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Recent highlights of the PALS research program*

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Abstract

The Prague Asterix Laser System (PALS) research program covers a broad spectrum of laser–plasma experiments in the range of power densities of 10^{14}-5×10^{16} W/cm^2, aimed at development and applications of laser plasma-based ion and soft X-ray sources of plasma based ultra-bright XUV lasers in particular. In parallel to these two main lines of research, various principal tasks of laser plasma physics are being studied, such as generation and propagation of laser-induced shock waves, laser ablation, and crater creation processes or laser imprint treatment. Results selected of numerous experimental projects performed at PALS within the period 2002–2004 are surveyed in the paper, experiments with intense soft XUV laser beams being highlighted on the first place.

Keywords: Ablation; Iodine lasers; Laser ion sources; Laser-produced plasma; Laser-target interaction; PALS; Shock waves; XUV lasers

1. INTRODUCTION

The PALS terawatt iodine laser facility (Jungwirth *et al.*, 2001, 2003) is unique because of its working wavelength (1315 nm), and high-energy output in a single-beam configuration (up to 1 kJ), which makes it a powerful driver for various practical applications, despite its relatively long pulse (~ 400 ps). The fundamental frequency of the main PALS beam can be up-converted to the red, blue, and even ultraviolet harmonics, the output energy can be varied over two orders of magnitude with essentially unchanged beam geometry. A multi-purpose target chamber and new options such as variable-delay red and blue auxiliary and diagnostic beam lines meet most of the demanding experimental needs. Due to all the above features, the PALS is being intensely exploited for laser-plasma experiments at power density levels ranging from 10^{14} to 5×10^{16} W/cm^2. Since September 2000, the PALS offers a substantial fraction of its beam time to both domestic and foreign external users. Within the 5th framework program of EU, it is coordinated as a separate European access project within the transnational access to major research infrastructures action. In the 6th FP, the PALS participates at the integrated project LASERLAB-EUROPE together with 17 European laser laboratories in the frame of the integrated infrastructures initiative (Research Infrastructures Action). Several tens of experimental projects were performed at PALS during the last four years; aimed at various applications of plasma XUV sources, QSS plasma XUV lasers, laser ion sources, and laser-induced shock waves. The PALS research program is stimulated to a far extent by hosting researchers from many European countries, including, for instance, Italian research teams from Universita di Milano-Bicocca and INFN-LNS Catania.

In what follows, the current research program at the PALS facility will be briefly overviewed and the main research results achieved during the last two years highlighted. In this context, the progress of the first ever user–friendly zinc plasma based XUV laser launched at PALS in 2001 (Rus *et al.*, 2001) should be mentioned on the first place.

2. PALS ZINC XUV LASER AT 21.2 nm

The program of the soft X-ray (XUV) lasers at PALS is pursued in two directions: implementation of novel generators of coherent radiation in the spectral range 13–21 nm, and the development of their applications in physics and biology. Several XUV lasing schemes were tested at the PALS, of which the Ne-like zinc laser at 21.2 nm is the most advanced one. With its ~10 mJ output energy achieved in the double-pass regime, corresponding to ~100 MW of peak power, the optimized PALS zinc soft X-ray laser constitutes the brightest laboratory soft X-ray source ever demonstrated (Rus *et al.*, 2001, 2002*a*). Recently, high power outputs were achieved also in unique laser pumping

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regimes with large separation of the prepulse (<10 J), and the main inversion-driving pump pulse (~ 600 J), of up to 50 ns (Rus *et al.*, 2004).

The PALS zinc X-ray laser delivers stable output parameters over a long series of shots (Präg *et al.*, 2003). High reproducibility and stability recommends this XUV laser as a robust and user-friendly tool for applications. The first French-Czech application experiment of that type was aimed at interferometric investigation of microdischarges occurring at the niobium surface subjected to very large DC electric fields, a Fresnel double mirror being used as the interferometric device. The obtained interferograms were characteristic by high fringe contrast and provided unique information about the nanometric topology of the investigated Nb surfaces (Ros *et al.*, 2002, 2002*b*).

