R&D INTO LASER APPLICATIONS FOR ACCELERATORS*

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Abstract

Lasers can be used for the generation of high brightness electron and exotic ion beams, the acceleration of particles with the highest accelerating gradients, as well as for the characterization of many complex particle beams by means of laser-based beam Diagnostics methods. In addition, (free electron) lasers can be used for achieving the highest time resolution and strongest fields for experiments in atomic physics, chemistry and biology, i.e. for studies into the dynamics of some of the most fundamental processes in nature. Without constant progress in laser technology and close collaboration between laser experts and accelerator scientists, many of today's most advanced experiments would simply be impossible. The LA^{3}NET consortium combines developments into laser technology and sensors with their application at advanced accelerator facilities, for the generation, improvement and optimization of a wide range of particle beams.. This contribution presents the consortium's broad, yet closely interconnected experimental program.

INTRODUCTION

As the limits of performance of conventional radiofrequency particle accelerators are reached new methods for particle acceleration and beam optimization are needed. Lasers will play a key role in the development of accelerators by improving the generation of high brightness electron and exotic ion beams and through increasing the acceleration gradient. Lasers will also make an increasingly important contribution to the characterization of many complex particle beams by means of laser-based beam diagnostics methods.

The LA³NET network [1] is built around 17 early stage researchers working on dedicated projects to research and develop a complete spectrum of laser-based applications for accelerators. The network presently consists of an international consortium of more than 30 partner organizations including universities, research centres and private companies working in this field. This will provide a cross-sector interdisciplinary environment for beyond state-of-the-art research and researcher training while developing links and new collaborations.

RESEARCH

Research within LA³NET is distributed in five different work packages: Laser-based particle sources, laser-driven particle beam acceleration, lasers for beam instrumentation, system integration and lasers and photon detector technology. Although each fellow works on an independent research project, there are many links between work packages. The following sections give some examples of research results to date.

Investigations into Cs_3Sb Cathodes for the CLIC Drive Beam Photo Injector

Within the Compact Linear Collider project, a photo injector is an interesting alternative for the drive beam to the baseline design thermionic electron gun. Investigations are currently carried out into both the laser and photocathode. Whilst the available laser pulse energy in the ultra-violet is currently limited by optical defects in the 4th harmonics frequency conversion crystal induced by the 0.14 ms long pulse trains, recent measurements of Cs_3Sb photocathodes sensitive to green light showed their potential to overcome this limitation. Moreover, using visible laser beams leads to better stability of the generated electron bunches, opening up opportunities for using higher quality optics. LA³NET fellow Irene Martini has started investigations into Cs_3Sb photocathodes.

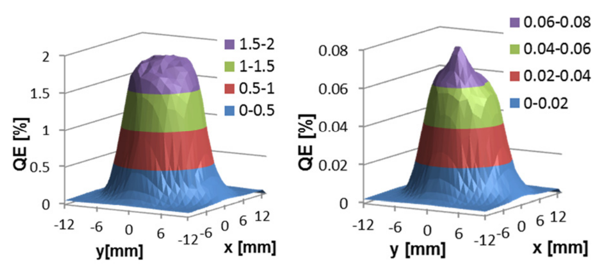

Figure 1: QE map of Cathode #192 before (left) and after (right) measurement at 120 µA.

These cathodes have been produced and characterized at the CERN photoemission laboratory, where a dedicated preparation setup and a 70 keV DC electron gun including a diagnostic beam line are available [2]. For measuring the electron beam current a Wall Current Monitor (WCM), a Fast Current Transformer (FCT) and a Faraday Cup (FC) are installed. Figure 1 shows Quantum Efficiency (QE) maps where scans of the cathode surface with a pencil laser beam have been performed, immediately after cathode production (left) and following high average current measurement (right). It can be seen that the initial flat top distribution experienced an overall QE reduction, which can be attributed to pollution of the cathode due to the beam induced high vacuum level. In addition a peak with QE=0.8% can be observed in the centre of the cathode, where the laser beam hits the cathode. The transversal dimensions of this peak are comparable to the estimated laser beam spot size. Although detailed investigations are on-going a possible explanation of this peak might be the laser cleaning process, which is in

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competition with QE degradation. Similar observations were made previously during high current electron beam production with Cs_2Te and UV laser beams in the same setup [3]. Further details about recent measurements can be found elsewhere in these proceedings [4].

