Experimental Investigation of Plasma Production by Irradiating Solid Hydrogen Foils with an Intense Pulse Laser

R. Sigel, P. Mulser and S. Witkowski
Institut für Plasmaphysik
8046 Garching bei München, Germany

It is already known [1,2,3] that interaction between intense laser light and solid hydrogen in a one-dimensional model yields three regions (0,1,2) with different states of matter (Fig. 1a): In a strongly absorbing deflagration front F a hot, transparent plasma of moderate density is produced and streams towards the laser with high velocity (Region 2, $v \approx 10^7$ cm/sec). F may be regarded as a piston almost impervious to matter that generates an intense shock wave in the solid because of the reaction of the escaping plasma. The compressed matter (Region 1, $v \approx 10^6$ cm/sec) streaming away from the laser with F is separated from the undisturbed solid with density ρ_0 (Region 0) by the shock front S. Most of the laser energy is transferred to Region 2.

The effect of a focused laser beam on a plane target can be described by a piston model based on the one-dimensional model. The

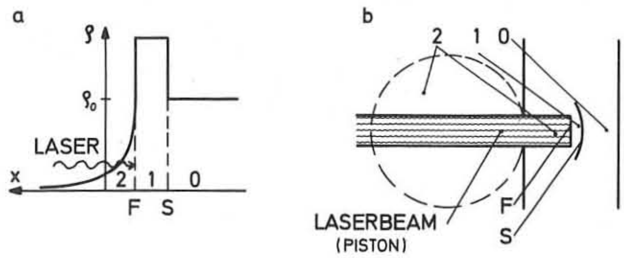

Fig. 1
a) Schematic density profile for a solid hydrogen target irradiated with an intense laser beam (one-dimensional model).
b) Piston model describing the penetration of a solid hydrogen target (foil) by a focused laser beam.

focused beam is represented in Fig. 1b as a parallel beam of finite cross section, the numbers denoting the regions 0 - 2 as in the one-dimensional model. The beam penetrates the target like a piston, the face of the piston being formed by F. The shock wave generated by the piston resembles a bow shock. The matter caught up by the shock front S is pushed aside owing to the high pressure between S and F [2] and thus transfers the reaction of the plasma to the matter surrounding the piston. The plasma produced in F is ejected towards the laser and expands in the front half-space. The ions and electrons are expected to expand at the same velocity. Since the plasma cools during expansion, its energy can be found far from the target as directed kinetic energy of the ions.

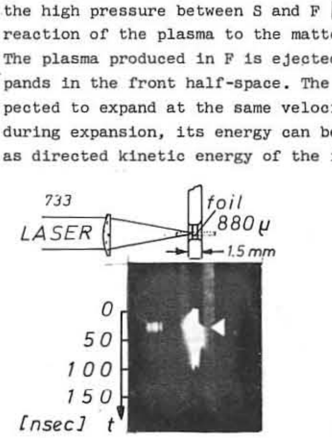

Fig. 2
Streak picture of a laser-irradiated solid hydrogen foil (time mark ◀ corresponds to the moment, when the foil becomes transparent to the laser light).

In the experiment a ruby laser was focused on solid hydrogen foils [4] in high vacuum. The intensity in the focus was about 10^{12} W/cm^2 over an area of diameter 0.1 mm. The model was verified in the following respects: 1) Absorption measurements [5] revealed the existence of the strongly absorbing deflagration front F, which moves with a velocity of 3×10^6 cm/sec. 2) Streak pictures (Fig. 2) taken tangentially to the surface of the foil show luminous phenomena caused by the penetrating piston on the front of the foil at the start of the laser pulse. The back of the foil is not affected until the piston appears there a few nanoseconds before the foil becomes transparent. 3) The plasma produced by the laser was observed at various times after the maximum of the laser pulse by

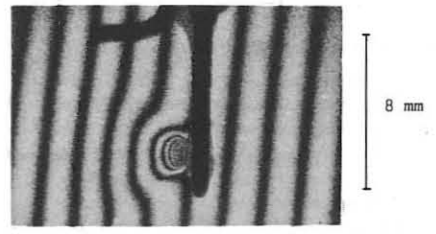

Fig. 3
Interferogram (reconstructed from a hologram) of the plasma produced by a laser from a solid hydrogen foil (18 nsec after maximum of laser pulse). The foil (thickness 1.5 mm) is not pierced by the laser, therefore no plasma is observed on the back of the foil.

means of holographic interferometry [6] (Fig. 3). In the case of thick foils that are not pierced by the laser the number of free electrons in the plasma attains the final value of 4×10^{16} after 30 nsec.. 4) Two charge separating probes each consisting of an earthed perforated plate and a collector at negative potential were mounted 20 cm in front of and behind the target at an angle of 45° to the laser axis for making time resolved measurements of the number of impinging ions. As in the interferometric measurements, it was found in agreement with the model that with thin foils as well the bulk of the plasma was ejected into the front half-space. Integration over the whole solid angle with the data of [7] yielded 4×10^{16} ions in the case of thick foils. This number agrees well with the value determined interferometrically for electrons. The mean kinetic energy of the ions was 200 eV. Thus 45 % of the laser energy was recovered as kinetic energy of the ions. Considering that part of the laser energy is transferred to the dense matter as work done by the plasma at the interface between the piston and dense matter and that ionization energy has to be provided and radiation losses covered, this result appears satisfactory and confirms the described model like the other results.

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