The peak brightness of the laser of ~10^{17} $\mathrm{Wcm^{-2}sr^{-1}}$ exceeds by several orders of magnitude the values currently attainable on synchrotrons, making the PALS XUV laser suitable for single-shot ablation and radiation damage studies. Encouraging were the preliminary studies of XUV damaging of desiccated DNA plasmids of *Escherichia coli*. In the first experiment on the XUV radiation damage of DNA samples (Rus *et al.*, 2004) a number of single- and double-strand breaks were observed. Similar priority results were achieved in the field of XUV ablation, which is discussed in the next section.

3. XUV ABLATION STUDIES AT PALS

At XUV ablation experiments, the PALS Zn XUV laser beam was focused on the substrate surface with a spherical Si/Mo multi-layer-coated mirror. Polymethylmethacrylate, mono-crystalline silicon, amorphous carbon, and carbon vapor deposited diamond (CVDD) films were successfully ablated by a filtered XUV radiation (Juha *et al.*, 2004), see Figure 1. To our knowledge, this was the first observation of material ablation and plasma production with a laser working in the soft X-ray region, that is, at radiation wavelengths below 30 nm.

The ablation of materials was studied also by using the non-coherent soft X-ray radiation emitted by the laser plasmas produced from gas-puff targets. A double coaxial nozzle developed at MUT Warsaw (Fiedorowicz *et al.*, 2001) was exploited at these experiments. Through the inner nozzle the heavy working gas (xenon) is let in, while the outer nozzle produces a helium barrier layer that prevents the target plasma from undue lateral expansion. The gas-puff plasma generates no debris and constitutes thus a "clean," highly intense (~ 100 J) point soft X-ray radiation source (Fiedorowicz *et al.*, 2004*a*). Ablation depths on the order of a few hundreds of nanometers were observed with PMMA, PTFE, and monocrystalline silicon samples (Juha *et al.*, 2003). Recent experiments on direct photo-etching of organic polymers performed at PALS with the gas-puff radiation source are described in more detail by Fiedorowicz *et al.* (2004*b*). Single-shot XUV imprints in PMMA photo resists are exploited also at the soft-X-ray contact microscopy technique. The recently published detailed images of living multi-cellular micro-organisms (Nematodae worm Caenorhabditis Elegans) represent another priority result of experiments performed at the PALS two years ago (Desai *et al.*, 2003; Poletti *et al.*, 2004).

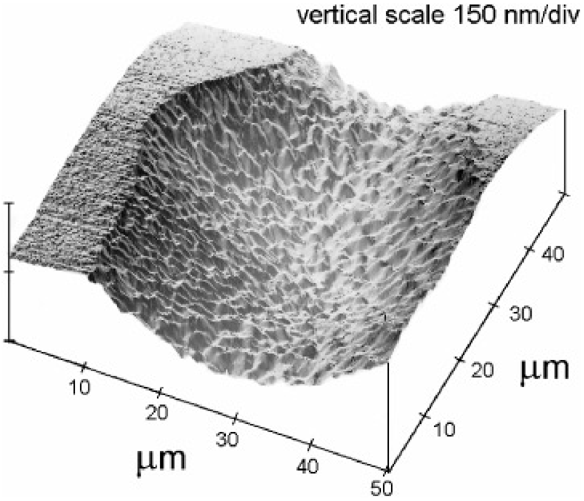

Fig. 1. The crater ablated in PMMA by a single shot of the PALS XUV laser beam filtered by 0.4 μm of Al.

4. LASER ION SOURCES

Development of laser ion sources continued to be one of the main research lines at the PALS facility (Wolowski *et al.*, 2002; Laska *et al.*, 2003). The huge number of comparative experimental data collected at PALS by Polish, Czech, and Italian research groups during the years 2000–2003, and parallel studies performed at the partner laboratories IPPLM Warsaw and LNS INFN Catania, lead to several important conclusions concerning the role of various mechanisms of ion acceleration observed in the laser plasma produced by laser pulses of ns duration (Rosmej *et al.*, 2002). Perhaps the most important result was the precise determination of the optimum focus position relative to the target surface, at which the most efficient ion generation occurs.

The intense streams of accelerated highly-stripped ions observed at PALS at the optimum focus position at relatively low focused laser power densities (starting with the threshold value of 2×10^{14} W/cm^2) correspond to those found at the interaction of ps laser pulses with the preformed plasma, at laser power densities above 10^{18} W/cm^2. Non-linear self-focusing of the laser beam, which develops during the interaction of ns-duration laser pulses with the plasma plume, was suggested as the most probable explanation (Laska *et al.*, 2004).

