FEL R&D WITHIN LA³NET*

C.P. Welsch#, Cockcroft Institute and The University of Liverpool, UK
on behalf of the LA³NET Consortium

Abstract

The detailed diagnostics of the shortest beam pulses in free-electron lasers still pose significant challenges to beam instrumentation. Electro-optical methods are a promising approach for the non-intercepting measurement of electron bunches with a time resolution of better than 50 fs, but suitable optical materials need to be better understood and carefully studied. In addition, adequate timing systems with stability in the femtosecond regime based on mode-locked fibre laser optical clocks, and actively length-stabilised optical fibre distribution require further investigation. These important problems are being addressed within the broader EU-funded LA³NET project by an international consortium of research centres, universities, and industry partners. This contribution gives an overview of the wider LA³NET project and results from initial studies in both areas. It also describes the events that LA³NET will organize.

INTRODUCTION

Lasers will make an increasingly important contribution to the characterization of many complex particle beams necessary for optimising FEL operation by means of laser-based beam diagnostics methods. As the limits of performance of conventional radiofrequency particle accelerators are reached new methods for particle acceleration and beam optimization are needed. Lasers will also 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.

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.

FEL 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 describe research being carried out by consortium Members University of Dundee and STFC in the UK to which LA3NET contributes

EO Bunch Temporal Profile Monitor

Detailed temporal diagnostics of the shortest electron beam bunches in free-electron lasers pose some of the most significant challenges in accelerator beam instrumentation. Electro-optical (EO) methods are a promising approach for the single-shot non-intercepting measurement of electron bunches with a time resolution of better than 50 fs, but new, more reliable methods of measurement require to be developed, and suitable electro-optical materials need to be better understood and carefully studied. These aspects are currently under study in a collaboration between the University of Dundee and STFC Daresbury Laboratory, and is partially supported through the EU-funded LA³NET project [1].

Current techniques, developed over the last decade by the Dundee-Daresbury Group, are based on either spectral or temporal decoding of the Coulomb field of ultra-relativistic electron beams. The former technique is limited to beam bunches around 1 ps [2], while the latter requires ultra-short-pulse lasers that are expensive and potentially unreliable, making them unsuitable for turn-key accelerator control systems. The Group is currently working with the CERN compact linear collider (CLIC) project, with the intention of measuring the 150 fs CLIC main beam bunches to an accuracy of 15-20 fs, and using relatively simple laser systems, which is better than the current state-of-the-art for such measurements.

This work is also of pivotal importance for future advanced light sources, free-electron lasers and laser plasma wakefield accelerators, all of which share the characteristic of few-femtosecond (and shorter) electron bunches. There is therefore a pressing requirement to devise methods of measuring and optimising such very short electron bunch profiles, which will ultimately extend to the attosecond regime.

All of these techniques rely on the generation of a faithful ‘optical replica’ of the Coulomb field of the beam. This is generated by a process termed ‘spectral upshifting’ or ‘pulse carving’, whereby the Terahertz pulse representing the transverse Coulomb field is upshifted to an optical frequency via sum and difference frequency mixing in a suitable optical detector material placed adjacent to (but not traversed by) the electron beam. This is currently achieved using thin inorganic electro-optic crystals such as GaP and ZnTe, but the optical bandwidth of these materials (a few THz) renders them inefficient at very short bunch lengths, partly due to the onset of transverse optical phonon resonances [3]. Since 2011 the Dundee Group have been investigating a range of

*Work supported by the EU under contract PITN-GA-2011-289191.
c.p.welsch@liverpool.ac.uk

ISBN 978-3-95450-126-7

alternative materials to substitute for GaP, including $GaSe_2$, organic crystals such as DAST and MBANP, and the development (at Dundee University) of novel "meta materials" tailored to have the appropriate optical characteristics.

The MAPS group (http://mapsatepm.org.uk/) specialises in the development of nano materials, and specifically (a) metal-dielectric nano composites (MDNs) such as silver-doped glasses and polymers, and (b) surface-modification of metals and other materials to produce periodic and aperiodic micro- and nano-structures.

