

# Relativistic Self-Focusing of fs-Laser Pulses and Their Heating Effect on the Preformed Plasma

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**Abstract**—Experiments in the context of fast ignition were carried out by focusing a 6-TW laser beam into a preformed plasma. An electron population with a quasi-temperature of 2 MeV was generated. The  $2\omega$  self-emission image reveals a self-focused plasma channel formation, whereas X-ray pinhole photography shows a postheating of the preformed plasma.

**Index Terms**—Electromagnetic propagation in dispersive media, laser beam distortion, laser fusion, self-focusing.

## I. INTRODUCTION

THE concept of fast ignition in inertial confinement fusion [1] is based on the separation of compression from ignition. In a first step, the fusion capsule is compressed to high densities by a conventional driving pulse and in the second step, a sequence of short laser pulses are used to ignite the compressed pellet. During the ignition phase, a laser beam having an intensity of  $10^{18}$ – $10^{20}$  W/cm<sup>2</sup> is used first to bore through the ablative corona and push the surface of critical density (up to where the laser light can propagate) near the high-density core of the pellet. Then, a separate laser pulse generates a forward propagating fast electron beam. The fast electrons are transported to the core where ignition takes place. The present investigation pertains to hole-boring and fast electron generation using the 6-TW laser system ATLAS at Max-Planck-Institute for Quantum Optics, Garching, Germany.

Laser hole boring becomes more efficient at higher laser intensities. It is enhanced by relativistic self-focusing [2] of the laser beam where the local laser intensity is increased.

As a model experiment for filamentation and fast-electron generation in the scope of fast ignition, a short, high-intensity laser pulse is focused into a preformed plasma. The experiments of Tanaka *et al.* [3] showed whole beam self-focusing in an experiment with a 100-TW laser pulse in a preformed plasma generated by the GEKKO XII laser system. They analyzed their results on the basis of the generated fast electrons with energy in excess of 1 MeV.

## II. EXPERIMENTAL

In the present experiment, a preformed plasma was generated by focusing a frequency-doubled Nd:Glass-laser pulse of 3-ns duration and 12 J of energy onto 40- $\mu$ m thick polypropylene foils. The focal-spot diameter was 200  $\mu$ m resulting in an intensity of  $10^{13}$  W/cm<sup>2</sup>. A preplasma was formed on the target front side, having a density scale length of  $\sim 100$   $\mu$ m. The synchronized pulse from the ATLAS laser system (850 mJ, 150 fs full-width half-maximum on 790 nm) was focused into this preplasma. It was focused by an off-axis parabolic mirror under 45° angle of incidence to a peak intensity slightly above  $10^{19}$  W/cm<sup>2</sup>. The delay between the two pulses was varied between 1 and 2.5 ns. A synchronized 150-fs probe beam converted to 395 nm back-lighted the target, providing interferometric images of the interaction region on a charge coupled device (CCD) detector. Furthermore, an X-ray pinhole camera with 50- $\mu$ m pinholes and Al or Be filters was used simultaneously. The angle of observation was 12° relative to the target plane. Fast electrons emerging from the rear side of the target were analyzed by the electron spectrometer [4].

## III. RESULTS AND DISCUSSION

This experimental arrangement proved to be successful for generating electrons with kinetic energies in excess of 10 MeV and a temperature of 2 MeV as measured with the electron spectrometer. Fig. 1 shows an interferometric snap shot of the preformed plasma approximately coincidental with the arrival of the CPA pulse, which was 1.9 ns after the onset of the 3 ns prepulse in this shot. The electron densities were between  $8 \times 10^{19}$  and  $8 \times 10^{20}$  cm<sup>-3</sup> with a scale length of 110  $\mu$ m on the laser axis. These results are in agreement with early calculations for similar conditions [5], and somewhat lower than in the experiments of Tanaka *et al.* [6]. The color insert illustrates the side-scattered  $2\omega$ -radiation without a probe beam. Both the interferogram and the side-scattered image show a self-focused filament extending to more than 100  $\mu$ m in length evincing whole-beam self-focusing.

