High repetition rate laser systems: targets, diagnostics and radiation protection

Leonida A. Gizzi[a], Eugene Clark[b], David Neely[c], Luis Roso[d], Martin Tolley[c]

[a]Intense Laser Irradiation Laboratory, CNR, Pisa, Italy & INFN, Pisa, Italy
[b]Dept Electronics, Technological and Educational Inst of Crete, Chania 73133 – Crete, Greece
[c]Central Laser Facility, Rutherford Appleton Laboratory, STFC, Chilton, Didcot, UK
[d]Centro de Laseres Pulsados Ultracortos Ultraintensos (CLPU), Salamanca, Spain

Abstract:: Accessing the high repetition regime of ultra intense laser-target interactions at small or moderate laser energies is now possible at a large number of facilities worldwide. New projects such as HiPER and ELI promise to extend this regime to the high energy realm at the multi-kJ level. This opportunity raises several issues on how best to approach this new regime of operation in a safe and efficient way. At the same time, a new class of experiments or a new generation of secondary sources of particles and radiation may become accessible, provided that target fabrication and diagnostics are capable of handling this rep-rated regime. In this paper, we explore this scenario and analyse existing and perspective techniques that promise to address some of the above issues.

Keywords: **ultraintense lasers, laser-plasma interactions**.

PACS: 52.38.-r Laser-plasma interactions, 52.57.-z Laser inertial confinement, 52.59.-f Intense particle beams and radiation sources, 52.70.-m Plasma diagnostic techniques and instrumentation

INTRODUCTION

Developments in the field of high power lasers lead to ever increasing peak energies (NIF[1], LMJ[2]), intensities(LULI[3], FIREX[4]), and higher repetition rate systems (ELI[5], HIPER[6], GEMINI[7], POLARIS[8], FLAME, etc.), is giving unprecedented opportunities for laser-plasma sciences to conceive a new class of experiments that call for a significant development of experimental target areas. At the same time, these areas are required to meet with radiation protection requirements set by the complex experimental configurations and by the ever increasing laser intensity. At a European level, these aspects have mostly been faced at a single laboratory level and have attracted significant resources. The launch of large collaborative programmes like HiPER and ELI is now leading to a more collective approach in which information, problems and possible solutions are being shared. HiPER and ELI are now preparing the construction of large scale laser infrastructures for applications to laser fusion (HiPER) and to laser-matter interactions in the ultra-relativistic regime of $>10^{23}$ W/cm². Both programmes aim at large laser systems capable of repetitive operation in the range between 1 and 10 Hz and based upon Diode Pumped Solid-State Laser technology. In the mean time, demonstration beam lines are being conceived to prove scalability of this technology from the existing sub-100 J- 10 Hz operation to the few-kJ level. Under these circumstances there is an increasing need to develop a new generation of experimental target areas, equipped with high rep-rate target handling systems and advances diagnostics capable of coping with the significant volumes of data which will be generated.

These requirements are already limiting the development of specific applications of laser-driven X-ray sources and laser-particle acceleration. In fact, laser systems based upon standard flashlamp pumping of Ti:Sa amplifiers are already capable of delivering repetitive operation at a sufficient energy, though at a low efficiency, to enable genera-

CP1209, *The 2nd International Conference on Ultra-Intense Laser Interaction Science – ULIS 2009*
edited by A. Gamucci, A. Giulietti, and L. Labate

tion of X-ray radiation using all-optical schemes like Thomson scattering[9] or GeV electron acceleration[10]. Indeed, the growing interest of the particle accelerator community for a practical exploitation of laser-driven acceleration for the future generation of particle accelerators and the strong convergence of the synchrotron radiation and X-ray free-electron laser community on femtosecond, high field physics, is giving thrust to the installation of medium and high energy laser systems integrated in LINAC and FEL laboratories. This opportunity is now becoming a reality that calls for significant improvement in handling higher repetition rate than those typically used in a typical laser-plasma interaction experiment.