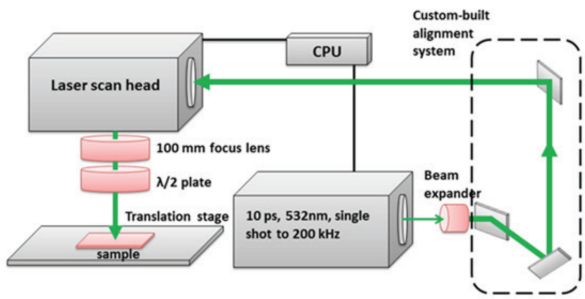

Figure 1: Ultra-short Laser configuration for materials processing.

These modifications are generated by a combination of nanosecond and picosecond pulsed high-power lasers with a range of wavelengths in the UV, visible and IR - facilities unique within the UK. Within the last six months we have made significant progress in the fabrication of silver-doped glass nano composites for EO applications in accelerators, and have demonstrated dichroism and SHG in these materials, a first step towards implementation as an EO detector material, see Fig. 1. LA³NET Fellow Mateusz Tyrk has made a major contribution to this project. He has been responsible for setting up and maintaining the recently-purchased Talisker picosecond laser from Coherent, designed and installed the X-Y scanning system to permit the Talisker to irradiate samples in a controlled pattern with a measured fluence, produced spheroidal nanoparticle distributions within these samples by picosecond-pulse laser irradiation at a wavelength of 532 nm and measured the extinction spectra of such samples, verifying the splitting of the surface plasmon resonance (SPR) into two bands. Moreover, he has verified the dichroism produced by the polarised laser irradiation and has liaised with colleagues at Daresbury Laboratory in the initial measurements of second-harmonic generation from these samples, which is an important precursor for an electro-optic effect.

Accelerator Timing Monitor with fs Precision

The next generation of accelerators and light sources require timing systems with unprecedented stability and precision for the synchronization of accelerator subsystems, diagnostics and photon experiments. Proposals and plans for new light sources such as CLARA at Daresbury laboratory [4] and SwissFEL [5] already require synchronisation to the several femtosecond level, a requirement which will rapidly advance towards the attosecond regime as future facilities generate increasing short photon outputs. The timing and synchronisation program at STFC's Accelerator Science and Technology Centre (ASTeC) is developing optically based techniques to meet these challenges. Leading technological techniques to providing such femtosecond level synchronisation is based on laser optical clocks distributed through actively stabilised optical fibre providing a stable common time base for remote components and high precision timing diagnostics [6]. One such technique and that adopted in ASTeC is to use highly stable mode-locked fibre lasers as optical clocks, producing a train of femtosecond pulses which act at clock ticks to be distributed across a facility. The clock pulses are then delivered by optical fibre to the remote sites and their transit time constantly monitored and stabilised by adjusting the fibre length. Over the last few years ASTeC's timing and synchronisation program has developed and grown, testing and implementing such a timing system on the ALICE test facility at Daresbury Laboratory and demonstrating delivered clock stabilities better than 10 fs rms, see Fig. 2. The program is now expanding to the new VELA facility, also located at Daresbury Laboratory, and developing novel methods of link stabilisation. These methods examine both the phase and group delay of distributed signals and show promise in improving clock delivery into the few and sub femtosecond regime [6].

