# Thermal Smoothing of Laser Imprint in Double-Pulse Plasma

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**Abstract**

The topic of the proposal is a study of the influence of the target illumination by an auxiliary prepulse on a smoothing of spatial non-uniformities in the main laser pulse. In this suggested scheme the prepulse generates an absorption zone near the target surface with non-zero thermal conduction before arrival of the heating pulse. The critical surface position and the size of the absorption zone of the main pulse are controlled by a relative time delay of both laser pulses and by ratio of their intensities. The aim is to assess the conditions under which an optimal smoothing effect takes place. It is expected that by this smoothing process an imprint of a residual non-uniformities on the target surface arising at an application of the optical smoothing methods will be removed, or at least, suppressed. An influence of the prepulse plasma on the effectiveness of the laser-target coupling will be explored. The high power iodine laser system PALS operating at 1.315 μm and 0.438 μm with 400 ps pulses (energies up to 1 kJ and 0.5 kJ respectively) will be exploited. The density structures in the expanding corona will be identified by the X-ray side-on laser shadowgraphy as well as interferometry. Two-dimensional hydrodynamic simulations of the proposed experiments will be performed. The results obtained from simulations will be post-processed to allow for direct comparison with the results provided by diagnostics from experiments.

## 1. Present State

In resent years the laser-produced plasma has found numerous applications. A considerable interest attracted the development of intense heavy ion sources for accelerators, high current ion implantation or high-brightness sources of incoherent X-ray radiation. The laser-produced line focus plasmas serve as an amplifying medium for soft X-ray lasers. Mostly, in these applications the overall uniform illumination of the target surface is desired to achieve the maximum effectiveness of the laser energy deposition in the plasma. Particularly, in the *direct drive fusion experiments* severe constraints on the laser wavefront uniformity are demanded to achieve an efficient compression of the target. The non-uniform target irradiation generates inhomogeneous plasma and causes a rise of various non-linear phenomena, resonances, parametric instabilities, which can lead to serious losses in the laser energy transfer to the plasma. The intensity non-uniformities may initiate an undesirable growth of Rayleigh-Taylor instability degrading the compression and destroying the symmetry of the target implosion [1].

To avoid undesirable effects encountered in direct drive experiments, an alternative approach of the so-called *indirect drive* has been applied [2,3]. In this case the target placed inside the cavity made of a high-Z material is driven by soft X-rays generated on the inner cavity surface by laser radiation entering the inside through a system of holes. However, this method is less effective in deposition of the laser energy into the target compared with the *direct drive* [4].

A number of smoothing techniques have recently been proposed and implemented to eliminate, or at least to reduce, the laser beam intensity non-uniformities. Worth mentioning are: *random phase plates* (RPP) [5], *phase zone plates* (PZP) [6], *kinoform phase plates* (KPP) [7], *induced spatial incoherence* (ISI) [8] and/or *smoothing by spectral dispersion* (SSD) [9]. The considerable success in the development of laser beam smoothing techniques has enhanced the prospects for direct drive fusion.

However, the optical smoothing techniques are in principle *unable* to eliminate the problem of laser beam non-uniformities on shorter time scales (≅ time coherence in the ISI-type smoothing) of the laser-target interaction. This is called *laser imprint* problem [10,11]. It may seed disturbances in the developing plasma, which have important consequences on compression uniformity and, particularly, on the development of Rayleigh-Taylor and Richtmyer-Meshkov instabilities, even if optical smoothing is ensured in later times. In the early-time stage of the laser target interaction, when the plasma corona has not yet formed, the critical and ablation surfaces are practically coincident and the thermal smoothing due to the transversal thermal conduction is not active. The residual structure of the intensity non-uniformities imprinted on the still cold target surface cannot be smoothed away in this transient stage and persists throughout the rest of laser-target interaction.

A promising method, how to overcome this difficulty, is the use of *foam buffered targets*, which has been invented and intensively explored for direct drive experiments [12,13]. It relies on the pulse smoothing in an X-ray preformed plasma buffer generated from the foam layer in front of the target. The presence of the foam plasma separates the critical and ablation surfaces on the target and enhances the effect of the plasma smoothing by a transverse thermal conduction. This smoothing method is still believed to be the only way how to solve the problem of early laser imprints [14]. Despite the encouraging results obtained from these special targets, much work remains to be done and many details must be studied before such scheme may really be considered for inertial confinement fusion application [15].