An example of a facility in which this high-repetition approach is being pursued is the FLAME [11]laser facility at LNF, Frascati. Here, the 10 Hz, 300 TW Ti:Sa laser system and the 10 Hz, 150MeV SPARC[12] linear accelerator are meant to be combined together to investigate electron acceleration with external injection as well as production of tunable X-ray radiation from Thomson scattering for bio-medical applications. In the first case, continuous operation at the 10 Hz regime is a requirement for a credible demonstration of the potential impact of lasers in the field of particle acceleration. In this perspective, a reliable repetitive or continuous operation of a gas target with suitable geometrical and physical properties must be developed, starting from state of the art gas-jet technology or capillary discharge waveguides[13]. In the second case, the repetitive operation is required to achieve the X-ray photon fluxes required for practical applications in medical diagnostics.

In the following we will review some of these issues, with particular attention to diagnostic techniques and targets, describing possible approaches to high repetition rate data and exploring new promising techniques for production of targets. Prior to these, we will focus on present and perspective requirements of experimental target areas for radiation protection set by repetitive operation of laser-target interaction at ultra-high intensity.

1. SAFETY FIRST

Accessing the high repetition regime of laser-target interactions requires a detailed knowledge of the safety issues concerning radiation protection. The key issue here is a proper knowledge on the expected source term. A possible approach here is to look at the way radiation safety and protection is handled in other existing facilities providing radiation or high energy particles for experiments, like synchrotrons, FELs, conventional accelerators. This approach, however, should take into account the large variety of possible experimental configurations that can be conceived with multiple, high-energy laser beams. In fact, each of these configurations may give rise to a different source term, which will require specific measures for radiation protection. This is a challenging task that requires convergence of expertise from different fields, including the energy physics, accelerator and high power lasers communities.

A code which is generally suitable for shielding calculations is the MCNPX code[14]. In this code 3D geometries can be specified to build a model of the target area and particles of a particular type, direction and spectrum can be injected into the geometry from a specified position and tracked through the geometry. MCNPX incorporates models to transport electrons, photons, neutrons, protons, pions and other exotic particles through cold static materials. Of course, all the basic single particle/photon interaction physics is considered and the secondary particles expected to be produced from the primary particles are also tracked. The code incorporates Monte Carlo methods and models the transport of particles through user defined geometries. The whole body dose to a human in all regions of the geometry can be calculated. MCNPX is capable of proton and neutron transport well beyond the TeV energy level and can transport photons to energies of the order of 100 GeV but, it is limited to the transport of electrons up to an energy of 1 GeV. Given the potential source terms anticipated for future high intensity laser facilities, there is a necessity to used codes developed for radiation shielding of high energy physics facilities. The FLUKA code[15] [18] is such a code and it is useful for considering the shielding of facilities that can generate multi GeV electron beams.

An example of such an MCNPX calculation is given in Figure 1, where radiation dose is calculated for a simple source term (high energy electrons are only considered for this example), typical of a laser-driven electron acceleration experiment at low laser energy[16] for a single shot.

Calculations like these give expected radiation doses as a function of the position in the laboratory in a full 3-D model which can be modelled with high accuracy in terms of geometrical and physical parameters using CAD based interfaces. Once calculations like these are checked against the maximum allowed dose of 20 mSv/year for registered Radiation workers (50 mSv/year in the USA), it is possible to estimate the maximum number of shots allowed for a given configuration/facility. During facility commissioning, the source term/dose would then need to be measured and confirmed before commencing routine operations.

By using this approach, detailed design of future high-energy, high rep-rate facilities can be performed, provided the specific interaction geometry is defined and proper modelling of the physics involved is carried out. Of course, as the interaction intensity increases new interaction physics takes place and cofirmation must be undertaken during facility commissioning and that the source term is accurate.

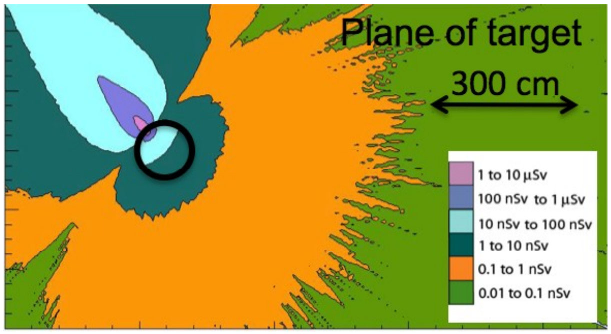

FIGURE 1 Example of calculated dose for a typical small-scale laboratory assuming as a source term a bunch of 10^9 laser accelerated electrons at 20 MeV with a 10 deg divergence. Also visible in the image is the steel target chamber, represented by a black circle.