Laser ion sources find their use as ion injectors (Neumayer *et al.*, 2005) and represent also a prospective tool for future ion implantation technologies. The implantation test performed at PALS demonstrated that this technique is efficient in implanting ions into the depths up to several hundreds of nanometers, while this figure extends to a few microns in the case of polymer substrates (Torrisi *et al.*, 2003; Mezzasalma *et al.*, 2004; Wolowski *et al.*, 2004).

5. SHOCK WAVE STUDIES

The shock wave experiments performed at PALS in cooperation with the Italian research group from the Università degli Studi di Milano-Bicocca were aimed at studying the equations of state of compressed materials at very high pressures, in relevance to various issues in astrophysics and planetary physics (Batani *et al.*, 2003*a*). Structured C, Fe, and Al two-step and "two steps–two materials" targets, as well as C-targets with a LiF ablator were used. The blue (3rd harmonics) laser beam used was defocused to the power density of 2×10^{14} W/cm^2 at the target and smoothed by a phase zone plate. The shock breakout times and hence the velocities of shock waves were determined through time resolved (streak camera) imaging (Fig. 2) of self-emissivity of the rear side of the targets (Batani *et al.*, 2003*b*). It was shown that Megabar pressures are easily reachable with the PALS laser driven shocks. Recently, the first ever Hugoniot data for carbon at pressures higher than 8 Mbar were thus obtained (Batani *et al.*, 2004).

The shock wave propagation in solids and crater formation physics was the subject of detailed studies performed at PALS by colleagues from the IPPLM Warsaw and the Czech Technical University in Prague (Borodziuk *et al.*, 2004). Recent results in this field were summarized in several papers at the 28th ECLIM conference. The crater creation in single massive targets and in double ones was investigated. In a double target, a foil or disc is placed in front of the massive background. The ablatively accelerated foil fragments or discs behave as high-speed projectiles, and may be thus used for simulation of impacts of macro-particles at very high velocities not achievable by any other way (Pisarczyk *et al.*, 2003). Velocities of the accelerated macro-particles as well as electron density distributions of plasma streams were determined by means of a sophisticated multi-frame laser interferometer/shadowgraph developed for PALS at IPPLM in Warsaw (Kasperczuk *et al.*, 2002; Pisarczyk *et al.*, 2002). For interpreting the experimental data an original 2D theoretical model of both the laser-produced plasma plume and the shock wave was developed (see a sample frame in Fig. 3). For more details on the calculated values of the energy absorption coefficient, ablation loading efficiency, and efficiency of the energy transfer see e.g. a parallel ECLIM paper by Pisarczyk *et al.* (2004).

Within the framework of a collaborative INTAS project, the energy transfer and ablation pressure smoothing effects in laser-irradiated low-density foams, and other volume-structured media were studied. Good-looking symmetry and absence of local perturbations observed both in the rear side plasmas of porous targets and in the shape of the accelerated Al foils, confirmed efficient acceleration of thin solid foils by the pressure of foam absorbers of laser radiation. The laser light absorption efficiency in the porous matter of supercritical density highly exceeds 50%, which results in generation of Mbar pressures (Kalal *et al.*, 2003). Initial experiments aimed at smoothing the laser beam imprint by foams, as well as by increasing the initial plasma thermal conductivity by a laser-prepulse, are reported in a parallel paper by Limpouch *et al.* (2005).

A more complete survey of the current experimental projects at PALS would reflect the fact that many valuable results and perhaps even highlights were obtained also e.g. in the field of high-resolution XUV spectroscopy, of XUV detection and dosimetry, multiframe laser inter-ferometry of laser-produced plasmas and at studies of photochemical processes in laser-induced discharges in gas mixtures and of