The X-ray pinhole image in Fig. 2 was obtained with a 2- $\mu$ m-thick Al filter, i.e., most of the detected radiation is above 1 keV with a fraction around 100 eV. The emission from the preplasma can clearly be distinguished at the target surface. The red cone is the image of the ultra-intense laser pulse propagating in the preformed plasma (note that it is longer than the total scale in Fig. 1). The conical structure corresponds to the focusing angle of the 150 fs pulse. The strong emission is clearly a consequence of heating and ionizing effect of the

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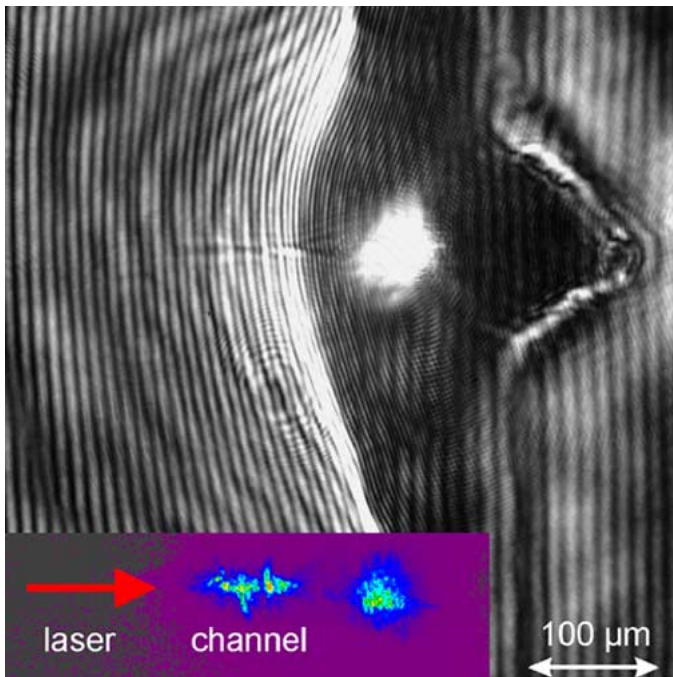


Fig. 1. Interferogram of the preplasma obtained with a  $2\omega$ -probe beam ( $\sim 150$  fs duration) passing the target parallel to its surface simultaneously with the arrival of the short pulse laser. The color insert shows  $2\omega$  self-emission of the self-focused channel and the  $2\omega$ -self emission at the critical surface. Main pulse is incident from the left.

ultrashort pulse; no signs of a self-focused filament can be seen within this cone.

The threshold for relativistic self-focusing is given as  $P_c(\text{GW}) = 17(\omega_0^2/\omega_p^2)$  with  $\omega_0$  laser frequency and  $\omega_p$  plasma frequency [2]. For the measured density values in our case, the threshold is around or slightly below 1 TW, i.e., our laser intensity is well above the threshold. Indeed, images in the visible spectral range clearly show whole beam self-focusing.

The reason that it is not seen within the X-ray spectral range of our pinhole camera is most likely because in this underdense plasma the optical thickness is low. The observation of whole beam focusing in the X-ray spectral range in the experiments of Tanaka [3] may be attributed to the higher density of the preformed plasma reaching critical density near the initial surface of the target. The arrangement used in the present experiment has however the advantage of generating high energy elec-

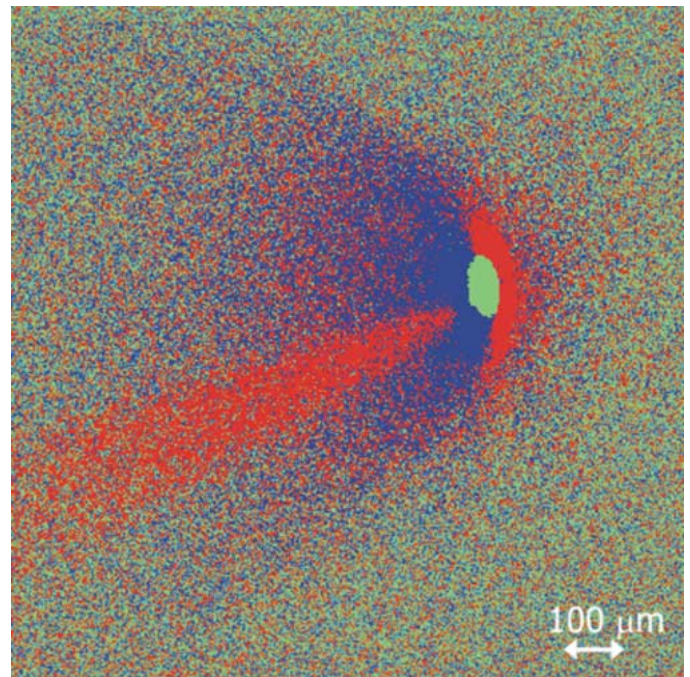


Fig. 2. X-ray pinhole photograph of the short laser pulse in the preformed plasma. A  $2\ \mu\text{m}$  Al filter was used here and the spatial resolution was  $50\ \mu\text{m}$ .

trons with modest lasers. The increase of on-axis intensity due to self-focusing and the heating of the preformed plasma is clearly demonstrated by the visible and pinhole-images.

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