For the proposed HiPER facility, in addition to the main fusion campaign, a fundamental science experimental activity is planned. For the case of fusion experiments, the source term will be determined with high accuracy based on full-scale numerical simulations and forthcoming experiments at the National Ignition Facility. In the case of basic science experiments, the geometrical and physical configuration of laser beams, targets and diagnostics is expected to change according to the experiment to be performed and each experimental campaign will present itself with a source term of primary particles whose radiation shielding requirement will have to be assessed.

Radiation shielding modelling has been applied to the proposed 10 PW upgrade of the VULCAN laser facility at RAL. MCNPX and FLUKA modelling has been performed using source terms consisting of 2 nC 12 GeV electrons and 10^{10} 0.5 to 1.5 GeV protons. Such an electron beam could be dumped in a specially designed electron and muon dump with associated shielding for secondary particles. Finally, a concrete bunker extension will be built on to the existing target area surrounding the beam dump. Provision for additional shielding to accommodate alternative experimental geometries must also be included in the design of the shielding. As new facilities with higher laser powers and different interaction geometries are constructed, detailed source term, activation and shielding calculations must be carried out and verified to ensure a safe working environment can be provided.

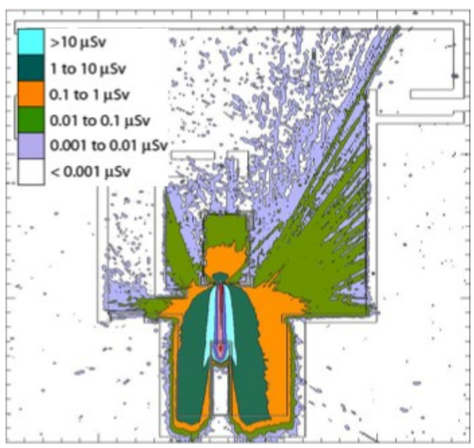

FIGURE 2. Example of calculated dose for a typical medium-scale laboratory like the proposed 10 PW upgrade of the Vulcan laser at RAL, assuming as a source term a bunch of 12 nC of laser accelerated electrons at 2 GeV with a 1 deg divergence. Visible in the image is the rectangular target chamber, the electron beam dump and the concrete walls surrounding the target area.

A plot of the whole body dose through the horizontal plane of the interaction due to all particles including electrons, photons, neutrons, pions and muons is shown in . Using tools such as MCNPX and FLUKA, a facility like the Vulcan 10 PW can be designed for a safe single shot operation in the case of a well directed electron bunch with a properly positioned beam dump. The use of these radiation transport codes for shielding applications for high energy laser facilities is now a necessity given the rapid progress in focused laser intensities and the penetrating nature of the particles that are produced in these interactions.

2. DIAGNOSTICS

Transition from single shot diagnostics typically used in laser-plasma experiments to higher repetition rates requires high through-put data transfer detectors. In addition, in the case of ultra-high intensity lasers, a critical issue is the protection from electromagnetic pulse (EMP). Existing general purpose hardware, in most cases, is dramatically affected by EMP, either directly or indirectly due to failure of electronic systems. A possible way out typically used in X-ray spectroscopy measurements at large laser facilities has been to use simpler image detectors based upon dose sensitive detectors like radiochromic films or image plates which, unfortunately, strongly limit the possible repetitive mode. In some cases, phosphor screens coupled to optical imagers, are a valid alternative, especially when looking at electron bunch cross section in electron acceleration experiments.

