# Interferometric investigations of dynamics and parameters of plasma created by Ti:Sa femtosecond laser

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**Abstract**

This contribution presents the first interferometric measurements of laser–produced plasma generated by the Ti:Sa high power laser (10 TW) installed in IPPLM (Institute of Plasma Physics and Laser Microfusion). The aim of the study was to learn the character of the plasma expansion and ions emission for different irradiation conditions of thin-foil targets. Measurements were carried out for different levels of laser beam intensity in the range of $10^{16}$-$10^{19}$ W/cm$^2$, which was achieved by varying a focal spot radius~~,~~ by changing the focus position of the main lens in relation to the target surface.

To illustrate the plasma expansion and to obtain information about the space-time changes in the electron density of the plasma stream, the 2-frame folding wave interferometer was used. This interferometer was irradiated by Ti:Sa laser pulse with wavelength of 812 nm and FWHM of 40 fs, separated from the main laser beam (Fig.1). To obtain space and temporal separation of the diagnostic beams, the polarizing optical delay line was applied, which irradiated the interferometer by 2 laser beams, separated in time, with mutually orthogonal polarizations. Additionally, measurements of ions emission by means of the grid collectors for different focus position were carried out (Fig.4).

The obtained information about the dynamics of the parameters of plasma generated in the femtosecond regime seems to be very useful in studies of of the proton streams by the TNSA (Target Normal Sheath Acceleration).

## Introduction

It is well known that high-intensity lasers incident on targets can generate electrons with kinetic energy higher than the mean electron energy. The mechanism of generation these so-called "fast" electron and their propagation in matter have received considerable attention from both theorists and experimentalists in the past years. The knowledge what mechanisms are responsible for the generation and the transport of fast electrons play an important role in the fast ignition approach to inertial confinement fusion.

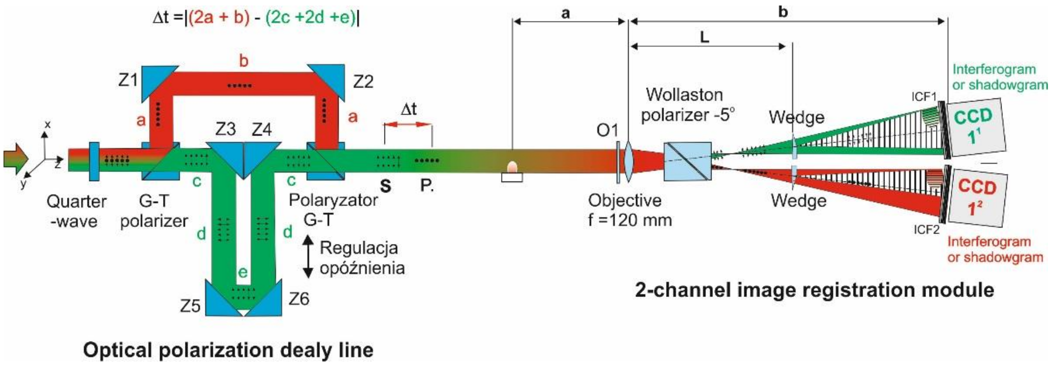


Figure 1. Optical scheme of the two-channel interferometr

## Experimental setup and results

The thin foil targets (3 μm) made of aluminum were irradiated by Ti:Sa laser pulse with wavelength of 812 nm and energy about 250 mJ. The interferograms were registered at time 1.8 ns under similar conditions of irradiation and the laser beam focused to minimum radius on the target (~10 μm). The exemplary sequence of interferograms and obtained on these the electron density distributions and the axial profile of electron density illustrating the ablative plasma expansion during the laser pulse interaction are presented in Fig.2.

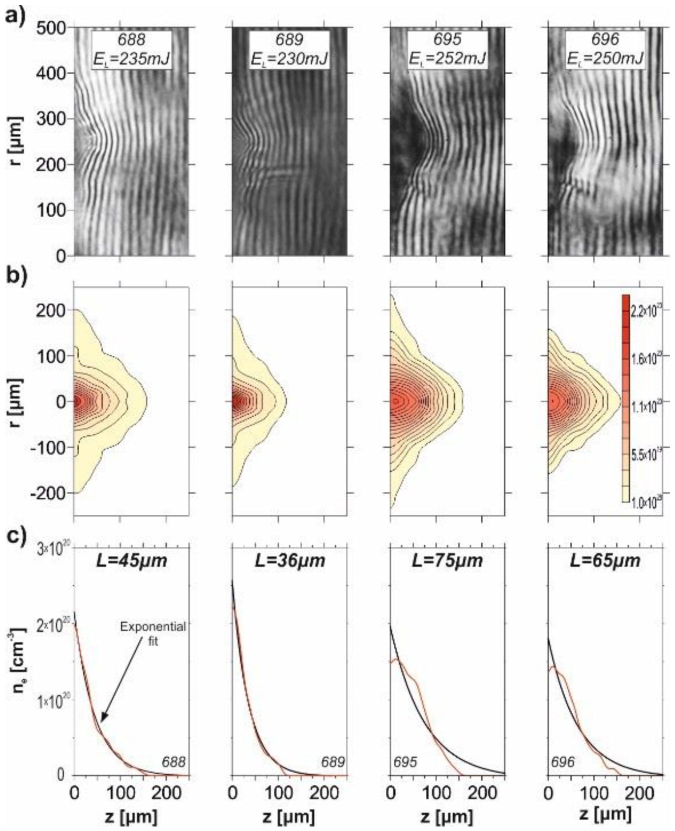


Figure 2. These sequence of: a) the raw interferograms, b) the electron density distributions calculated on the basis of interferograms registered at time 1.8ns and c) the fitting of the axial density profile to the exponential function.

