Laser-induced cavity pressure acceleration – a novel highly efficient scheme of acceleration of dense matter

J. Badziak, T. Pisarczyk, T. Chodukowski, S. Borodziuk, S. Jabłoński, Z. Kalinowska, A. Kasperczuk, P. Parys, P. Rączka, M. Rosiński, J. Wołowski

Institute of Plasma Physics and Laser Microfusion, Euratom Association, Warsaw, Poland

E. Krousky, M. Pfeifer, J. Skala,

Institute of Physics AS CR Prague, Czech Republic

J. Ullschmied

Institute of Plasma Physics AS CR Prague, Czech Republic

R. Liska, M. Kucharik

Czech Technical University, FNSPE, Prague, Czech Republic

K. Tomaszewski

ACS Ltd., Advanced Diagnostics Laboratory, Warsaw, Poland

P. Pisarczyk

Warsaw University of Technology ICS, Warsaw, Poland

Yong-Joo Rhee

KAERI, Daejeon, Korea

A novel efficient scheme of acceleration of dense matter is proposed and examined. In this scheme, a projectile placed in a cavity is irradiated by a laser beam introduced into the cavity through a hole and accelerated along the guiding channel by the thermal pressure generated in the cavity by the laser-produced plasma or by the photon pressure of the ultra-intense laser radiation trapped in the cavity. Using 1.315 μm or 0.438 μm, 0.3-ns laser pulse of energy up to 200 J and a thin target (CH, CD_2) placed in the cavity it was shown that the forward accelerated dense plasma projectile produced from the target can be effectively guided and collimated in the 2 mm cylindrical or conical guiding channel and the energetic efficiency of acceleration in this scheme is an order of magnitude higher than in the case of conventional ablative acceleration.

Introduction

A commonly used method for laser-driven acceleration of dense matter is the ablative acceleration (AA), based on the “rocket effect“ [1, 2]. Unfortunately, the energetic efficiency of acceleration (η_{acc}) in the AA scheme is rather small: $\eta_{acc} = \eta_{abs}\,\eta_h \sim 10\%$, where η_{abs} is the laser absorption coefficient and η_h is the hydrodynamic efficiency. Very recently, a novel highly efficient acceleration scheme – called the laser-induced cavity pressure acceleration (LICPA) – has been proposed [3]. In this scheme, a projectile placed in a cavity is irradiated by a laser beam introduced into the cavity through an aperture and accelerated along the guiding channel by the thermal pressure generated in the cavity by the laser-produced plasma or by the photon pressure of the ultra-intense laser radiation trapped in the cavity.

The aim of this contribution is to provide a brief review of our LICPA-related experiments performed at the kilojoule PALS laser facility in Prague. In these experiments the properties of plasma accelerated and collimated in various (cylindrical, conical) LICPA schemes were investigated using several diagnostics (interferometry, ion, X-ray, and neutron diagnostics, as well as measurements of the plasma-produced impact craters) and compared with the corresponding properties of plasma accelerated in the AA schemes. Two-dimensional hydrodynamic simulations were carried out to support and explain experimental results.

Results

Exemplary results of measurements of volumes and depths of craters produced in the Al target by high-density plasma accelerated in the LICPA and AA conical schemes driven by the 1ω PALS laser beam (λ= 1.315μm) are presented in Fig.1.

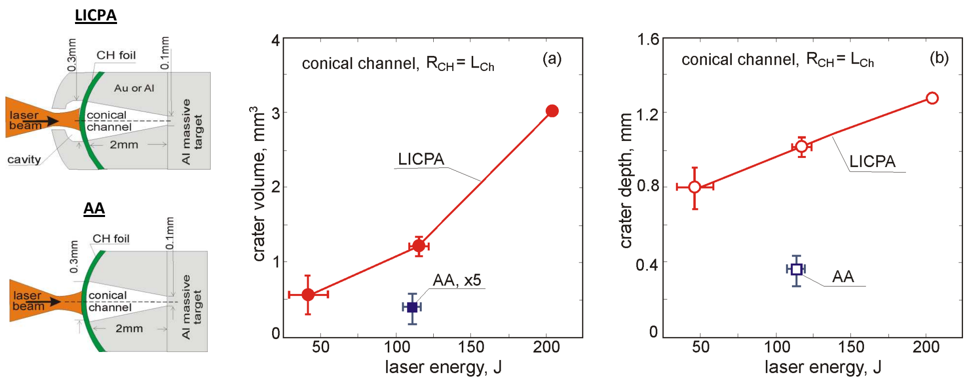

Fig. 1. The volume and depth of craters produced in the Al target by high-density plasma driven by LICPA or ablative acceleration (AA) as a function of laser energy. The case of conical channel with shaped CH foil of L_T = 20μm irradiated by the 1ω PALS laser beam .

The crater volume – which is a measure of the energy deposited in the target by the plasma – increases quickly with the laser energy in the LICPA scheme and is at least 15 times greater than in the case of the AA scheme. The differences in crater parameters produced with LICPA and AA observed for the cylindrical schemes were even bigger than those shown in Fig. 1.

Two-dimensional hydro simulations performed for the input parameters similar to those in the experiment confirmed the big differences in the craters produced by plasma accelerated in the LICPA scheme and the AA scheme (Fig. 2), which are the result of much higher (about order of magnitude) kinetic energy of the plasma accelerated by LICPA.