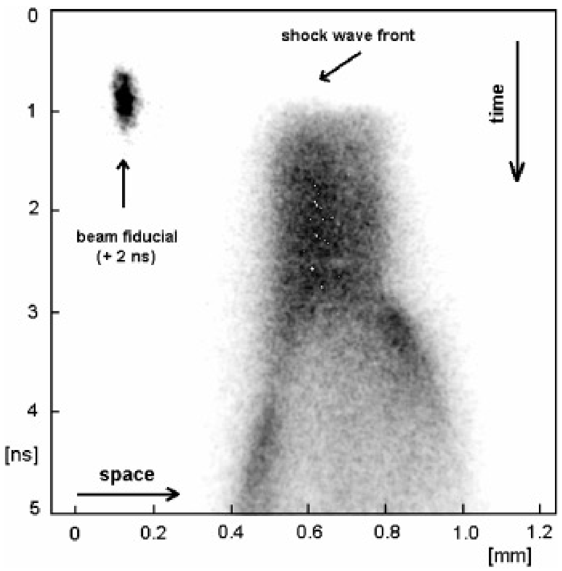

Fig. 2. Shock wave structure in the layered CH-C-foam target. (Infrared streak camera Hamamatsu C5680).

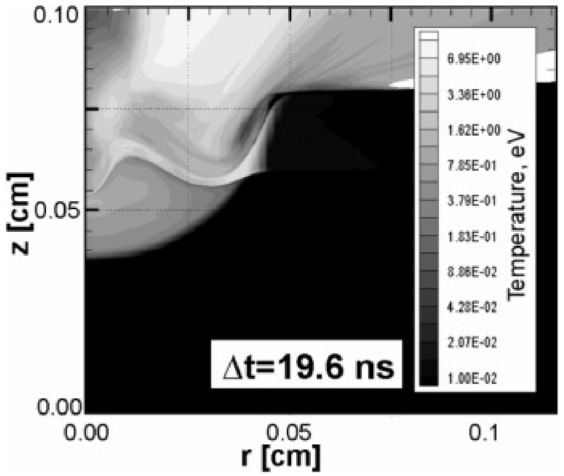

Fig. 3. Sample frame from the simulation of the plasma plume and crater formation. (2-D Lagrangian hydrodynamic code ATLANT-HE).

materials modification by high-power laser beams. Let us instead mention, however, the basic upgrades of the laser system being under way in our laboratories.

6. ON A WAY TO HIGHER LASER POWERS

The PALS laboratory is going to enhance the laser power density on the target from the present value of 10^{16} W/cm^2 up to 10^{20} W/cm^2 by implementing the OPCPA method of generation of ultra short PW-power pulses, similarly as at the Vulcan laser at RAL (Danson *et al.*, 2005). This will allow increase in the range of the studied phenomena to very high energy densities including for example relativistic plasma, inertial fusion oriented experiments, physics of hot dense matter (HDM with pressures of thousands of Mbar), atomic physics (HDM interaction with internal atomic fields), and laboratory astrophysics.

The first steps in this direction were made in a new laser laboratory built in Prague last year. A unique hybrid laser system was launched there, which consists of a commercial crystal oscillator, and two power amplifiers (reconstructed amplifiers of the PERUN II laser). The system gave the laboratory the name: SOFIA = Solid State Oscillator Followed by Iodine Amplifiers.

The SOFIA hybrid laser system is the first to exploit an optical parametric oscillator as a front-end of a high power iodine laser (Straka *et al.*, 2003). The commercial MOPO-HF oscillator (Spectra Physics) pumped by an Nd:YAG laser (Quanta Ray) was chosen for its very narrow spectral line (0.01 nm) and the possibility to tune its idler to the iodine laser frequency (1315.24 ± 0.01 nm). The 5-ns oscillator pulse is cut to a shorter pulse width by two Pockets cells, which also provide synchronization with the OPCA module. Then, it is amplified by two (double and single-pass) iodine booster amplifiers. A stable operation of the system was achieved for output energies up to 50 J, at a pulse length of 2 ns. The third harmonics beam (438 nm) is used to pump parametric crystal OPCPA amplifiers. At standard conversion efficiency value of 30–40% and the pulse duration of 0.6–1 ns the pump power can be as high as 30 GW.