The alternative so called *double pulse* method assumes that the smoothing plasma buffer layer is now generated by an *auxiliary prepulse* preceding the main high power laser pulse. In this method, which was suggested in [16], the thermal conduction in the absorption zone is thought to be a central smoothing process. The degree of smoothing, due to the *lateral thermal conductivity*, in the target plane can be characterized by a ratio of the ablation-to-critical surface separation to the characteristic perturbation length of the energy deposition. The preformed underdense plasma produced by the prepulse pushes away the critical surface of the main pulse of the shorter wavelength radiation from the ablation surface [17]. Thus the prolongation of the distance allows the heat conductivity to wash out the spatial fluctuations occurring on the critical surface. The method should overcome the trouble with the laser imprint preventing the production of the uniform ablation pressure on the target.

The reduction of imprint by the uniform preformed plasma in front of the target surface, which is created by external X-ray source, has been demonstrated in [10,18]. In this case, however, there is a higher danger of the target preheating [12] than if the prepulse of a longer wavelength is used. The smoothing effect of double pulse of the second and third harmonics of iodine laser has been already successfully observed in our laboratory [19]. In these experiments a timing of the main pulse with respect to the prepulse enabled to control and optimise the position of the critical surface. But some additional effort must still be devoted, especially to the preformed subcritical plasma between the front of the heating pulse and the solid surface of the target which favours the rise of parametric instabilities. The laser light-target interaction coupling should be discussed in connection with application of double pulse method in case of high power laser pulses.

## 2. Goal of the Proposal and the Time Schedule

Previous studies [20,21] of the thermal smoothing, when targets were illuminated by double pulses, have used the technique of *optical probing* to investigate behaviour of the front and rear side of the target in the dependence on delay time of the main pulse. This project is intended to bring more detailed information on denser region close to the ablation front, which is more important from viewpoint of uniformity of the plasma. For this purpose, newly installed high-power *Prague Asterix Laser System* (PALS) will be used, which provides 20 times higher output energy then our previous laser facility PERUN. The parameters of the laser and the plasma are now expected to be closer to those generated by the world largest laser facilities.

The high-power laser facility PALS (installed in the joint Laboratory of the Institutes of Physics and Plasma Physics of the Academy of Sciences of the Czech Republic located in Prague) will be used as a driver [22]. PALS is a single-beam iodine photo-dissociation laser, which is capable of providing a single or multiple-pulse irradiation with a variable pulse duration ranging from 100 to 500 ps. The output energy can be converted to 3ω harmonic by the use the deuterated KDP crystal twin employed in the polarization-mismatch scheme of Craxton [23] and with their respective thickness optimised for a power density of 3 $GW/cm^2$. The PALS facility produces the NIR ($\lambda$=1.315 μm) pulses with energies up to 1 kJ (on the first harmonic). For formation of the double pulse irradiation scheme the focusing optics will be set to 3ω radiation while the preceding first harmonic will be focused by an auxiliary lens to create a preplasma of the proper size. The time delay of the spatially modulated 3ω beam will be adjustable in the range from zero to several nanoseconds. The smaller auxiliary beam of the PALS with the energy of up to 100 J will be employed for setting up an auxiliary X-ray source or as a diagnostic beam converted to the third harmonic for the purpose of interferometry. Targets are supposed to be stripes of plastic or aluminium, 500 μm wide and up to 10 μm thick.

The basic plasma diagnostics at the interaction chamber and the laser driver including two streak cameras from the NIR to visible region, optical multi-channel analyser, X-ray imaging techniques (streak camera, pinhole cameras), X-ray spectrometers (crystal, transmission grating) and particle diagnostics (electrostatic analyser, Thomson mass spectrometer) are ready for use.

The research programme of the proposal concerns a very important problem of the laser energy and momentum transfer to target. This is attractive not only in the laser fusion experiments but also for a creation of a lasing medium for X-ray lasers [24, 25] or for development of effective ion source for accelerators of heavy particles (maximum yield of ions at highly ionised state) [26].