Timing systems contribute to accelerator stability not only through stable clock delivery, but also with high precision timing diagnostics. Single-shot techniques for measuring the arrival time of electron bunches are important for assessing accelerator stability, data binning and providing feedback signals to other accelerator systems. Current state-of-the-art beam arrival-time monitors (BAMs) use electrical pickups it the beamline to convert the Coulomb field of passing electron bunches into an electrical timing signal. The electrical signal can then be sampled by the distributed optical clock in an electro-optic modulator to convert beam timing deviations into optical pulse amplitude modulation which can be measured with higher fidelity. The time to amplitude conversion ratio defines the sensitivity of this technique, and is largely limited by the attainable bandwidth of the beamline pickups. Recently the timing and synchronisation program has been developing new pickup designs to extend the bandwidth of beamline pickups beyond the current 10-40 GHz limits [7]. However, the use of in-beamline EO techniques is one method which could drastically boost the detection bandwidth of BAMs into the Terahertz range. This would eliminate the bandwidth limitations of coupling the Coulomb field into the electro-optical modulator through an radiofrequency pickup by placing the EO crystals directly into the beamline. In the coming months, a Marie Curie fellow funded through LA³NET will undertake a project to investigate these concepts using nonlinear optical

ISBN 978-3-95450-126-7

materials with ultrafast response times to develop BAMs targeted at achieving femtosecond level precision in determining arrival times. These high precision BAMs will form a critical part of the optical timing system, complementing the advancing link stabilisation and contributing to the development of accelerator stabilisation technology for future light sources.

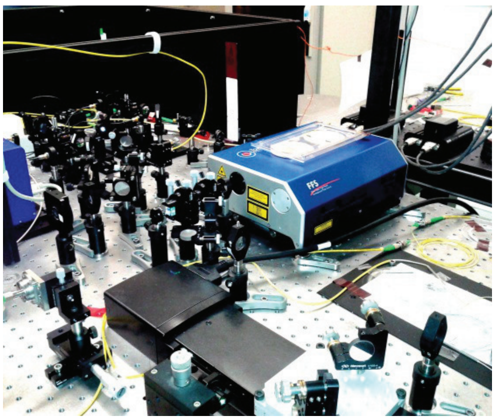

Figure 2: Photograph of current timing setup.

TRAINING EVENTS

Training of all LA³NET fellows will be mostly through specific project-based research. In addition, the consortium will organize a number of network-wide events that will be open to the wider accelerator and laser community.

International Schools

A first international school on laser applications at accelerators was held at GANIL in Caen, France between October 15th-19th 2012 [8]. 80 participants from inside and outside the LA³NET Consortium were introduced to the state of the art in this dynamic research area. Lectures covered topics such as introduction to lasers and accelerators, beam shaping, laser ion sources, laser acceleration, laser based beam diagnostics and industrial applications. A second school will be held in September 2014 at CLPU in Salamanca, 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 in February 2013. 10 invited speakers gave 40-minute talks on their current research in this area and an additional 22 delegates delivered shorter oral presentations providing a good balance of talks on the generation of electron and ion beams using laser methods. 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 [9].

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 in June 2015 in Liverpool, UK to promote the project's research outcomes.

CONCLUSION

In this contribution an overview of the initial research activities within LA³NET related to FELs was given. The projects at the University of Dundee and STFC address the important challenge of measuring ultra-short beam pulses with very high precision and first measurements have been done. Furthermore, the LA³NET training events to date were summarized and a brief overview of upcoming events was given.

REFERENCES

[1] http://www.la3net.eu
[2] S.P. Jamison, et al, 'Limitations of Electro-optic measurements of Electron Bunch Longitudinal Profile', Proc. EPAC, Genoa, Italy (2008) (TUPC042).
[3] S. Casalbuoni, 'Numerical studies on the electro-optic detection of femtosecond electron bunches#, Phys. Rev. STAB 11, 072802 (2008).
[4] J. Jones, et al. 'CLARA Accelerator Design and Simulations', Proc. FEL, New York City, USA (2013).
[5] SwissFEL Technical Design Report
[6] T.T. Thakker, S.P. Jamison, 'Effect of Active Fibre Stabilization on Group and Phase Delay', Proc. FEL '12, Nara, Japan (2012).
[7] A. Kalinin, 'Novel Pickup for Bunch Arrival Time Monito', Proc. IBIC, Oxford, UK (2013).
[8] http://www.liv.ac.uk/ditanet
[9] http://indico.cern.ch, confID: 212365.

ISBN 978-3-95450-126-7