STUDIES INTO ELECTRON BEAM GENERATION, ACCELERATION AND DIAGNOSTICS WITHIN LA³NET*

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on behalf of the LA³NET Consortium

Abstract

The Laser Applications at Accelerators Network (LA³NET) is receiving funding of up to 4.6 M€ from the European Union within the 7th Framework Program to carry out R&D into laser-based particle sources, laser acceleration schemes and laser-based beam diagnostics. This international network joins universities, research centers and private companies and has been training 19 early stage researchers at network nodes across Europe since 2011. This contribution presents research outcomes from LA³NET's main work packages, covering electron beam generation, acceleration and diagnostics. Results from surface studies of photocathodes for photo injector applications in the framework of the CLIC project are presented along with information about expected accelerating gradients in dielectric laser-driven accelerators as identified for non-relativistic and relativistic electron beams using the CST and VSIM simulation codes. Initial results from energy measurements using Compton backscattering at the ANKA Synchrotron at KIT are also presented. In addition, a summary of recent and upcoming international events organized by the consortium is also given.

INTRODUCTION

The LA³NET Fellows are hosted by 11 partner institutions all over Europe and although their work focuses on research, they are provided not only with scientific supervision and opportunities of secondments to other institutions involved in the project, but also complementary training through network-wide events [1]. This includes international schools and topical workshops, as well as a final project conference and numerous outreach events. Through the involvement of almost 30 associated and adjunct partners the project gains an interdisciplinary dimension including strong links to industry. The network carries out many dissemination and outreach activities aimed at interesting a wide audience in science and to raise public awareness of the application of lasers and accelerators in many different fields that have influence on everyone's life, such as medicine, electronics, energy and the environment. LA³NET trains accelerator experts for academia and industry, joins the accelerator and laser communities and to raises public awareness of the importance of this research for society. In the following section examples of recent research results from across the consortium are given.

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RESEARCH

The Fellows carry ou research within one out of 5 thematic work packages within LA³NET. These are particle sources, acceleration, beam diagnostics, system integration and detector technology.

Surface Characterization of Photo Cathodes for Photoinjector Applications

Within the CLIC (Compact Linear Collider) project, feasibility studies of a photoinjector option for the drive beam are on-going, covering both, the laser and the photocathode side. The main challenge is to achieve high bunch charges, long trains and high bunch repetition rates together with sufficiently long cathode lifetimes. Cs_2Te cathodes, sensitive to ultra-violet (UV) laser beam that were produced at CERN showed good quantum efficiency and reasonable lifetime [2]. However, the available laser pulse energy in the UV for 140 µs long pulse trains is currently limited due to a degradation of the beam quality during the 4th harmonics conversion process. Using green laser beam in combination with Cs_3Sb cathodes would overcome this limitation. Cs_3Sb and Cs_2Te photocathodes were produced at CERN by co-deposition process and tested in the PHIN RF photoinjector, see [3]. LA³NET Fellow I. Martini who is based at CERN led a detailed analysis of cathode surface composition through X-ray Photoelectron Spectroscopy (XPS) and correlated the findings to the cathode performance [4]. The Quantum Efficiency (QE) map shows an overall efficiency reduction in used cathodes as compared to newly produced ones, see Fig. 1 as an example. This can be explained by changes in the composition of the photoemissive layer.

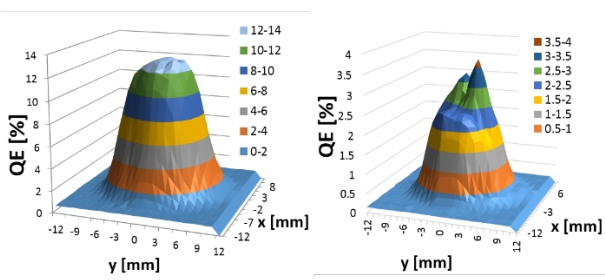

Figure 1: QE maps of Cathode #198 (Cs_2Te) as newly produced (left) and used in the RF photoinjector (right).

The XPS studies showed that both cathodes were oxidized during operation. Moreover, the detailed

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analysis of the XPS spectra measured on the used cathodes identified as contribution to the surface composition some compounds with the wrong stoichiometry that could explain the poor photoemissive properties. Further studies on newly produced photocathodes are planned to better understand if degrading effect during photoinjector operation, , such as backscattered high energy ions or also inaccuracies in the deposition process, lead to the formation of different compounds.

Dielectric Laser Acceleration

Dielectric laser-driven accelerators (DLA) based on a grating structure have good potential as ultra-compact electron accelerators, benefitting from high acceleration gradients of up to GV/m and mature lithographic techniques for the fabrication of the microstructures. Within LA³NET, A. Aimidula has carried out initial studies into the optimization of such gratings structures, modifying a range of geometry parameters and critically assessing their impact on the acceleration efficiency [5]. Fellow Y. Wei from the Cockcroft Institute/University of Liverpool is building up on this early work and investigates acceleration of relativistic and non-relativistic electrons in double gratings silica structures, using different harmonic modes of the accelerating field [6]. When a double grating structure is driven by two transverse magnetic (TM) polarized lasers from opposite sides, different harmonic modes of the accelerating electric field are simultaneously excited, see Fig. 2.