We propose a detailed testing of the double pulse plasma formation using various combinations of the prepulse energy and of the delay of the main pulse. The first and third harmonics of the iodine laser as the prepulse and heating pulse will be employed, respectively. The main pulse will be modulated spatially by means of a wedge or a mask inserted into the beam to generate a well-defined non-uniformity on the background of the preformed plasma.

A novel X-ray imaging technique with submicron spatial resolution and approximately 100 ps temporal resolution will be used. We expect that the time resolved measurements by X-ray streak camera will bring a more quantitative information on the dynamics of the double pulse heated targets. We expect to exploit the X-ray shadowgram method to get a stronger evidence of thermal smoothing by the prepulse plasma. The X-ray backlighter allows to probe the denser regions close to ablation surface and provides a higher contrast and resolution of plasma inhomogeneities. Time shifting of the backlighter pulse with respect to the arrival of the main pulse can yield an instantaneous 2D image of the plasma in different times.

The measurements will be supplemented by interferometry in visible region for quantitative determination of plasma density. The auxiliary beam of the PALS will be serving as a probing beam to ensure the synchronization. This beam will be converted to the 3rd harmonic and sent through the time delay line for getting interferograms at different stages of plasma development. A three-channel polaro-interferometric system with automated image grabbing [27] will be employed together with highly sophisticated interferogram analysing software packages [28,29]

Two-dimensional hydrodynamic simulations of the proposed experiments will be conducted using the code Atlant-C [30]. This code contains ray-tracing algorithm for laser propagation, collisional and anomalous laser absorption, flux-limited and non-local heat conduction, Thomas-Fermi-corrected equation of state, time dependent ionisation, (radiative heat conduction is only in 3 temperature approximation). The results will be post-processed to obtain direct comparison with experimental data obtained by various diagnostics.

Our current experience in this field of research is illustrated by Figs.1-6 where the experimental results obtained using the laser system PERUN together with computer simulations are displayed.

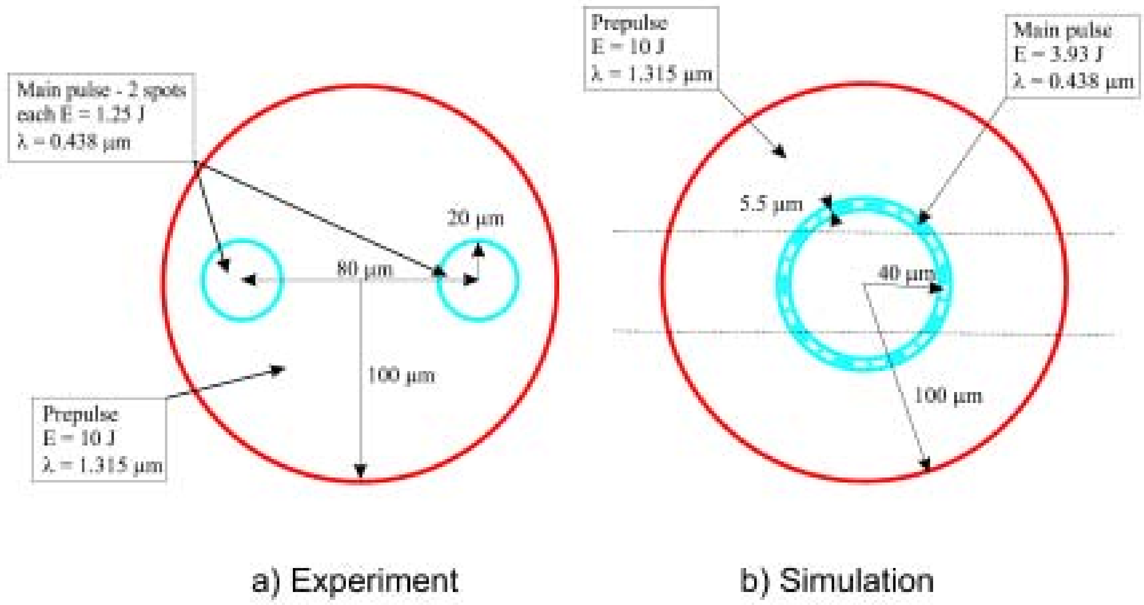



***Fig. 1.*** *Target illumination (focal plane) scheme in the experiment (a) and in the simulation (b) with the outline of the slab (dashed horizontal line) used for the shadowgraph reconstruction.*