2.1 Future diagnostic needs of high power laser systems

The diagnostics can be broadly divided into two categories: system and experimental interaction. In general, the system or laser performance diagnostics are semi-permanent in nature, some existing almost unchanged during the lifetime of a facility examining parameters such as beam energies, temporal profile, spectral bandwidth, near fields and far fields, whilst some[17] are developed typically over timescales of a few months to years to meet new performance criteria i.e. contrast[18]. The experimental laser plasma diagnostics typically change on a much more rapid basis than laser diagnostics and must also be capable of operating in the challenging experimental environment where, significant electro magnetic noise[19] or radiation sources[20] are routinely present.

2.2 Noise immunity for Data Acquisition

Experimental laser plasma interaction information currently consists of a large number (~5-30 per shot) of digital, particle and film based detector [21] systems acquiring data on each shot or integrating over a number of shots. As the intensities and energies on target have increased, the associated laser plasma shot noise has grown non-linearly. To enable reliable data acquisition, systems immune to shot noise are required. Four specific routes have been commonly adopted by many facilities to provide a suitable solution,

(i) Improved hardware immunity to noise,

Investigations have demonstrated that using electromagnetic shielded enclosures, low pass filters and on chip CCD integration avoids some of the difficulties associated with acquiring digital data as the laser is fired. Also, as the experiments push closer to limits of sensitivity and resolution, detectors capable of delivering higher performance are required. Newer CCD's have higher pixel density and operate at faster clock rates providing higher resolution and faster read-out than before. However, acquiring multi Mega pixel 16 bit data at ~1 Hz is currently at the limit of data acquisition and transfer rates. Data transfer by optical fibre directly from the detector can avoid some of the issues.

(ii) Noise immune detectors

For low repetition rate systems, particle and film data such as radiochromic film or CR39 provide a cost effective solution to acquiring data. The information is processed subsequently to a shot on time scales of hours to weeks. As such systems typically require no triggering they are usually highly flexible and simple to implement and are totally immune to electro magnetic noise. However, such systems are generally unsuitable for high repetition rate data acquisition, but are suitable for multi shot or signal integration over long periods.

(iii) Active probes

As the interaction conditions have become more extreme, brighter[22] and new laser generated secondary sources[23] have been employed to probe the plasma conditions[24]. K_a and X-ray sources have long been used for radiography or X-ray absorption and more recently for scattering studies[25]. Source development in these areas will be essential to enable probing of denser and hotter plasma regions in the future.

(iii) Signal transducers to convert and transfer the signal to a more benign area for digitisation.

Scintillator and phosphors are two of the most commonly used transducers in laser plasma experiments which have been used to convert X-rays, ions, electrons or neutrons into optical signals which can then be read out on suitable detectors. As issues with electro magnetic noise and penetrating γ-ray radiation have become more prevalent, the optical signal can be relayed out to a more benign environment before being digitised. Long term stability and lifetime issues are a consideration with such systems but this can be overcome by improved transducer materials, diagnostic design and ongoing calibration. The use of transducers in higher intensity, higher repetition rate laser plasma investigations is a trend which will increase as more extreme environments are studied.

2.3 Requirements for data management

For current Nd:glass laser systems, typically a few thousand shots are delivered per year[26] with each shot easily generating between 10–200 MB of digital information. With the new Ti:Sapphire and diode pumped lasers presently coming on line, a 10-1000 fold increase in the amount of data is expected and will require new methods of data processing and storage with data streaming rates of ~ 20 MB/sec being typical.

A data management system capable of automatically acquiring, cataloguing backing-up and storing digital format data on shots and during off-line calibration will be required. Such systems must automatically acquire each piece of data immediately after a shot and must information stamp each record. A data management system capable of providing the users with an interface to a manageable database must also be provided. It is essential that the users are able to easily exploit the information recorded on each shot in an efficient way if the full scientific potential of future facilities is to be exploited i.e. providing feedback on the acquired data to highlight potential acquisition failure or saturation etc. of data channels within set limits.

