Sheet laser lightning in Prague

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In order to stop a painful brain drain and to make the domestic research career more attractive for young physicists, the Czech science policy makers promote natural centres of excellence formed around groups of the most experienced scientists or around key research facilities. In the year 2000, several selected Czech Research Centres gained substantial additional financial support from the Ministry of Education, Youth and Sports of the Czech Republic. One of them, the Laser Plasma Research Centre in Prague, has already gained a good reputation throughout laser Europe. Its key laser facility, the Prague Asterix Laser system (PALS), lists now among the European Major Research Infrastructures. This first international multi-user high-power laser system in Europe's newly associated countries, and a European LASERNET member, celebrated recently its second anniversary.

The PALS's predecessor, the German Asterix IV high-power iodine laser, had already gained a good renown among the European laser plasma research community in the first half of the nineties of the last-century. Developed at the Max-Planck-Institut für Quantenoptik in Garching by Munich and operated there successfully since 1991, the laser suddenly faced a serious decision about its further destiny in spring 1997. Since that time it turned out that saving it for further use was very wise, and that moving the laser to Prague was really a coup for its new mother institution, the Academy of Sciences of the Czech Republic (AS CR). Due to its unique features, several new options and some principal innovations, the reincarnated Asterix/PALS facility is enjoying now a permanently increasing interest of both domestic and foreign researchers.

The risky operation of the laser transfer to Prague began in late summer 1997, with an ambitious goal to put the giant laser into full operation again by spring 2000. At that time, very few people believed that the tight schedule of all the necessary operations could be maintained. For instance, in the Czech Republic no suitable housing for the laser was available. It had to be projected and built first. Nevertheless a rather small group of Czech enthusiasts managed to cope with all the obstacles that came up and fulfilled the virtually impossible. A new laser hall for the laser grew up almost overnight, the reassembling of the laser was finished and its operational tests started in late 1999, and the laser reached its full parameters in May 2000. In September 2000, the laser started to offer its beam time to European physicists.

PALS is a single-beam kilojoule-class pulsed laser. Its kilojoule output, together with a relatively long pulse (~400 ps), make it a powerful driver for various practical applications. Unlike the other, mostly solid-state, high-power lasers in Europe, PALS has an iodine gaseous medium, which gives it some unique advantages. It generates a high-quality infrared beam of an almost flat intensity profile. A single-beam configuration of a chain of laser amplifiers permits the variation of the output beam energy over two orders of magnitude. The fundamental frequency of the beam (1315 nm) can be up-converted to the 2nd, 3rd and even to the ultraviolet 4th harmonics. The laser pointing is stable over two-months, its operation is relatively cheap. Due to all the above features, PALS is almost ideally suited for the basic and applied studies of laser interaction with matter at power density levels ranging from 10^{14} to 10^{16} W/cm^2.

Although the PALS laser still keeps the original configuration of the former Asterix, it has been upgraded by new beam lines and diagnostics options. A new original-concept twin target chamber with several beam focusing assemblies has been designed in co-operation with French laser specialists, which permits the performance of even the most sophisticated laser plasma experiments, such as development and applications of plasma soft x-ray lasers.

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Current PALS main research priorities are aimed at exploiting the laser plasma as a source of soft x-radiation, of highly charged ions, and at relevant scientific applications. As a users facility, PALS is offering its beam time to both domestic and foreign researchers. Since September 2000, the laser is being intensely exploited by scientists from France, Germany, Italy, Poland, Russia, Slovakia, and The Netherlands. Eighteen research projects in total, proposed both by domestic and foreign research groups, have been already performed at PALS during the years 2000-2002, and a number of new ones are planned. The research projects for PALS are peer-reviewed by an international User Selection Panel, the best projects for EU member and newly associated states being recommended for support by the European Commission's 5th Framework Programme (Transnational Access to Major Research Infrastructures and INTAS projects). Most of the projects already supported follow two main research lines: development of ultra-bright x-ray sources, of the soft x-ray

▶ **Photo:** The PALS twin target chamber. Josef Krasa (PALS ion group) adjusting diagnostics for an experiment with laser ion sources.

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▲ **Photo:** View of the chain of PALS laser amplifers, with an oscillator block in the foreground.

lasers in particular, and development of laser plasma ion sources. The diverse PALS research programme includes also various basic laser plasma studies, such as x-ray spectroscopy, multi-frame laser interferometry and soft x-ray dosimetry, and also investigation of laser-generated shock waves and gas discharges.