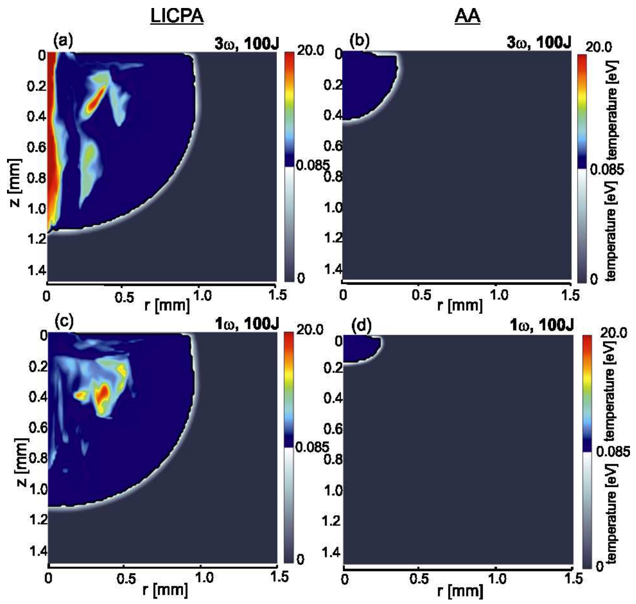

Fig. 2. Simulations of crater production in the Al target by plasmas accelerated in the cylindrical LICPA and AA schemes. CH target of L_T= 20μm, L_{ch}= 2mm , L_{cav} = 0.1mm, τ_L = 0.3ns, E_L = 100J, 1w or 3ω laser beam.

Significantly higher acceleration efficiency in the LICPA scheme was also confirmed by our interferometric measurements and the ion diagnostic. They proved that the plasma accelerated in the LICPA scheme is more dense, faster and more collimated than that accelerated in the AA scheme, as it can be seen in Figs. 3 and 4.

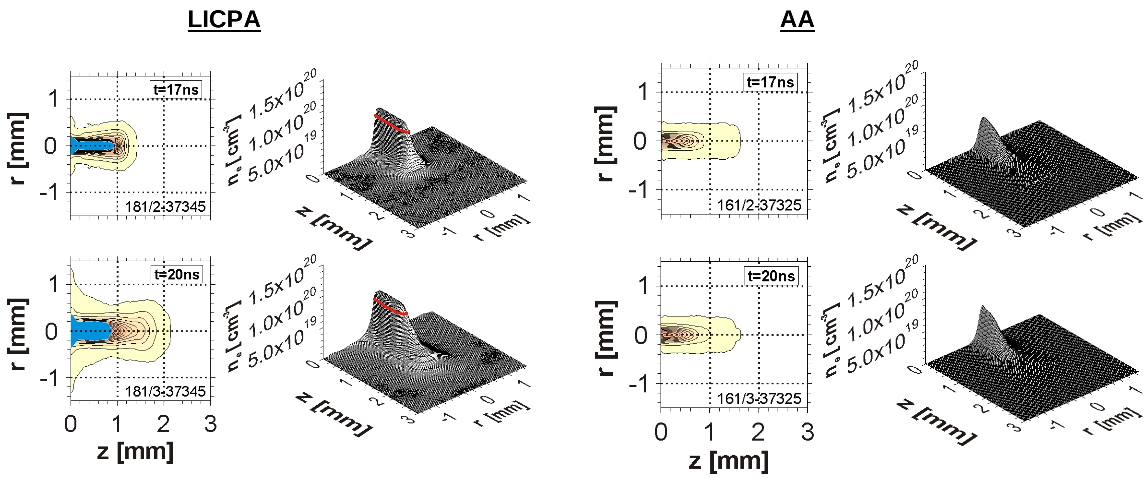

Fig. 3. The electron isodensitograms and space profiles of electron density distributions for the plasma leaving the 2-mm channel in the cylindrical LICPA scheme and in the ablative acceleration (AA) scheme, obtained for 3ω PALS laser beam. E_L≈ 200J, L_T = 20μm, L_{ch}= 2mm, d_{ch}= 0.3mm.

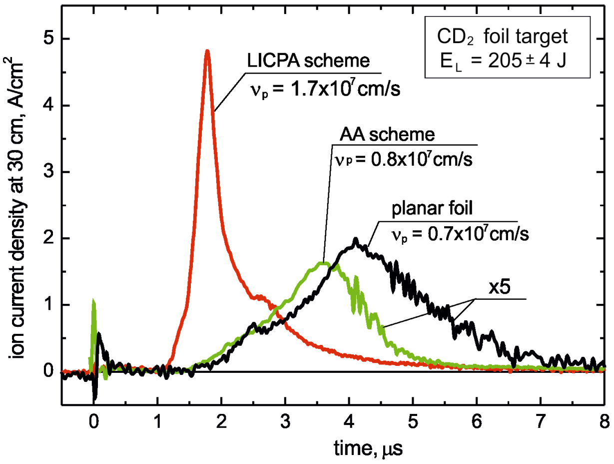

Fig. 4. The ion current density of plasma accelerated in the cylindrical LICPA scheme, AA scheme and planar foil target and measured on the laser beam axis at a long distance (30cm) from the plasma source.

Conclusions

In conclusion, a novel efficient scheme of high-density plasma acceleration and collimation using laser-induced cavity pressure has been proposed and demonstrated. Due to higher hydrodynamic efficiency and higher absorption of laser radiation in the cavity, the energetic efficiency of acceleration in this scheme may be an order of magnitude greater than in the case of the conventional ablative acceleration based on the “rocket effect”, reaching values above 50%. The proposed LICPA accelerator has a potential to be highly useful for fusion-related applications (e.g. for impact fusion), as well as for other fields of research such as high energy-density physics, laboratory astrophysics or material processing.

References

[1] A. Atzeni and J. Meyer-ter-Vehn, Physics of Inertial Fusion, Clarendon Press, Oxford (2004).

[2] J. Lindl, Phys. Plasmas **2,** 3933 (1995).

[3] J. Badziak et al., Appl. Phys. Lett. **96**, 251502 (2010).