In the OPCPA module, the seed signal is produced by a 10-fs Ti:sapphire pulser (Femtolasers). Prior to amplification, the seed pulse is chirped and stretched from its initial duration of ~ 10 fs to ~ 300 ns to match the 3ω pump pulse of the iodine laser. The pump energy transfer is accomplished in parametric crystal amplifiers (LBO and KDP). The amplified stretched pulse is then compressed to ~ 50 fs by a final pulse compressor. According to the performed simulations, it is expected to obtain with the SOFIA system about 30 TW of output power in the wavelength range centered near 800 nm. The experimental tests of the parametric amplification of the chirped Ti:Sapphire laser pulse in one-stage KDP-crystal amplifier is just in progress. More detailed information on the status of the OPCPA experiment at the SOFIA laboratory was presented at the 15th GCL/HPL Conference in Prague (Turcicova *et al.*, 2004).

The primary task of the pilot OPCPA experiment at the SOFIA laboratory is to demonstrate generation of high-power (>10 TW) femtosecond pulses by applying the OPCPA technique at the iodine laser system. In this period, the SOFIA substitutes for PALS at its first step to petawats (Straka *et al.*, 2002), saving thus a considerable part of the PALS beam time for users. Target experiments with focused fs-duration laser beams are planned in the SOFIA laboratory for the not too distant future.

7. SUMMARY

The PALS terawatt user facility is being widely exploited by an international laser research community for interaction experiments at a focused laser power density of 10^{14}–$5 \cdot 10^{16}$ W/cm^2. The selected experiments highlighted in the paper have brought priority results e.g. in the field of development of plasma based XUV lasers and their applications in physics, material science and radiation biology, at using plasma sources of non-coherent XUV radiation for XUV ablation studies and XUV contact microscopy of living micro-organisms. Equally valuable results have been obtained e.g. at investigating the mechanisms of ion acceleration in laser-produced plasmas, at studying the equations-of-state of materials at very high pressures, as well as the crater formation and ablation pressure smoothing processes. The OPCPA pilot experiment under way in the SOFIA laboratory breaks a PALS's path to multi-terawatt laser powers and to laser interaction experiments at the power density levels exceeding 10^{17} W/cm^2.

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REFERENCES

Batani, D., Stabile, H., Ravasio, A., Lucchini, G., Strati, F., Desai, T., Ullschmied, J., Krousky, E., Skala, J., Juha, L., Kralikova, B., Pfeifer, M., Kadlec, C., Präg, A., Nishimura, H. & Ochi, Y. (2003*a*). Ablation pressure scaling at short laser wavelength. *Phys. Rev. E* **68** 7403.

Batani, D., Stabile, H., Ravasio, A., Desai, T., Lucchini, G., Strati, F., Ullschmied, J., Krousky, E., Skala, J., Kralikova, B., Pfeifer, M., Kadlec, C., Mocek, T., Präg, A.R., Nishimura, H., Ochi, Y., Kilpio, A., Shashkov, E., Stuchebrukhov, I., Vovchenko, V. & Krasuyk, I. (2003*b*). Shock pressure induced by 0.44 μm laser radiation on aluminum targets. *Laser Part. Beams* **21**, 481–487.

Batani, D., Strati, F., Stabile, H., Tomasini, M., Lucchini, G., Ravasio, A., Koenig, M., Benuzzi-Mounaix, A., Nishimura, H., Ochi, Y., Ullschmied, J., Skala, J., Kralikova, B., Pfeifer, M., Kadlec, C., Mocek, T., Präg, A., Hall, Milani, P., Barborini, E. & Piseri, P. (2004). Hugoniot data for carbon at megabar pressures. *Phys. Rev. Lett.* **92**, 5503.

Borodziuk, S., Kasperczuk, A., Pisarczyk, T., Gus'kov, S.Yu., Ullschmied, J., Kralikova, B., Rohlena, K., Skala, J., Kalal, M. & Pisarczyk, P. (2004). Investigation of plasma ablation and crater formation processes in the Prague Asterix Laser System laser facility. *Optica Applicata* **34**, 31–42.

Danson, C.N., Brummitt, P.A., Clarke, R.J., Collier, J.L., Fell, B., Frackiewicz, A.J., Hawkes, S., Hernandez-Gomez, C., Holligan, P., Hutchinson, M.H.R., Kidd, A., Lester, W.J., Musgrave, I.O., Neely, D., Neville, D.R., Norreys, P.A., Pepler, D.A., Reason, C.J., Shaikh, W., Winstone, T.B., Wyatt, R.W.W. & Wyborn, B.E. (2005). Vulcan Petawatt—design, operation and interactions at 5.10^{20} Wcm^{-2}, *Laser Part. Bea*ms **23**, 87–93.