These figures show sequence of: a) the raw interferograms, b) the electron density distributions calculated on the basis of interferograms and c) the fitting of the axial density profile to the exponential function.

In the interferometric investigations the main attention was paid to the plasma parameters just after the laser pulse end, i.e. when the laser radiation absorption is already completely terminated. In this late phase the strong influence on the expansion has slow component of the plasma which leads to formation the elongated plasma stream on the axis.

To obtain the information about the gradient density scalelength, an exponential fitting of the experimental axial density profiles have been applied: $n_e(z) = n_0 e^{-z/L}$. The parameters of this function determine the maximum electron density gradient: $[dn_e/dz]_{z=0}=n_o/L$, where L is the scalelength of the density gradient and $n_0$ is the maximum electron density (Table1).

Table 1. Comparison of the maximum electron density, scalelength and density gradient.

| SHOT No. | $n_0$ [$cm^{-3}$] | L [μm] | $dn_e/dz$ [$cm^{-4}$] |
|---|---|---|---|
| 688 | $2.16x10^{20}$ | 45 | $4.80x10^{22}$ |
| 689 | $2.58x10^{20}$ | 36 | $7.17x10^{22}$ |
| 695 | $2.01x10^{20}$ | 75 | $4.01x10^{22}$ |
| 696 | $1.83x10^{20}$ | 65 | $2.82x10^{22}$ |

In order to estimate the influence of the targets irradiation conditions on the character of plasma stream expansion, on the basis on the spatial electron distribution the linear concentration distribution have been calculated (Fig.3). These distributions inform about the electrons number in the cross-section of the plasma stream per unit length.

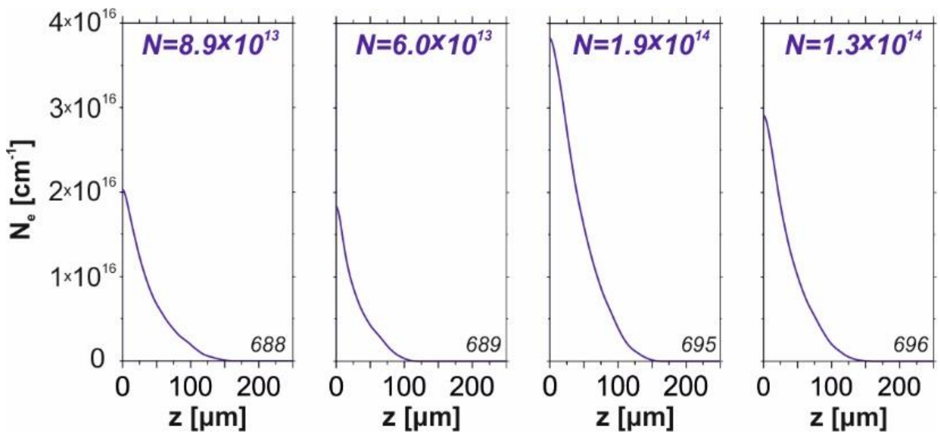


Figure 3. The linear concentration distribution.

The acceleration of protons in plasma produced from aluminum (2 μm) targets by a 40 fs laser pulses with the energy of 400 mJ and the intensity of up to $10^{19}$ W/cm$^2$ by means of SiC detectors was measured (Fig.4). Characteristics of forward-accelerated protons were measured by the time-off light method. In the measurements, special attention was paid to the dependence of proton beam parameters on the laser focus position (FP) in relation to the target surface. It can be observed that Epeak does not have any significantly dependence, while for the Emax there is a small but distinctive maximum by the 0 focus position.

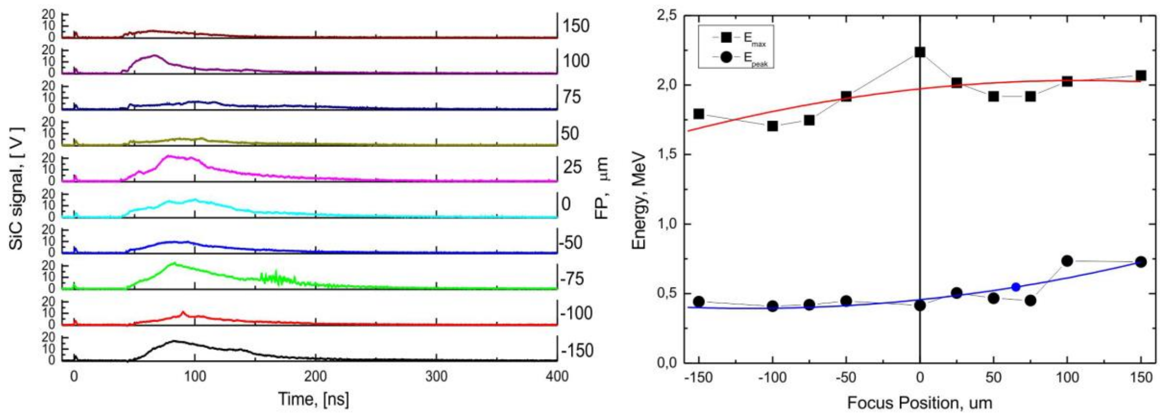


Figure 4. Target Al 2μm. Energy vs Focus Position

**Conclusions**

The first interferometric results obtained in the High Power Laser Laboratory are very promising and can be briefly summarized as follows:

- the bigger number of electrons is situated on the axis which leads to elongation of plasma stream on the axis,
- the elongation of plasma stream on the axis leads to enlargement of the scalelength, which can be seen for the shot 695 and 696.

Based on the results from the SiC detectors for the aluminum foil, the dependence of the laser beam intensity (controlled by the focus position) is rather small. The maximum ion energy approaches 2.2 MeV.

**References**

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