L.3 Quasi-mono-energetic Au ion acceleration using high intensity lasers

The Laser Plasma Division at RRCAT is involved in study of ion acceleration in thin foil targets irradiated with ultra-high intensity laser pulses. Normally, the ion acceleration in thin foil targets is attributed to the Target Normal Sheath Acceleration (TNSA) mechanism, which occurs due to generation of hot electron of multi-MeV energy produced during ultra-high intensity laser - matter interaction. These hot electrons come out from the thin foil target, both from front as well as rear side, and generate an electrostatic sheath field at both the target surfaces. The electric field strength in the sheath is ~1 TV/m. As a result, the hydrocarbons, which are always present on target surface as contaminants under normal vacuum conditions (~10-5 mbar), get ionized and are accelerated by the sheath field. Even if higher-Z atoms are present on the surface, the lighter species like proton and carbon ions get preferentially accelerated due to lower mass. One can also accelerate the heavier ions if the low-Z hydrocarbon contaminants are removed from the surface prior to the laser shot. Although, the heavy ions can be accelerated by TNSA, like proton and carbon ions, they will also have a broad continuum energy spectrum.

We have demonstrated for the first time generation of quasi-mono-energetic gold ion acceleration from a nano-composite target. Au nano-particles of size 2-8 nm were embedded in thick carbon layer of around 100 nm thickness deposited on Si substrate. Figure L.3.1 (a) shows the ion emission recorded using Thomson Parabola Ion Spectrograph (TPIS) from Au nano-composite target from the front side. One can see that all the charge states of Au ions have same kinetic energy and exhibit mono-energetic feature. On the other hand, Si1+ ions show a continuous energy distribution. The derived energy spectrum for various charge states of gold is shown in Fig. L.3.1 (b). As all the charge states of Au possess the same kinetic energy, the possibility of Coulombic acceleration is completely ruled out.

The above observations can be explained phenomenologically as follows. As the total coating thickness is less than the laser skin depth, the main plasma formation takes at the Si substrate. As Au is in nano-particle form, due to the field enhancement occurring inside the nano-particle, it gets ionized to multiple charge states. The lighter species C and proton are accelerated by the TNSA process and hence exhibit continuous energy distribution. At a later time, the bulk substrate plasma (of silicon) expands and pushes out (i.e. accelerates) the Au ions. Hence the Au ions of all charge states gain energy by the push of the expanding substrate plasma and therefore possess the same kinetic energy. The carbon layer on the top of the Au layer inhibits the Au layer expansion resulting in mono-energetic feature in gold ions.

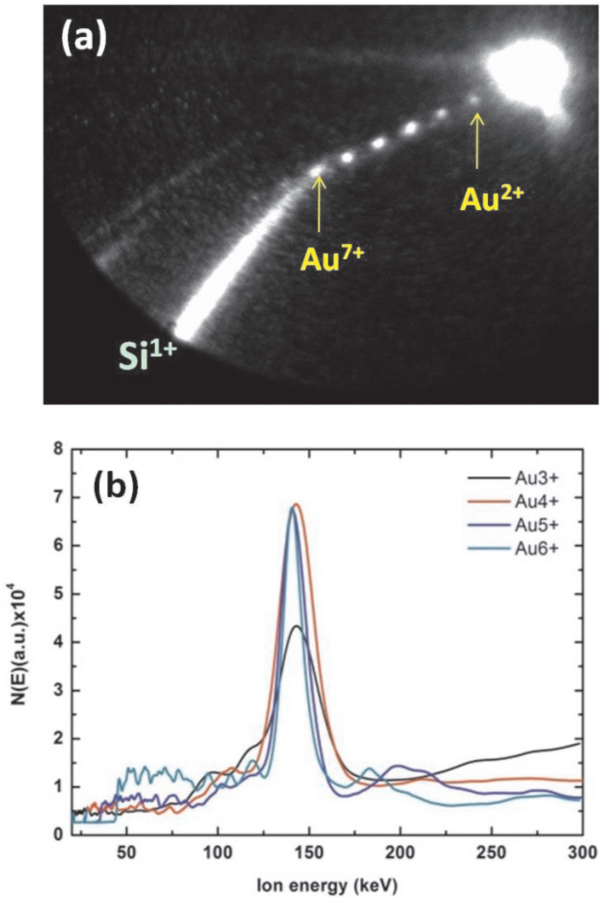

Fig. L.3.1 (a) Ion emission recorded with TPIS from nano composite targets; (b) The derived ion energy spectra.

Our hypothesis is supported by the fact that in the case of pure Au layer, the Au ion energy spectrum is continuous. It is also found that Si1+ ion maximum velocity (i.e. substrate plasma expansion velocity) matches with Au ion velocity, and the same is observed to match in the parabola trace. This establishes the fact that Au ions are accelerated because of kinetic plasma pressure of the substrate (Si) plasma.

These observations are highly consistent and repeatable, and offer a new way of producing mono-energetic ions. A 1-D hydrodynamic simulation was carried out using the Multi-fs code for the present target geometry and experimental condition. The simulation results were found to match quite well with the experimental observations.

These above experimental results can be important for different applications like compact plasma based ion sources, as injector to conventional accelerators, inertial confinement fusion studies, and shock related studies.

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