Desai, T., Batani, D., Bernardinello, A., Poletti, G., Orsini, F., Ullschmied, J., Juha, L., Skala, J., Krali-Kova, B., Krousky, E., Pfeifer, M., Kadlec, C., Mocek, T., Präg, A.R., Renner, O., Cotelli, F., Lamia, C.L. & Zullini, A. (2003). X-ray microscopy of living multicellular organisms with the Prague Asterix Iodine Laser System. *Laser Part. Beams* **21**, 511–516.

Fiedorowicz, H., Bartnik, A., Wawer, J., Juha, L., Jungwirth, K., Kralikova, B., Krasa, J., Mocek, T., Pfeifer, M., Skala, J., Ullschmied, J., Horvath, M. & Pina, L. (2001). Investigation of soft X-ray emission in the 'water window' for microscopy using a double-stream gas puff target irradiated with the Prague Asterix Laser System (PALS). *Proc. SPIE* **4502**, 47–54.

Fiedorowicz, H., Bartnik, A., Jarocki, R., Kostecki, J., Rakowski, R. & Szczurek, M. (2004). Generation of X-ray radiation using a laser-irradiated gas puff target. *Proc. 28th ECLIM*, 661–680.

Fiedorowicz, H., Bittner, M., Bartnik, A., Juha, L. & Krasa, J. (2004). Photo-etching of organic polymers using a laser plasma XUV source irradiated with the PALS facility. *15th GCL/HPL Conf. Prague*.

Juha, L., Bittner, M., Kozlova, M., Krasa, J. & Letal, V. (2004). Material ablation induced by focused 21.2-nm radiation from Ne-like Zn X-ray laser. *15th GCL/HPL Conf. Prague*.

Juha, L., Krasa, J., Cejnarova, A., Chvostova, D., Vorlicek, V., Krzywinski, J., Sobierajski, R., Andrejczuk, A., Jurek, M., Klinger, D., Fiedorowicz, H., Bartnik, A., Pfeifer, M., Kubat, P., Pina, L., Kravarik, J., Kubes, P., Bakshaev, Yu. L., Chernenko, A. S., Korolev, V. D., Ivanov, M.I., Scholz, M., Ryc, L., Feldhaus, J., Ullschmied, J. & Boody, F.P. (2003). Ablation of various materials with intense XUV radiation. *Nucl. Instrum. Meth. Phys. Res.* **A 507**, 577–581.

Jungwirth, K., Cejnarova, A., Juha, L., Kralikova, B., Krasa, J., Krousky, E., Krupickova, P., Laska, L., Masek, K., Mocek, T., Pfeifer, M., Präg, A., Renner, O., Rohlena, K., Rus, B., Skala, J., Straka, P. & Ullschmied, J. (2001). The Prague Asterix Laser System PALS, *Physics of Plasmas* **8**, 2495–2501.

Jungwirth, K., Rohlena, K., Ullschmied, J., Cejnarova, A., Juha, L., Kozlova, M., Kralikova, B., Krasa, J., Krousky, E., Kubat, P., Laska, L., Masek, K., Mocek, T., Pfeifer, M., Präg, A., Renner, O., Rus, B., Severova, P., Skala, J., Straka, P. & Turcicova, H. (2003). Prague Asterix Laser System (PALS)—results and upgrades, invited talk. *ECLIM 2002 Moscow, SPIE Proc.* **5228**, 651–664.

Kalal, M., Limpouch, J., Krousky, E., Masek, K., Rohlena, K., Straka, P., Ullschmied, J., Kasperczuk, A., Pisarczyk, T., Guskov, S.Yu. Gromov, A.I., Rozanov, V.B. & Kondrashov, V.N. (2003). Thermal smoothing by laser-produced plasma of porous matter. *Fus. Sci. Tech.* **43**, 275–281.

Kasperczuk, A., Pisarczyk, P., Pisarczyk, T., Kralikova, B., Masek, K., Pfeifer, M., Rohlena, K., Skala, J., Ullschmied, J. & Kalal, M. (2002). Interferometric investigation of an early stage of plasma expansion on the high power laser system PALS. *Czech. J. Phys.* **52**, 395–404.