Electron Bunch Shape Detection

Typically, synchrotron light sources use incoherent light in their experiments. Coherent synchrotron radiation arises when the longitudinal electron bunch length is smaller than the wavelength, which can normally only be achieved for relatively long wavelengths in the (sub-) THz regime. Substructures on the electron bunches (micro-bunching) can then lead to strong «bursting» in the emission of coherent radiation. The physics behind these effects is still poorly understood, mainly because it is rather difficult to measure the bunch profile with sufficient temporal resolution.

Figure 2: Photograph of an electro-optic GaP crystal, mounted on its support.

Electro-optic measurement uses the linear electro-optic or so called «Pockels» effect. This effect – usually a change in polarization, which is turned into a change in optical power at a polarizer – can then be measured with a photo detector yielding the bunch signal. Andrii Borysenko is carrying out a project aiming at the realization and use of a high resolution electron bunch shape detection system at the new linear accelerator FLUTE, currently being designed at KIT, Germany [5]. Within his project he is designing and building up an electro-optic system for FLUTE. For this purpose, a system currently being developed for the ANKA ring shall be adapted. In addition, studies into performance limitations with regard to temporal resolution shall be carried out. Figure 2 shows a phot of one of the crystals under investigation.

Fibre Optics Electron Accelerator

Photonic crystals are a promising way to realize an on-chip electron beam source for fundamental radiation biology. They provide a unique combination of nanometre beam size and attosecond-short pulses which would be beneficial for use in microscopic and ultra-fast analyses of damage and repair of radiation-irradiated DNA and chromosomes. Currently, there are three different candidates for photonic crystal accelerator structures: the dual-grating structure, photonic crystal fibres and the woodpile structure. Aimierding Aimidula, a fellow at the Cockcroft Institute/University of Liverpool, UK has started simulation work on a new dual-grating structure, based on work from Plettner [6]. By carefully adjusting the position of the pillars, it can be used to efficiently modify the laser field. The operating principle of this structure is based on a decrease of the phase velocity of the electric field and its synchronization with non-relativistic and relativistic electrons. Different structure geometries have been studied with regard to maximum achievable field gradients and field distribution along the structure.

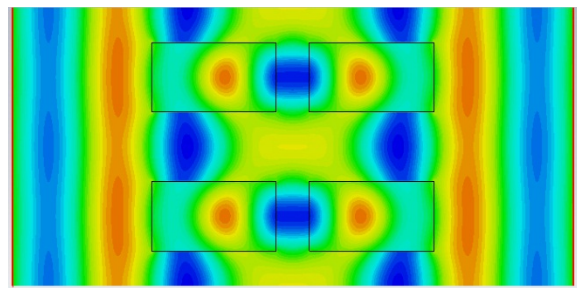

Figure 3: Field distribution as calculated with CST Microwave Studio in dual-grating structure.

With λ being the wavelength of the operating laser, the structure features a lattice length of λ, as well as pillar and vacuum lengths of λ/2. The driving laser light is fed from the two outer surfaces, perpendicular to the direction of motion of the electrons. The laser light then traverses through both vacuum and the grating pillar, leading to different velocities. Thereby the necessary phase delay of π and hence a periodic electric field distribution inside the vacuum channel along the longitudinal beam axis can be generated. Figure 3 shows the z-component of the electric field distribution with z being the direction of motion of the electron beam. Along the vacuum channel, regions of opposite field strength are separated by λ/2 which will allow relativistic electrons to catch up with oscillating electric field and be accelerated.

Optimum pillar height and vacuum channel gap are determined in simulation runs. For electric field calculation CST Microwave Studio was used. It can be seen from Figure 3 that a two side feeding mechanism efficiently decreases the transverse field, i.e. the x-component of the electric field, perpendicular to the direction of travel of the electrons, which is unusable for longitudinal acceleration. A laser wavelength of 1,550 nm was chosen for all simulations. Several dielectric materials have good transparency at this wavelength and the final material is chosen on the basis of its transparency range, the electric field damage threshold, its thermal conductivity, nonlinear optical coefficients, chemical stability and refractive index. In the first studies silicon was used, which has a refractive index of n=1.527. Detailed results can be found in [7].

TRAINING EVENTS

Training of all LA³NET fellows will be mostly through specific project-based research realized by the respective host institutions with specific secondments to other partners for specialized techniques and cross-sector experience. In addition, the consortium will organize a number of network-wide events that will be open to the wider community, including schools, topical workshops, as well as an international conference and symposium in the project's final year.