2.4 Future diagnostic trends

With the developments in the field of laser matter interactions the demands on experimental data acquisition have also increased both in terms of quality and reliability. Ensuring that high quality data is obtained on experiments is essential to maintaining progress in this highly demanding field. For the highest intensity systems, new experiments (i.e. photon – photon scattering and QED studies) will require signal averaging over many shots to ensure high quality data. In such systems, batch processing automated analysis capability and efficient data portals to enable good access and manipulation of the data will be essential to ensure that data can be simply extracted, correlated and displayed. For systems built to deliver programmatic aims (i.e. Fusion studies, accelerator development, secondary sources) diagnostic demands will continue to expand as the field develops. As future high repetition rate laser facilities become capable of delivering many more experimental shots in a given period, it is likely that producing sources of radiation or particles for secondary studies will become more common in the ultra intense laser field. In this case, the provision of secondary beam monitoring diagnostics will eventually become routine and such diagnostics will rapidly become to be considered by the new user community as system diagnostics as is now standard in the synchrotron community.

3 MICROTARGETRY FOR HIGH REP. RATE, ULTRA HIGH POWER LASERS

3.1 Impact on targetry by moving to high repetition rate

As previously discussed in this paper anticipated developments in the field of high power laser systems will give increasing peak energies, increasing intensities and higher repetition rates. The most significant impact for microtargetry will almost certainly arise from the increase in repetition rate (with increases of target production and delivery numbers of three to four orders of magnitude anticipated over the next few years). Early experience in the Central Laser Facility at the Rutherford Appleton Laboratory with fielding high repetition rate experiments on the GEMINI laser[27] and work on the HiPER project 6 has already given valuable insight into several important microtargetry issues and some of the main lessons learnt are summarised in the following sections. Perhaps the single most important observation is the necessity to integrate microtarget production solutions with microtarget delivery solutions.

3.2 High repetition rate microtarget production

Several techniques are well established for high repetition rate targetry most notably; gas jets, tape drives and droplet generators. However, the techniques have (differing) limitations, most notably target geometry and complexity. Additionally, complex 2D and 3D targets in many designs have been requested for high repetition rate experiments. The following sections of 3.2 briefly summarise some of the work which has been done to produce solid targets for high repetition rates.

3.2.1 Thin and ultrathin foil targets

Thin foils can be coated onto substrates treated with releasing agents. Such foils can then be floated off onto the surface of water and subsequently lifted from the surface onto a suitable mount, typically having through holes. It has been possible to develop a mount that enabled simultaneous mounting over an array (for example 5 x 5) of holes giving multiple thin film targets. Some of the challenge in these techniques are to ensure that the foils are sufficiently flat. Complex multilayer foil target arrays have been similarly prepared. It has also been possible to produce ultrathin foils (thinner than 50nm) in a range of materials (with the thinnest, although not in arrays, of 2.5 nm carbon).

3.2.2 Ultraprecision CNC Milling

Using ultra high precision micromachining it is possible to produce high aspect ratio 3D microparts with submicron accuracy. The technique has been developed at RAL to produce microparts (for example AFI cones) in batches with high yield.

3.2.3 Micro-assembly

In the past microtarget assembly time has not frequently been a limiting factor for experiments since microtargets could usually be produced at rates suitable for HPL system repetition rates. However, this is no longer the case and automated microassembly using microrobotics was trialled. Introducing the technology proved to be a significant technological challenge. One of the main lessons learned was to redesign microtargets where possible, particularly by machining down from solid, to completely remove the need for some microassembly steps.

3.2.4 Wafer-based and MEMS techniques

A series of 2D and 2 1/2D microtargets have been fabricated at RAL using wafer-based MEMS techniques. A good example of 2D microtargets are the silicon nitride membrane targets shot at RAL by Strangio et al in 2006 [28]. (See Figure 3.)

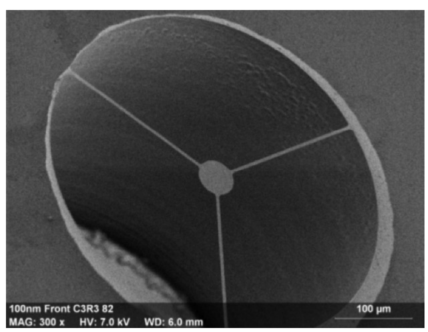

FIGURE 3. Example of microtarget consisting of a 32 µm diameter, 40nm thick silicon nitride membrane, fabricated at RAL using wafer-based MEMS techniques.

