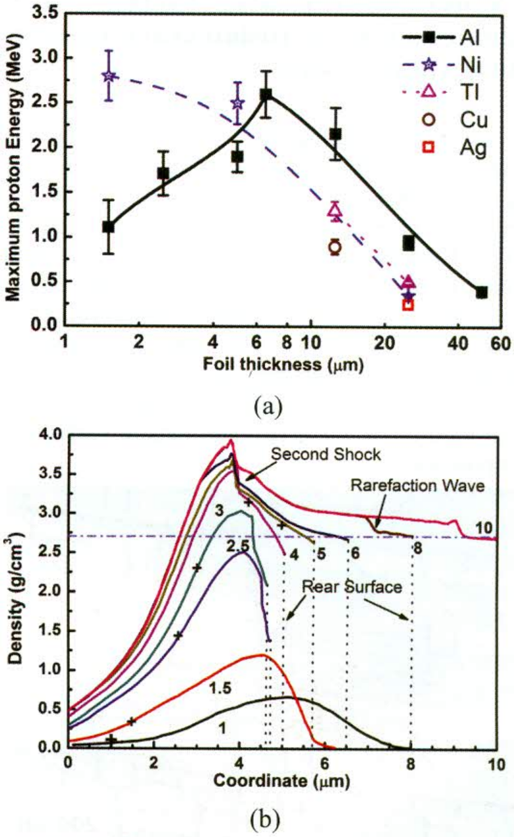
## L.4: Laser driven high energy proton acceleration by thin foils

The interaction of ultra-short, intense laser pulses with thin foils offers a high brightness, low emittance charge particle source on a table top, and thus has the potential to be a viable alternative as an injector to a conventional particle accelerator, in addition to applications in hadron therapy, proton driven fast ignition, and particle radiography. The dynamics of the interaction of an ultra-short laser pulse with matter is primarily governed by electrons, which due to their lighter mass, instantly respond to the incident laser electric field (> $10^9$ V/cm) and gain very high energy via various absorption mechanisms. The energetic electrons, because of their high energy, can break away from the plasma leading to a sheath formation. The protons and heavy ions are accelerated in this strong sheath electric field (~ TV/m). This acceleration mechanism is known as "Target Normal Sheath Acceleration (TNSA)". At RRCAT, we have studied the proton emission from thin metallic foil targets by the above process.

The experiments were carried using the 10 TW Ti:sapphire laser system at RRCAT, delivering 45 fs , 420 mJ pulses. The p-polarized laser beam was focused at an angle of 45° to a focal spot of 10 μm dia. using an off-axis parabolic mirror, giving a peak intensity of the order of $\sim 3\times10^{18}$ W/cm$^2$. Aluminium foils of varying thicknesses were used. To study the effect of foil material, Ni (1.5, 5, and 25 μm), Ti (12.5 and 25 μm), Cu (12.5 μm), Ag (25 μm), and Ta (25 μm) foils were also used as target. The accelerated ion beam was characterized using a Thomson Parabola Ion Spectrograph. Proton, which has the highest charge to mass ratio, is the dominant species. Carbon charge states from C1+ to C6+ are also present. Source of these protons and carbon ions is the hydrocarbon contaminants present on the foil surface under normal vacuum (10-5 mbar) conditions.

The maximum proton energy obtained for different targets and foil thicknesses used in the experiment is plotted in Fig.L.4.1(a). The maximum proton energy observed was 2.8 MeV for the case Ni 1.5 μm foil. It is evident from the figure that in the case of Al target, as the foil thickness decreases the proton energy increases, and beyond certain thickness any further decrease in thefoil thickness reduces the proton energy. The optimum foil thickness (which gives the highest proton energy) for our laser parameters was around 6-7 μm. This can be understood as follows. Protons are accelerated due to the sheath field formed at the target back surface. For thick targets, the density of hot electrons in the sheath field reduces because of higher divergence of these hot electrons as they have to propagate through thick target, which consequently results in reduction of the sheath field and hence the maximum proton energy.



(a)

(b)

*Fig. L.4.1: (a) Dependence of the maximum proton energy on the foil thickness for different foil materials. (b) 1-D hydrodynamic simulation of density evolution and the shock wave caused by a 1.5 ns ASE pre-pulse with intensity 2 x $10^{12}$ W/cm$^2$, for Al foil of different thicknesses. Numbers next to the curves indicate the foil thicknesses in micrometer.*

Below a certain optimum thickness, this trend reverses, which can be attributed to the ASE pedestal (pre-pulse) present before the main laser pulse. The ns prepulse launches a shock wave which travels through the foil and generates long density gradient plasmas by target vaporization, thereby disturbting the accelerating field, and hence the proton energy. Using one dimensional hydrodynamic code MULTI-1D, we have studied the propagation of the shock wave caused by the ASE pre-pulse inside the foil (Fig.L.4.1(b)). One can see that for foil thickness less than 6 μm, the target rear surface gets strongly perturbed, therby affecting the accelerating field. An optimum foil thickness of ~5-6 μm observed in the case of Al foil in our experiment matches well with the hydrodynamic simulation. For more details, please see Tayyab et al, Phys.Rev. E 90, 023103, 2014.

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