Laska, L., Jungwirth, K., Kralikova, B., Krasa, J., Pfeifer, M., Rohlena, K., Skala, J., Ullschmied, J., Badziak, J., Parys, P., Wołowski, J., Woryna, E., Gammino, S., Torrisi, L., Boody, F.P. & Hora, H. (2003). Generation of multiply charged ions at low and high laser-power densities. *Plasma Phys. Contr. Fus.* **45**, 585–599.

Laska, L., Jungwirth, K., Krasa, J., Pfeifer, M., Rohlena, K., Ullschmied, J., Badziak, J., Parys, P., Wołowski, J., Boody, F. P., Gammino, S. & Torrisi, L. (2004). Generation of extreme high laser intensities in plasma. *Czech. J. Phys.* **54-C**, 370–377.

Limpouch, J., Demchenko, N.N., Gus'kov, S.Yu., Gromov, A.I., Kalal, M., Kasperczuk, A., Kondra-Shov, V.N., Krousky, E., Masek, K., Pisarczyk, P., Pisarczyk, T. & Rozanov V.B. (2005). Laser interactions with low-density plastic foams *Laser Part. Beams* **23** (in press).

Mezzasalma, A.M., Torrisi, L., Gammino, S., Mondio, G., Franco, G., Wolowski, J., Krasa, J. & Laska, L. (2004). Scanning Auger microscopy of laser-produced Cu ions implanted in silicon. *Proc. 28th ECLIM*.

Neumayer, P., Bock, R., Borneis, S., Brambrink, E., Brand, H., Caird, J., Campbell, E.M., Gaul, E., Goette, S., Haefner, C., Hahn, T., Heuck, H.M., Hoffmann, D.H.H., Javorkova, D., Kluge, H.J., Kuehl, T., Kunzer, S., Merz, T., Onkels, E., Perry, M.D., Reemts, D., Roth, M., Samek, S., Schaumann, G., Schrader, F., Seelig, W., Tauschwitz, A., Thiel, R., Ursescu, D., Wiewior, P., Wittrock, U. & Zielbauer, B. (2005). Status of PHELIX laser and first experiments. *Laser Part. Beams* **23** (in press).

Pisarczyk, T., Badziak, J., Kasperczuk, A., Parys, P., Pisarczyk, P., Wolowski, J., Woryna, E., Jungwirth, K., Kralikova, B., Krasa, J., Laska, L., Masek, K., Pfeifer, M., Rohlena, K., Skala, J., Ullschmied, J. & Kalal, M. (2002). Fast and slow plasma components produced by the PALS facility—comparison of interferometric and ion diagnostic measurements. *Czech. J. Phys.* **52-D**, 310–317.

Pisarczyk, T., Borodziuk, S., Kasperczuk, A., Jungwirth, K., Kralikova, B., Krousky, E., Masek, K., Pfeifer, M., Rohlena, K., Skala, J., Ullschmied, J., Kalal, M., Limpouch, J. & Pisarczyk, P. (2003). Application of the laser simulation method of crater creation in the laser Al solid target experiment on the PALS facility. *High Temp. Mater. Processes* **7**, 319–326.

Pisarczyk, T., Borodziuk, S., Demchenko, N.N., Guskov, S.Yu., Kalal, M., Kasperczuk, A., Kondrashov, V.N., Limpouch, J., Pisarczyk, P., Rohlena, K., Rozanov, V.B., Skala, J. & Ullschmied, J. (2004). Energy transfer and shock wave generation at the collision of laser-driven macroparticle. *Proc. 28th ECLIM*.

Poletti, G., Orsini, F., Batani, D., Bernardinello, A., Desai, T., Ullschmied, J., Skala, J., Kralikova, B., Krousky, E., Juha, L., Pfeifer, M., Kadlec, C., Mocek, T., Präg, A.R., Renner, O., Cotelli, F., Lamia, C.L. & Zullini, A. (2004). Soft X-ray contact microscopy of nematode Ceanorhabditis Elegans. *Eur. Phys.* **30**, 235–241.

Präg, A.R., Mocek, T., Kozlova, M., Rus, B., Jamelot, G. & Ros, D. (2003). on the stability of the X-ray laser beam quality using a half cavity. *Europ. Phys. J.* **22**, 31–40.

