L.6: Demonstration of 20 MeV proton beam with laser driven ion acceleration at PW Laser Facility, RRCAT

There has been growing interest in laser-driven ion acceleration using ultra-short, ultra-intense laser pulses due to its potential applications in high-energy-density physics, medical science, and materials research. When ultra-intense laser pulses interact with thin solid targets, extreme plasma conditions are generated at target surface leading to efficient ion / electron acceleration. Proton acceleration experiments were carried out using the petawatt (PW) Ti:Sapphire laser facility at the Laser Plasma Division, RRCAT. When an ultra-short, high-intensity laser pulse is focused onto a thin metal foil, it creates a hot plasma on the target surface and generates a population of energetic electrons. These electrons propagate to the rear surface of the target, forming a strong sheath electric field, typically of the order of a few TV/m. This field ionizes and accelerates surface contaminants, primarily hydrogen and carbon, resulting in a beam of energetic protons and ions. This mechanism is known as Target Normal Sheath Acceleration (TNSA). The resulting ion beam exhibits unique features such as ultra-short pulse duration (~ps), short source size, laminar flow, and high peak current.

The experimental arrangement is shown in Fig. L.6.1. Laser pulses of ~ 9 J energy (~370 TW) were focused using an f/3 off-axis parabolic (OAP) mirror (focal length 60 cm) to a spot size of ~5 μm × 6 μm (FWHM), achieving an on-target intensity of ~2 × 10^{20} W/cm². Thin foil targets of aluminium (0.8 μm and 3 μm) and copper (1 μm and 2 μm) were used.

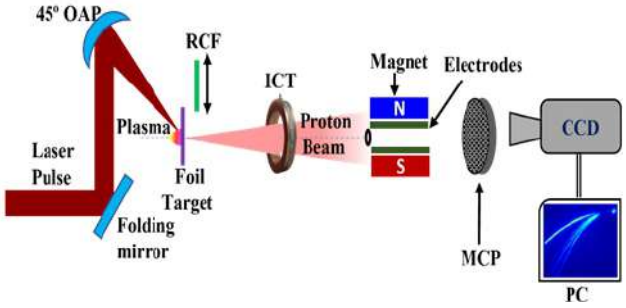

Fig. L.6.1: Schematic of experimental setup for laser-driven proton acceleration with diagnostics.

The accelerated ion beam was characterized using an in-house developed high energy Thomson Parabola Ion Spectrometer (TPIS) placed along the target normal direction. In the TPIS, crossed electric and magnetic fields separate ion species based on their charge-to-mass ratio, producing distinct parabolic traces. These were recorded using a microchannel plate (MCP) coupled with a phosphor screen and imaged using a 14-bit CCD camera. The spatial profile of the proton beam was recorded using a stack of radiochromic films (RCF) placed ~3.5 cm behind the target and covered with an 11 μm thick Aluminium foil to filter out low-energy ions. An Integrated Current Transformer (ICT) was used to measure the total proton beam charge.

The ion emission was observed to originate from a small region (tens of micrometres) on the rear surface and within a cone angle of ~10°–15°. The accelerated ion species mainly consisted of protons and carbon ions. Fig. L.6.2(a) shows the TPIS image with distinct ion traces, while the corresponding proton energy spectrum, derived using a MATLAB-based reconstruction algorithm, is shown in Fig. L.6.2(b). The maximum proton energy achieved was ~23 MeV at ~0.37 PW laser power. Fig. L.6.2(c) shows the proton beam profiles recorded on different RCF layers, clearly indicating the presence of protons with energies exceeding 20 MeV. The total proton beam charge was estimated using the ICT. The integrated beam charge of ~100 nC is measured from the ICT signal.

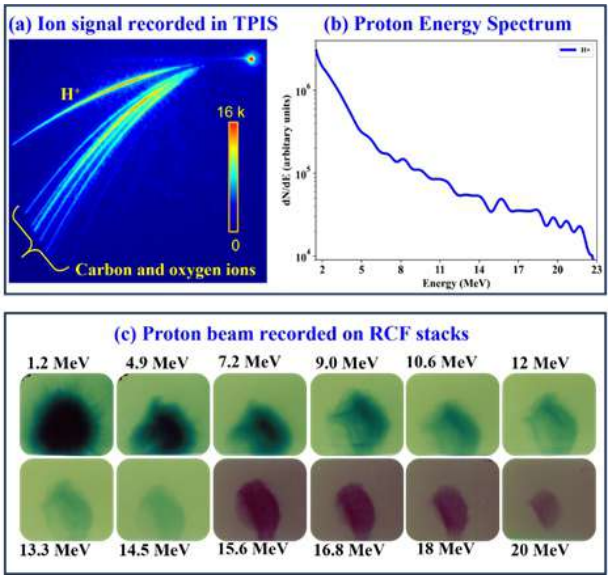

Fig. L.6.2: (a) TPIS image showing ion species separation, (b) derived proton energy spectrum, (c) proton beam profiles recorded on RCF stack with energy cut-offs.

This work demonstrates successful acceleration of protons to energies exceeding 20 MeV using the PW laser facility at RRCAT for the first time in the country. The combination of diagnostics such as TPIS, RCF, and ICT enables comprehensive characterization of the proton beam in terms of energy, spatial profile, and charge. These results establish a strong foundation for further studies on beam transport, control, and application-oriented developments / applications.

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