Although significant initial expense can be required for MEMS manufacturing the technique does give the possibility of producing (large numbers of) microtargets or microcomponents which it is not possible to produce using other techniques. Additionally, if large numbers are required there can be significant cost savings.

3.3 High rep rate microtarget placement in chamber

With the introduction of high repetition rates high accuracy microtarget placement at matching rates has become a significant technical challenge. Target wheels have been used in many facilities but have significant limitations if several tens of shots are required without breaking vacuum. In a joint collaboration between General Atomics and the CLF an Inserter system (see Figure 4) was developed to meet this requirement. The system comprises a linear arm equipped with grippers that can pick up targets mounted on special carriers and then place them on a hexapod (for accurate positioning) in the interaction chamber. Positional accuracies of a few microns can be achieved. Target carriers are individually identified using a machine readable (2D) bar code.

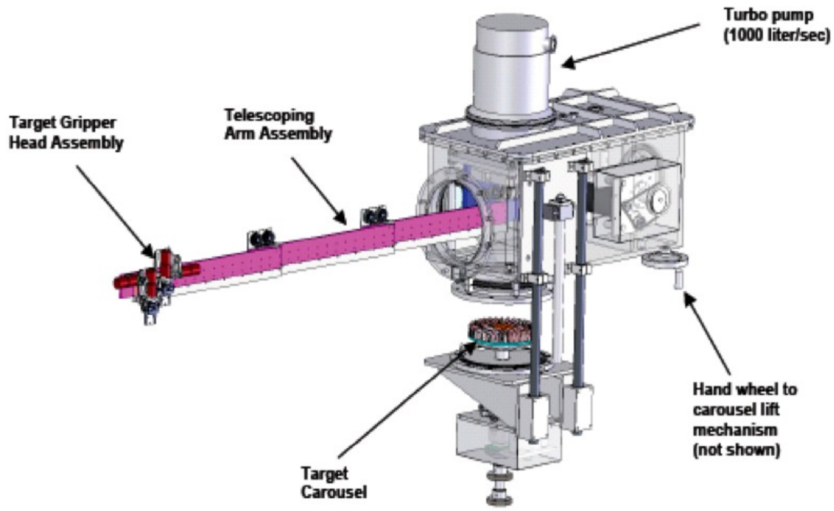

FIGURE 4. Example of a target insertion mechanism developed as a joint collaboration between RAL and General Atomics. Devices like this allow multiple (tens of) targets to be used in a continuous operation.

Future projects, such as HiPER, will almost certainly require the development of Injector technology in which (cryogenic) microtargets will be injected with high accuracy into an interaction chamber reaching their shot position without mechanical support.

3.4 High rep rate characterisation and quality assurance

Several methods of automated metrology already exist in various sectors of industry, for example automated CMMs (coordinate measuring machines). Some of the methods have been directly applied to mass-produced microtarget component metrology. Challenges have particularly arisen for 3D microtargets and this may require the introduction of automation to techniques such as confocal microscopy.

One possibility arising from suitable automated metrology is to store the information as a 3D spatial image (for example). This gives rise to a large amount of metrology data (of the order of 1Gb per target) but there are significant advantages from both reducing the amount of non-automated metrology and also introducing the possibility of *post hoc* characterisation. A sophisticated data management system has been developed to record the characterisation data for each individual target and synchronise it with the relevant individual shot data.

Such high levels of control of individual target data are highly amenable to quality management systems and several microtarget fabrication facilities have already introduced ISO9001, which would be an obvious international standard to use.

3.5 High repetition rate logistics and methodology for targetry

Target production and placement may become a limiting factor in future high rep rate experiments. Accurate insertion/injection of targets is a significant challenge and the solutions are intimately related to microtarget design and production. Also insertion mechanisms introduce further experimental complexity (and possibly extra characterisation). Due to microtarget production times there can be a significant number of unshot targets at the end of a high repetition rate experiment if it does not run smoothly and the ability to make target modifications in reaction to ongoing experimental data is significantly reduced.. Large amounts of metrology data are produced which needs careful control, especially in synchronising with other (shot and diagnostic) data streams. To enable the targetry activities new production and characterisation techniques will be required. For efficient experimental delivery there is a necessity for early and detailed planning of targetry.