Ros, D., Mocek, T., Rus, B., Joyeux, D., Präg, A.R., Kozlova, M., Carillon, A., Phalippou, D., Ballester, F., Jacques, E., Boussoukaya, M. & Jamelot, G. (2002). XUV interferometric diagnostic of thin Niobium layer under high electric field using the new zinc X-ray laser at PALS. *8th Int. Conf. on X-ray Lasers*, Aspen, CO, USA, May 27–31, 2002.

Rosmej, F.B., Renner, O., Krousky, E., Krousky, E., Wieser, J., Schollmeier, M., Krasa, J., Laska, L., Kralikova, B., Skala, J., Bodnar, M., Rosmej, O.N. & Hoffmann D.H.H. (2002). Space-resolved analysis of highly charged radiating target ions generated by kilojoule laser beams. *Laser Part. Beams* **20**, 555–557.

Rus, B., Mocek, T., Präg, A.R., Lagron, J.C., Hudecek, M., Jamelot, G. & Rohlena, K. (2001). X-ray laser facility at the PALS Centre. *J. Phys. IV* **11**, 589–596.

Rus, B., Mocek, T., Präg, A.R., Kozlova, M., Jamelot, G., Carillon, A., Ros, D., Joyeux, D. & Phalippou, D. (2002*a*). Multi-millijoule, highly coherent X-ray laser at 21 nm operating in deep saturation through double-pass amplification. *Phys. Rev. A* **66**, 063806–12.

Rus, B., Mocek, T., Präg, A.R., Kozlova, M., Jamelot, G., Carillon, A., Ros, D., Joyeux, D. & Phalippou, D. (2002*b*). Multi-millijoule, highly coherent X-ray laser at 21 nm as a routine tool for applications. Invited talk at the *8th Int. Conf. on X-ray Lasers*, Aspen, CO, USA, May 27–31, 2002.

Rus, B., Kozlova, M., Polan, J., Präg, A.R., Stupka, M. & Mocek, T. (2004). Development and user applications for soft X-ray lasers at PALS. *15th GCL/HPL Conf., Prague*, invited paper S10-2.

Straka, P., Turcicova, H., Rohlena, K., Rus, B., Skala, J., Kralikova, B., Ullschmied, J. & Jungwirth, K. (2002). Proposed upgrades of the laser system PALS: From a novel solid-state oscillator toward petawatt. *Czech. J. Phys.* **52-D**, 368–374.

Straka, P., Turcicova, H., Skala, J., Kralikova, B., Dostal, J., Rohlena, K., Ullschmied, J. & Jungwirth, K. (2003). High power hybrid laser with an optical parametric oscillator and gaseous amplifiers. *Proc. CLEO 2003 and QELS 2003 Conference*, Baltimore, USA, June 2003, p. 211.

Torrisi, L., Gammino, S., Mezzasalma, A.M., Badziak, J., Parys, P., Wolowski, J., Woryna, E., Krasa, J., Laska, L., Pfeifer, M., Rohlena, K. & Boody, F.P. (2003). Implantation of ions produced by the use of high power iodine laser. *Appl. Surf. Sci.* **217**, 319–331.

Turcicova, H., Dostal, J., Kocourkova, G., Knyttl, J. & Skala, J. (2004). Solid-state-gas-laser SOFIA as a pump for the optical parametric chirped pulse amplification. *15th GCL/HPL Conf. Prague*, oral paper S5-5, to appear in SPIE proc.

Wolowski, J., Badziak, J., Boody, F.P., Hora, H., Hnatowicz, V., Jungwirth, K., Krasa, J., Laska, L., Parys, P., Perina, V., Pfeifer, M., Rohlena, K., Ryc, L., Ullschmied, J. & Woryna, E. (2002). Fast ion emission from the plasma produced by the PALS laser system, *Plasma Phys. Control. Fusion* **44**, 1277–1283.

Wolowski, J., Badziak, J., Boody, F.P., Gammino, S., Jungwirth, K., Krasa, J., Laska, L., Mezzasalma, A.M., Parys, P., Pfeifer, M., Rohlena, K., Torrisi, L., Ullschmied, J. & Woryna, E. (2004). Laser-produced ion streams useful for technological applications. *Proc. 28th ECLIM*.