International Schools

A first international school on laser applications at accelerators was held at GANIL in Caen, France between October 15^{th}-19^{th} 2012. 80 participants from inside and outside the LA³NET Consortium were introduced to the state of the art in this dynamic research area.

This five day event followed the successful format pioneered in the DITANET project [8, 9]. Lectures covered topics such as introduction to lasers and accelerators, beam shaping, laser ion sources, laser acceleration, laser based beam diagnostics and industrial applications. In addition there were study groups, poster sessions and two evening seminars on major international initiatives in the laser and light sources field. Several prizes were awarded during the school. Jurjen Couperus (HZDR, Germany), Kyung Nam Kim (Kongju University, South Korea) and Andrii Borysenko (KIT, Germany) all received prizes for excellent poster contributions. The annual LA³NET prize of 1,000 € for an outstanding contribution to the field of laser applications at accelerators by an early stage researcher was awarded to Dr. Sebastian Rothe (U Mainz, Germany). The call for applications for the 2013 prize has recently opened with a deadline of 30.6.2013. Full application details can be found on the LA³NET web site.

A second school will be held in autumn 2014 at CLPU, Spain and will cover advanced laser and accelerator technologies, in particular the combination of different fundamental techniques.

Topical Workshops

The first LA³NET Topical Workshop covered laser based particle sources and was held at CERN attracting nearly 50 researchers from Europe and beyond. CERN provided the ideal location for the workshop being a centre of expertise on the production of electron beams with photo injectors and resonance laser ionization of radioactive isotopes. This expertise was complemented by the invitation of 10 international renowned speakers to give 40-minute talks on their current research in this area. An additional 22 delegates delivered shorter oral presentations providing the perfect balance of talks on the generation of electron and ion beams using laser methods. Among these speakers were LA³NET fellows Jose Luis Henares from GANIL and from CERN Irene Martini and Thomas Day Goodacre who also both helped in the organization of the event. LA³NET fellows Pengnan Lu from HZDR and Kamil Nowacki from FOTON also attended the Workshop. The following main topics were covered:

- Lasers and photocathodes for production of high brightness electron beams
- RF and DC photo injectors
- Hot cavity and gas cell ion sources for radioactive ion beam facilities
- Laser systems for efficient resonance ionization
- Optimizing selectivity for RILIS
- In-source spectroscopy of rare nuclides.

All contributions to this event can be found in indico [10].

Conference on Laser Applications

In the last year of LA³NET, a 3-day international conference on R&D in laser applications at accelerators will be organized, with a focus on the methods developed within the network. This event will also serve as a career platform for the network's trainees who will get the opportunity to present the outcomes of their research projects. In addition, a symposium open to the general public will be held at Cockcroft Institute/U Liverpool to promote all research outcomes.

CONCLUSION

Within an international consortium of more than 30 institutions, training of 15 early stage researchers has recently started across five thematic work packages. In this paper, examples from ongoing studies into beam generation, acceleration and diagnostics were given. LA³NET has also delivered successful international training events, such as schools and topical workshops with many more to come in 2013-2015.

REFERENCES

[1] http://www.la3net.eu

[2] E. Chevallay, CTF3 Note 104, CERN (2012).

[3] E. Chevallay et al., CTF3 Note 020, CERN (2001).

[4] I. Martini, et al., "Studies of Cs_3Sb cathodes for the CLIC drive beam photo injector option", Proc. IPAC, Shanghai, China (2013).

[5] N. Hiller, A. Borysenko, et al., „Electro-optical Bunch Length Measurements at the ANKA Storage Ring", Proc. IPAC, Shanghai, China (2013).

[6] T. Plettner, P. P. Lu, and R. L. Byer, "Proposed few-optical cycle laser-driven particle accelerator structure", Phys. Rev. ST Accel. Beams 9, 111301 (2006).

[7] A. Aimidula, et al., "Design of a Photonic Crystal Accelerator for Basic Radiation Biology", Proc. IPAC, Shanghai, China (2013).

[8] http://www.liv.ac.uk/ditanet

[9] G.P. Wall, C.P. Welsch, "Enhancing Post-Graduate Complementary Skills Training", Proc. HEASTEM, Birmingham, UK (2013).

[10] indico.cern.ch/conferenceDisplay.py?confId=212365