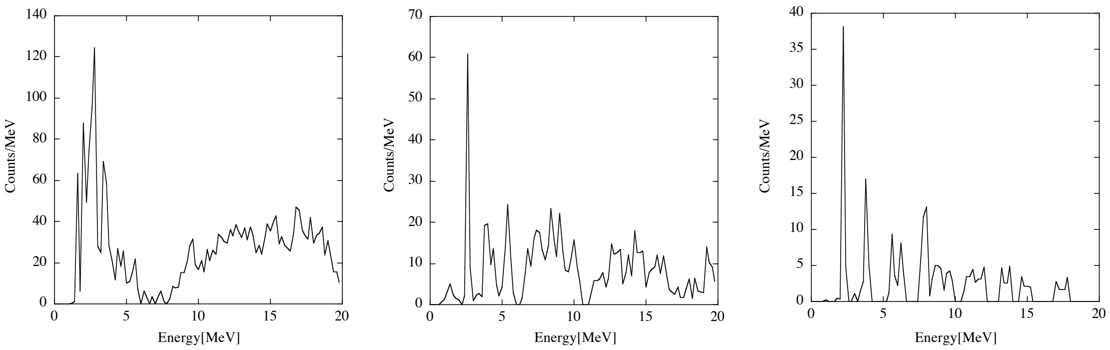

Figure 1: Observed neutron spectra for 0.1μm (left), 3μm (centre), and 10μm (right) thickness front CH layer target.

The observed neutron signal shows the 2.45MeV peak produced by thermal fusion processes of the $d(d,n)^3He$ reaction as well as higher energy signals by beam fusion reactions. The energy width of the thermonuclear neutron signal decreases with increasing front CH thickness, corresponding to a reduction in temperature inside the target. Figure 1 shows a typical neutron spectrum using a bare CD target, one with a 3μm-thick CH overlay and also one with a 10μm-thick CH overlay. For thin CH overlay targets, the thermal neutrons were clearly observed at 2.45MeV. More deeply buried layers also exhibited peaks at 2.45 MeV, but the signal to noise for those shots was too low to unambiguously identify them as thermonuclear in origin. The ion temperature was estimated from the width of the thermonuclear neutron energy. Figure 2 shows the ion temperature dependence as a function of the front CH overlay thickness. The temperature appears to be surprisingly high: for example, we measured 100 keV for bare targets, 7keV for 3μm CH and 1.2keV for 10μm CH. The deduced temperatures are consistent with those calculated from the observed neutron counts assuming a thermonuclear origin with a fixed heating volume.

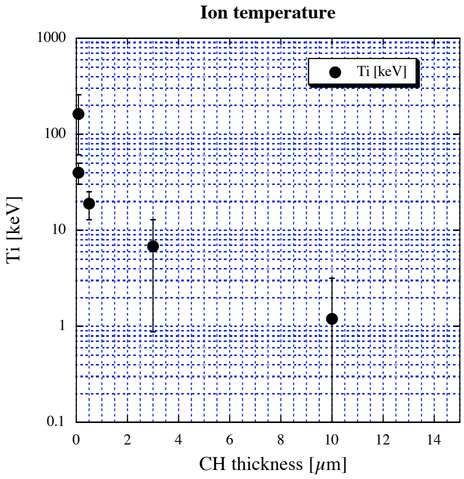

Figure 2: *Calculated ion temperature from the neutron signal width*

We also performed 2-dimentional MHD calculations using the 2D Eulerian hydrodynamics code POLLUX [8] to quantify the “bottled up” effect on the fast electron transport in the surface layers when there is a relatively large scale length pre-plasma formed by the pedestal. Figure 3 shows the temporal evolution of ion temperature as a function of position in the target. The ion temperature at the critical density surface reaches 100keV, but at 10μm inside the target the temperature rises only to 1keV, which is in agreement with our observations.

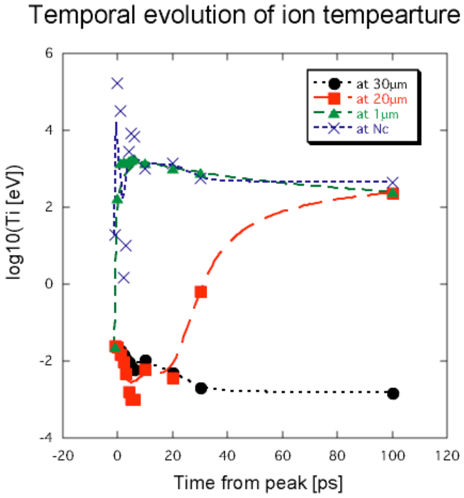

Figure 3 : *The temporal evolution of ion temperature as a function of the position inside target.*

There are several possible explanations for the high surface temperature seen in Figure 1 (a). Coalescence of filaments of the electron beam can occur during electron transport in dense plasmas [2]. However this effect is more likely to generate beam fusion reactions which might be the origin of the high energy component in the neutron spectra. Anomalous stopping is also a possible explanation – but here simultaneous measurements of electron and ion temperatures are needed. These experiments are being planned for the near future.

In summary, neutron spectra were observed in the PetaWatt Facility at Rutherford Appleton Laboratory using the LaNSA system. The obtained spectra had two components: a high energy component generated by beam-fusion reactions and a component around 2.45MeV most likely to be thermonuclear in origin. The ion temperatures calculated from the neutron signal width clearly demonstrate a dependence on the front CH thickness of the layered target. 2D MHD calculations were performed in order to quantify the ion heating due to the heat conduction into the target, assuming the energy is bottled up between critical and solid density. They explain the measured temperatures for thin CH overcoat layers, but the details of the physics that causes the high surface temperatures requires further investigation.

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