Spectral distribution of laser accelerated protons by multilayer CR-39 nuclear track detectors

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Motivation

Energetically characterization of laser-accelerated proton beams generated in high power laser-solid target experiments using passive detectors

Calibration of the passive detectors

Identification of laser-accelerated protons energies
Summary

• Target Normal Sheath Acceleration Mechanism
• Experimental Set-up
• Calibration of passive detectors using monoenergetic proton beams and dedicated software codes
• Atomic force microscopy analysis of laser accelerated proton tracks in CR-39 detectors stack
• Conclusions
• Acknowledgments
Target Normal Sheath Acceleration mechanism in high power laser - solid target interaction

The energy deposits by the laser pulse at the target surface is partially absorbed (conversion efficiency factor $\eta$) into the hot electrons

$$N_e \approx \frac{\eta E_L}{k_BT}$$

$I > 10^{18}$ W/cm$^2$

The most energetic electrons accelerated in the forward direction escape from the rear side of the target and form an electron sheath resulting in an electric field of TV/m on the rear surface.

Protons from impurities on the target rear surface are field ionized and accelerated normal to the surface in vacuum along the electric field line.

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Experimental Set-up

5 and 10 µm thick targets was prepared by magnetron sputtering technique

Laser parameters in focus:
laser energy 8 J
45° laser incidence angle on the target
laser spot dimensions 9 x 23 µm²
I = 5 x 10^{19} W/cm²

detectors stack
for laser beam focal point profile analysis
to visualize the reflected laser light on target
Calibration of CR-39 nuclear track detectors used for laser accelerated proton track analysis

- irradiation of CR-39 detectors with monoenergetic proton beams
- estimation of bulk etching rate of the CR-39 detectors in specific etching conditions
- calculation of proton range and proton track diameter using dedicated numerical codes
- finding of the correspondence between the proton incident energy on the detector stack and the proton incident energy on the second CR-39 detector
- establishment of a calibration curve that relates proton track diameter with proton energy

Experimental results on the irradiation of CR-39 detectors with monoenergetic proton beams

- the black circular tracks are attributed to protons
- the spots with irregular shapes and sizes are due to the chemical etch of the detector’s material
- similar results obtained from AFM investigations
proton track diameter depend on the chemical etching condition of the detectors

determination of the bulk etching rate of CR-39 detectors

\[(M_1 - M_2)D/2M_1 = v_b t\]

proton range in CR-39 detectors

protons with maximum energy of 14.5 MeV can be stopped in the second CR-39 detector of the stack

correspondence between the incident proton energy on the detectors stack and second CR-39 detector

essential in the finding of the correspondence between proton track diameter and proton energy

bulk etch rate of 1.65 ± 0.05 µm/h over an etching time of 20 h
Evolution of the proton track diameter in CR-39 detector as function of proton energy

Minimum proton track diameter that can be observed on a CR-39 detector is 0.8 µm which correspond to 9 MeV proton energy.

9.38 µm (for 1 MeV proton energy) 0.8 µm (for 9 MeV proton energy)

Comparison between experimental data and the computed one considering the etching parameters of the CR-39 detectors.

A fitted curve and a fitted function.
Data obtained from SRIM simulation of the detector stack.

<table>
<thead>
<tr>
<th>Layer No.</th>
<th>Energy (MeV)</th>
<th>Proton range (mm)</th>
<th>Stopping power intensity (eV/A)</th>
<th>Simulation structures of the experimental stack (10 μm Al +2 mm of the CR-39 detectors)</th>
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<tr>
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<td>2.59</td>
<td>layer 14 + 200 μm</td>
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</table>

protons with energies higher than 10.5 MeV can fully deposit their energies in the second CR-39 detector.

Bragg peak positions in CR-39 detector stack.
Analysis of the laser driven proton tracks in CR-39 detectors by atomic force microscopy.

- Minimum track diameter that can be attributed to protons is about 0.8 µm.
Evolution of proton track diameters on first and second post etched CR-39 detector

Establishment of proton energies resulted as a consequence of high-power laser-solid target interaction

Maximum proton energy of 13.8 MeV within ±15% error

Minimum track diameter that can be attributed to protons is about 0.8 µm
Conclusions

We propose a method to assess the energy of the laser-accelerated proton beams within the 1-15 MeV range, by investigating the tracks left in a stack made of two CR-39 detectors. All issues that occur after the exposure of CR-39 type to laser- accelerated proton beams, followed by etching in specific physical and chemical conditions was analysed and discussed. Only individual tracks with circular or elliptic shapes, with very well defined edges and diameters in the 0.8 – 8 µm range, which are theoretically established, are assigned to protons.

The most important step consists in the calibration of the CR-39 detectors and finding of an analytical expression of the calibration curve in the 1-9 MeV energy range.

Estimation of the proton energy from the track diameter measured by AFM in each detector that compose the irradiated stack.

Acknowledgements

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