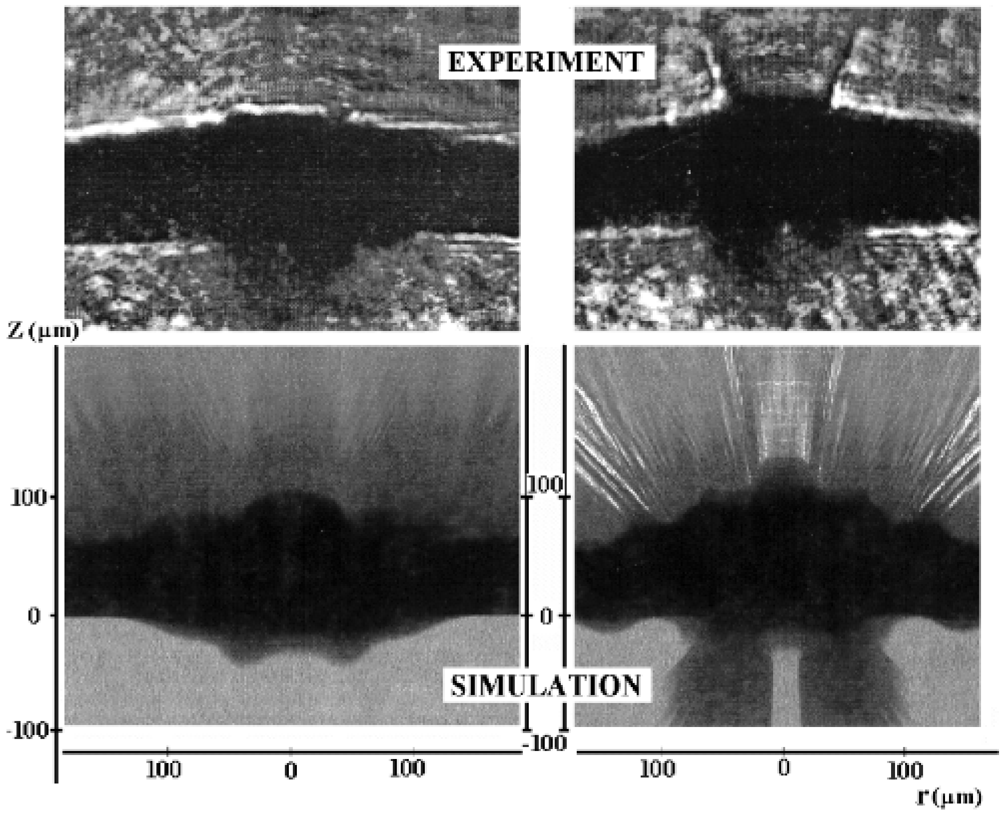
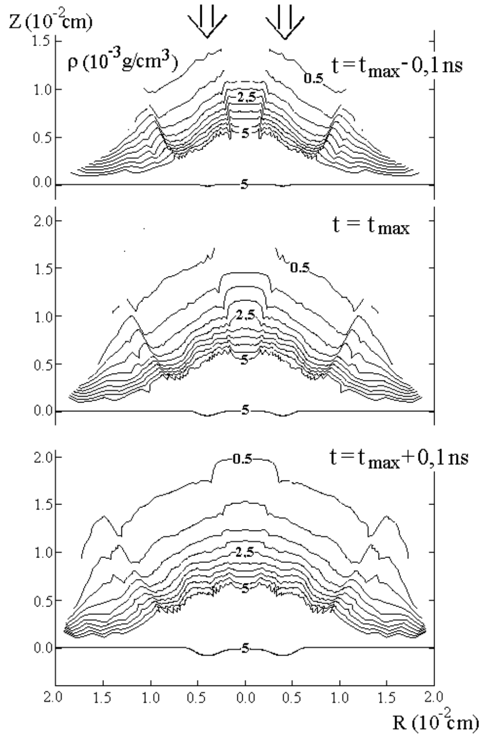