4 FORWARD LOOK - GREEN PHOTONS FOR EVEN HIGHER REP. RATES: ANOTHER BOTTLENECK

4.1 Introduction

CPA lasers are optically pumped lasers. It is well known that the only efficient way so far for delivering the fast income of energy necessary for Titanium:Sapphire to lase is by introducing this energy, as a Q-switched laser with the appropriated time duration. We can simplify this limit in a sentence such as "no pump, no laser" to stress the importance of the pumping.

On the other side, now that Terawatt and even Petawatt laser pulses are possible, the current drive is towards higher repetition, producing faster experiments with more data and reducing statistical errors. Up to what extent is this possible?

4.2 Some numbers

To understand the communities perspective considering higher repetition rates, we can prepare some approximate numbers. Imagine you have a 100 TW laser that delivers 2 J per shot with 20 fs duration. Depending of the quality of your system it is reasonable to say that 2 J of infrared energy after compression implies 10 J of green light pump. This therefore requires 20 W of green pump when the 100 TW laser operates at 10 Hz. This equates to a powerful laser at a reasonable energy price. But the laser operates at only 10 Hz, which is fine provided only a few shots are needed to finalise the experimental configuration. At kHz repetition rates this very same laser (assuming the cooling is enough) will require about 2 kW of green (in Q-switched pulses). This begins to be a problem. You need a pulsed laser at high repetition rate with a lot of technical difficulties due to the high average power that goes close to 100 kW electrical power in total (maybe less with modern efficient systems).

But kHz repetition rates are still low compared to other experimental systems. For example, lasers for pump probe experiments with electron accelerators (such as synchrotrons or XFEL's) need to shoot at MHz rates. This implies 2 MW of green pump light, which is impossible for a laboratory. Even working at the TW peak power level, one MHz requires 20 KW of green which is very difficult to achieve.

Most of the systems for pumping Titanium:Sapphire at thesee high energies per pulse use now Nd lasers of different kinds with a frequency doubling crystal and a flash lamp for pumping the Nd ions. So a Titanium:Sapphire laser is a laser pumped by another laser, and this second laser is again pumped by a flash lamp. This is too much pumping to be efficient at large scales and to enter industrial applications.

4.3 The future

For CPA lasers to enter into more applications and eventually into industry, it is necessary to advance in pumping technology. It is necessary to have simpler and more reliable pumping systems, but moreover, it is necessary to have systems that are more efficient than present ones.

Probably the future is going with semiconductor lasers. Semiconductor lasers have entered our lives in the last decade. Today we have several of them at home in gadgets as CD's, DVD's, … Such lasers are efficient and cheap. Even blue lasers have entered our lives increasing the capacity of most advanced DVD's. So what is the problem?

The problem in semiconductor lasers is green: the green problem. Red semiconductor lasers are simple and reliable, at one side of the visible spectrum. Blue lasers are now ready to enter the industry at large scale. So life seems quite pleasant in this respect at both ends of the visible spectrum. The problem is with green light. Today it is very difficult to get directly green light from a semiconductor laser. The present technology of green lasers relies on micrometer wavelength (Infra-red) lasers doubled in frequency. Frequency doubling is a well-known process, but even in the most convenient phase matching situation it implies a lot of losses, unfeasible for large-scale applications. There are two approximations to solve green pumping problem: the indirect and the direct.

What do we mean by indirect solution? If we do not have the right pump for this crystal, then, change the crystal. Since green is necessary to pump Titanium:Sapphire crystals, we can change the crystal and choose one that emits in the infrared beyond one micrometer and uses red light for pumping. For most of the ultrashort ultraintense applications wavelength is not an issue. In fact for many acceleration schemes a longer wavelength represents some help. Many laboratories around the world are working in that direction and many improvements are expected soon.

What do we mean by direct solution? We simply mean a new class of efficient green lasers. In a recent review[29] Shuji Nakamura and Michael Riordan present what they call "Green Lasers: The Next Innovation in Chip-Based

Beams". There are new approaches based on the last developments of the semiconductor industry to produce semiconductor lasers that lase directly in the green region of the visible spectrum, without the need of frequency doubling systems. Those lasers, when ready, will represent a significant advance in the laser technology. But the pocket size Terawatt laser is still a long way in the future.