As for the current PALS x-ray projects, their main motivation is a number of emerging applications of laser x-ray sources in science and (high) technology. Recent research highlights include development and application of a highly coherent double-pass XUV laser based on Ne-like zinc, x-ray contact microscopy of living biological objects, and encouraging results on x-ray-induced ablation. Undoubtedly, the greatest success for the PALS laser laboratory is last year's launching of an extremely brilliant pulsed zinc soft x-ray laser, by a group of Czech and French scientists headed by B. Rus (PALS) and G. Jamelot (LSAI Orsay). High-quality x-ray interferograms, obtained with the PALS x-ray laser in a subsequent application experiment – in the first successful experiment of this kind – testify not only to a high spatial coherence of the x-ray laser beam, but also to the high qualities of the PALS laser used as driver. The output power of the PALS x-ray laser is probably the highest ever achieved in laboratory, at least in the soft x-ray region in question. Another group of the laser x-ray sources studied at PALS, namely point sources of non-coherent x-radiation with characteristic photon energies ranging from tens up to hundreds of eVs, is finding its application e.g. in soft x-ray microscopy for biologists, or in extreme ultraviolet lithography, long called for by the electronics industry. Another great challenge consists in exploiting ultra-bright laser x-ray sources in future nano-technologies, for instance in nanomachining of various materials or in controlled modification of their surface structure.

The main goal of the PALS ion projects is to develop flexible laser ion sources for industrial ion implantation, and powerful ion injectors for future particle accelerators. The laser ion sources (LIS) generate ions with practically any atomic number, in particular heavy ions with a very high charge ($Z > 50$), and with energies ranging up to several tens of MeVs. The high ion energy, high current values and partial directionality of the generated ion streams make the LISs very attractive in competition with conventional ion sources.

It not possible to recount here all the experiments performed or to be performed at PALS and, thus, we have to refer just to a regularly updated list of the PALS projects and their outputs at the PALS homepage www.pals.cas.cz. Nevertheless, let us mention at least one more project, the goal of which is to simulate the effects of impacts of extraterrestrial bodies and of the radiation of the young Sun in the deep past of the solar system with, perhaps, some relations to the origin of life. In these experiments the PALS laser beam is used for plasma generation in a mixture of gases, the composition of which is similar to that of early planetary atmospheres. A number of organic compounds have been already found in the investigated samples.

In order to meet the requirements of even the most exacting future projects, several substantial upgrades of the PALS performance are being prepared, which include e.g. application of the elements of adaptive optics, replacement of the original iodine oscillator by a solid-state based one, and, most importantly, implementation of the optical parametric chirped pulse amplification (OPCPA) technique. A new compact solid state front-end will enhance the variability of the laser pulse width and will make it possible to increase the pulse repetition rate. The controlled feedback adaptive mirrors inserted in the laser beam path are intended to remove some residual wave front aberrations, and to further improve the beam quality, in order to achieve focal power densities of around 10^{17} W/cm^2.

The OPCPA implementation, for which the PALS iodine laser is particularly suitable, should make it possible to boost the PALS power up to the ultra-high-power domain (10 TW – 1 PW). In a projected system, the seed signal pulse with a sufficiently broad spectrum will be generated by a minute Ti:Sapphire oscillator and chirped in a pulse-grating stretcher. Non-linear crystal amplifiers (LBO, KDP), pumped by the blue (3ω) PALS beam, will parametrically amplify the chirped pulse to a level of 100 J. The optical compression of the chirped pulse is expected to compress the output pulse into the femtosecond domain (20-40 fs). This would result in a power density on the target exceeding even 10^{21} W/cm^2.

Direct application of OPCPA at PALS would reduce significantly the available beam time, which is severely limited now, owing to all the current PALS user activities. Therefore a new, smaller-scale, hybrid laser SOFIA (λ=1315 nm) is being currently built. SOFIA is an acronym for a hybrid laser chain, in which a nanosecond laser beam, generated by a solid-state oscillator, is amplified in a gaseous laser medium of iodine photodissociation laser amplifiers (Solid-state Oscillator Followed by Iodine Amplifiers). The upgrades tested with the SOFIA laser will not only speed up their implementation at PALS, but also reduce the final costs. The SOFIA laser is scheduled to run before the end of 2003. If successful, it will take over the role of PALS in the first step to petawatts.

Having successfully passed its first baby steps during the first two years of its operation, the Prague Asterix Laser System has grown up into a flourishing adolescent. Being more mature with each laser shot, it stands already on its own feet, having become a recognised partner of its laser pals. Looking around now, PALS has chosen the way leading to ultrahigh power in general and to ultra-bright x-ray sources in particular. This way will no doubt be far from easy and will be hard to accomplish without a continuing mutually-advantageous co-operation with European partners, and also with partners outside Europe. Nevertheless, the die is cast. For the sake of all your present and future users, sail in PALS!