The possibility of producing, in a controlled way, matter at solid density (1-10 g/cm^3) while maintaining it at a high temperature (1-100 eV) has been for a long time a desired goal. Studying matter in these conditions would provide an array of information useful for a variety of problems that range from fundamental physics (dense and relatively cold matter at the frontier of plasma physics) to astrophysics (matter in the planetary cores) through applications like ICF (stopping power of particles in warm dense matter). To achieve this, energy has to be deposited in a short time scale before heating-induced expansion decreases the density of the heated matter, i.e. isochorically. The heated material is then inertially confined. Up to now, attempts to achieve isochoric heating have been pursued using either using short-pulse lasers or short-duration laser-produced x-rays. Optical frequencies are very limited in their penetration of solid matter, typically 5 nm of skin depth in Al for 1 µm light. Therefore only the surface layer is directly heated while the inner part of the sample gets heated on a much longer time scale through heat conduction accompanied by thermal expansion. This does not allow to maintain a high density and temperature.

Therefore, high intensity laser pulses incident on a thin foil cannot create a uniform, hot dense plasma. In comparison, ions have a much higher penetration depth, allowing deposition of energy at a much shorter time scale due to the interaction process of ions with matter. Several diagnostics are employed on the rear surface to determine its temperature.

**The art of protons**

When a high energy laser hits a thin metal target (e.g. Aluminum of some microns thickness), electrons are accelerated forward due to the Ponderomotive Force. The electrons propagate through the target, reaching the rear side. Some electrons are ejected at the rear side, creating a very high (>10^12 V/m) local electrostatic field on the rear surface. This field accelerates protons, which originate primarily from ionisation layers of water vapor and hydrogen located on the rear surface of the target.

Protons are emitted with a certain spectrum, i.e. from the rear surface of the target to a certain number of protons with a specific energy are detected. The more energetic the protons, the deeper they can penetrate in the target and deposit their energy. The quantity and the spatial characteristics of protons determine the deposited energy in the target and thus the target heating.

The pictures show a 1D image of the rear surface heating of the target through black body emissivity. The heating process takes place in 3 steps: 1) when the protons have not reached the target yet; 2) when the protons deposit their energy and heat the target; 3) when no more protons are arriving and the target « cools down ». The heating decreases with increasing thickness, since only high energy protons can reach the rear surface and they are less in quantity than low energy protons. Moreover, heating is dependent on the atomic number and the target properties (stopping power). In the circle the Optical Transition Radiation (OTR) of the electrons is shown. This is not proton radiation but is generated by electrons. The OTR can be isolated from heating.

**Experimental setup**

When the high intensity laser hits the first target (proton source), protons are emitted on the rear surface. These protons are accelerated towards a second metal target. Protons deposit their energy inside the target due to the interaction process of ions with matter. Several diagnostics are employed on the rear surface to determine its temperature.

Dependence of the atomic number and thickness

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Dependence using curved targets

Curved targets can collimate the proton beam better on the second target. However, to irradiate a curved target, the laser beam needs to be defocused and this decreases the laser intensity which decreases also the proton beam intensity. Hence, no improvement of the heating can be obtained with curved targets.

**Conclusions**

- We have measured heating in various conditions: Temperatures of ~2 - 6 eV for target rear side are obtained
- Using focused targets does not improve heating (at least with our laser)
- Due to experimental proton spectrum, foil is heated inhomogeneously, on rear side: adiabatic ideal expansion
- Interest for equation of state in a few eV range
- Knowledge of ion stopping in warm dense matter

**Application of laser-accelerated high-energy protons for isochoric heating of matter**

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