CONCLUSIONS

Laser-plasma science is entering a new phase of medium and large-scale programmes based upon repetitive operation of ultra-high intensity lasers. These programmes call for a coordinated effort in designing experimental target areas capable of exploiting this unprecedented potential. Some of the existing facilities are already hitting the limits of present technology in terms of target manufacturing and handling and performance of diagnostic devices. At the same time, repetitive operation of ultra-intense laser interactions and related high-energy radiation and particle production sets new constraints from a safety viewpoint.

A discussion was presented in this paper anticipating, were possible, recipes for a systematic approach to these critical issues including a safe design of experimental target areas, new concept diagnostics and advanced techniques for target manufacturing and delivery. Some comments on the requirements for pumping lasers are also included.

ACKNOWLEDGMENTS

Thanks in particular to R. Clarke for source term discussions and to the U.K. Engineering and Physical Sciences Research Council, Basic Technology scheme "LIBRA" grant No. EP/E035728/1 for financial support. We also achnowledge contribution arising from MIUR-FIRB project "SPARX" (Sorgente Pulsata Auto-amplificata di Radiazione X), from the MIUR-PRIN-2007 "Studio della generazione di elettroni veloci [...]", from the INFN project: PLASMONX and from the HiPER Project.

[1] https://lasers.llnl.gov/
[2] http://www-lmj.cea.fr/html/cea.htm
[3] http://www.luli.polytechnique.fr/
[4] http://www.ile.osaka-u.ac.jp/zone1/public/publication/apr/2007/pdf/1/1.1.pdf
[5] http://www.extreme-light-infrastructure.eu/
[6] http://www.hiper-laser.org/
[7] http://www.clf.rl.ac.uk/facilities/AstraWeb/AstraMainPage.htm
[8] http://www.physik.uni-jena.de/ioq/Jahresbericht/PDFs/2002/Hein_POLARIS.pdf
[9] H. Schwoerer et al., *Phys. Rev. Lett*. **96**, 014802 (2006)
[10] W. P. Leemans et al., *Nat. Phys*. **2**, 696 (2006).
[11] L.A.Gizzi et al., *Eur. Phys. J. Special Topics* **175**, 3–10 (2009).
[12] D. Alesini, et al., Proceedings of EPAC (Edinburgh, Scotland, 2006), p. 2439
[13] A. Butler, D. J. Spence, and S. M. Hooker, *Phys. Rev. Lett.* **89** 185003 (2002)
[14] JS Hendricks et al, MCNPX, Version 26E Los Alamos Report, LA-UR-07-6632 (2007)
[15] http://www.fluka.org/
[16] L.A.Gizzi et al., Channeling 2008, Science and Culture Series, World Scientific Press, 2009, in press.
[17] P. McKenna et al, *Rev. Sci. Inst* ., **73**, 12, 2002
[18] A. Pirozhkov et al, *Appl. Phys. Lett*., **94**, 241102, 2009,
[19] M. Mead et al, *Rev. Sci. Inst*, **75**, 10, 2004,
[20] C. Stoeckl et al, *Rev. Sci. Inst*, **77**, 10F506, 2006,
[21] , F. Nurnberg et al, *Rev. Sci. Inst*., **80**, 0333 2009,
[22] B. Dromey et al, *Phys. Rev. Lett*., **99**, 085001, 2007
[23] K. Quinn et al, *Phys. Rev. Lett*., **102**, 194801, 2009
[24] A. MacKinnon et al, *Phys. Rev. Lett*., **97**, 045001, 2006
[25] E. G. Saiz et al, *Nat. Phys*., **4**, 940-944, 2008
[26] C. N. Danson et al, *Laser and Part. Beams*, **23**, 1, P87-93, 2005
[27] http://www.clf.rl.ac.uk/facilities/AstraWeb/AstraMainPage.htm
[28] C Strangio et al, *Laser and Part. Beams*, 25, 85-91, 2007, Strangio,
[29] S Nakamura and M Riordan, *Scientific American*, May 2009 issue.