***Fig. 2.*** *The experimental and synthetic side-on view shadowgraphs taken with the probe beam shifted 0.3 ns after the main pulse. The delay of the main pulse with respect to the background pulse is 0.5 ns (left) and 0 ns (right). The laser beams are incident downwards along Z axis, original foil position z = 0-7 μm, focal plane center r = 0.*



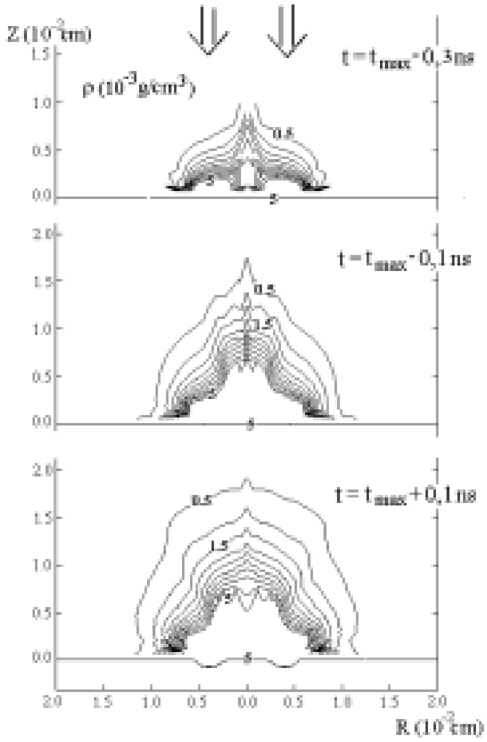
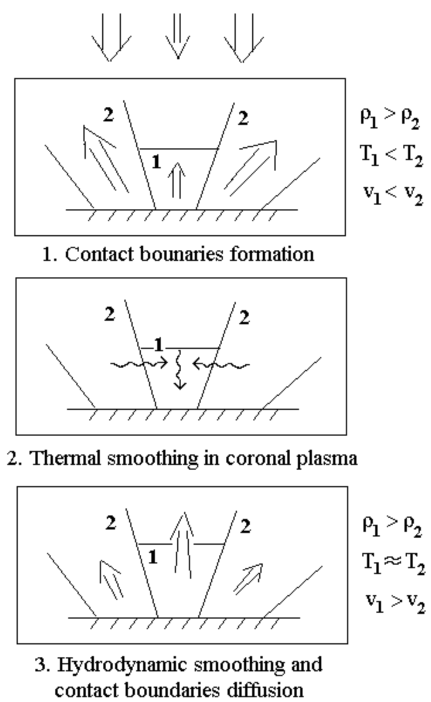




***Fig. 3 (left).*** *The instant side-on view profiles of plasma density at different times for the foil irradiation without the background pulse.*
***Fig. 4 (right)****. The instant density profiles for simultaneous irradiation for different moments.*



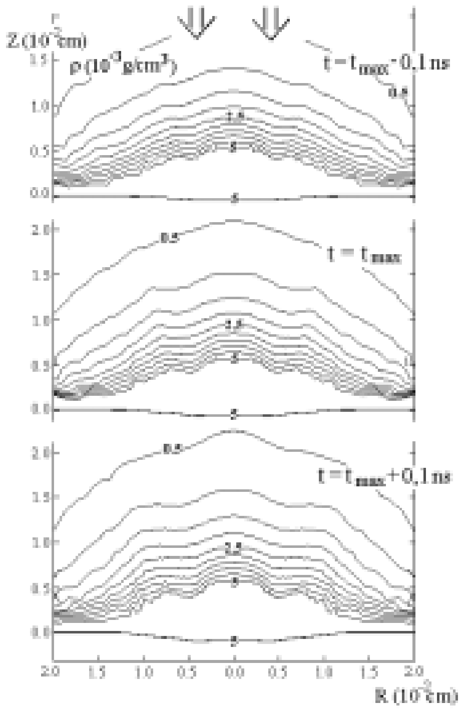




***Fig. 5 (left).*** *Three stages of contact boundaries evolution.*
***Fig. 6(right)****. The instant side-on view profiles of plasma density at different times for the foil irradiation with the main pulse 0.5 ns delayed.*

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