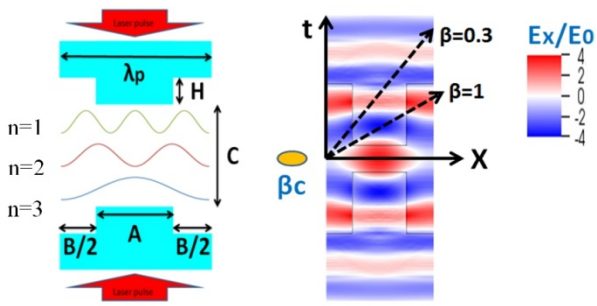

Figure 2: Illustration of the first, second and third spatial harmonic mode in one grating period, driven from opposite sides by laser.

Assuming an erbium-fiber laser emitting a wavelength of λ_0=1550 nm and Silica with a refractive index of n=1.528 as substrate simulations were carried out into the acceleration efficiency using the commercial CST and VSim simulation codes. Both codes yielded very similar results over a wider range of parameters, supporting the findings of earlier studies. For highly relativistic electrons a maximum achievable acceleration gradient of around 2.2 GV/m was found. For non-relativistic electrons at β=0.3 the first spatial harmonic gave access to the largest acceleration gradient of around 0.33 GV/m, as compared to 0.25 GV/m for the second harmonic and 0.16 GV/m for the third harmonic. Taking into account manufacturing constraints a grating period of 930 nm was found to be optimum in terms of simplicity of production and acceleration efficiency. This work will now be extended towards multistage acceleration.

Beam Energy Measurements Using Compton Back Scattering

For Compton back scattering (CBS) measurements at storage rings, the electron beam energy of the stored beam can be determined from the known values of the electron rest energy, the laser photons energy, and the measured collision angle φ and Compton edge energy. LA³NET Fellow C. Chang and colleagues from ANKA at KIT have now used a High Purity Germanium (HPGe) spectrometer to determine the energy of the emitted photons [7]. Figure 3 shows a typical spectrum that was acquired from a 1.3 GeV electron beam over 120 seconds. The mechanical centers of two quadrupoles were used as reference line and the laser direction measured relative to this line with a laser tracker and a camera. In addition beam position monitors were used to check the electron orbit orientation relative to the reference line.

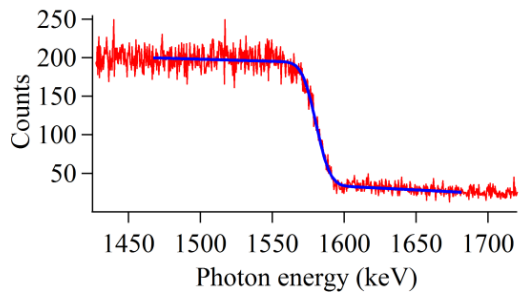

Figure 3: Measured CBS spectrum at 1.3 GeV with fit to determine the Compton edge energy. Signal integrated over 120 seconds.

The collision angle φ was determined from this measurement and yielded an average value of the beam energy of 1287.0 MeV ± 0.2 MeV. As compared to conventional CBS methods for energy measurement, a compact setup based on a transverse scheme has been successfully tested at ANKA. These measurements have been extended to beam energies of 0.5 GeV, 1.6 GeV and 2.5 GeV and gave promising initial results. It was shown that longer acquisition times can help further reduce statistical uncertainties in the Compton edge and hence beam energy. This might give access to measurements uncertainties to below a few10^{-5} in the future.

TRAINING EVENTS

Training within the LA³NET network is primarily through cutting edge research. In addition, the network organizes a number of network-wide events that are also open to the wider community, including international

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schools on laser applications at accelerators and workshops on specific topical areas, as well as an international conference and symposium that take place in 2015.

International Schools

A first international school on laser applications was held at GANIL, France in 2012 and was reported on in the Proceedings of IPAC13 [8]. Between 29 September and 3 October 2014 the consortium held an Advanced School on Laser Applications at Accelerators. The event was hosted by the Spanish Pulsed Lasers Centre (CLPU) in Salamanca, Spain and attracted over 70 participants from all over the world. The school started with lectures about an introduction to lasers, the history of accelerator development in Europe, accelerator applications, as well as beam generation, acceleration and diagnostics – all given by internationally renowned lecturers. Day two included lectures on laser ion sources, photo injectors and Free Electron Lasers (FELs), in addition to a two-hour study session giving delegates a chance for a hands-on look at some of the topics covered. An outreach talk about "attosecond science" by Prof. Luis Plaja in the evening on the main University of Salamanca campus attracted more than 100 students from the university and local high schools in addition to the school participants. The following days covered more advanced topics in ion and electron acceleration, commonly used simulation codes for accelerator design and optimization, as well as industry applications of accelerators and lasers. This was complemented by a Laserlab-sponsored visit to the facilities at CLPU, a second study session and a lively poster display and industry exhibition, sponsored by Danfysik. The School drew to a close with talks on THz applications, compact X-ray sources and the Extreme Light Infrastructure (ELI) project. The School stimulated many fruitful discussions throughout the week and was an excellent addition to the many scientific events the network has organized to date. All presentations can be found on the school's indico page [9]. In addition, the network has organized two researcher skills schools for all Fellows, covering wider skills, such as presentation skills, scientific writing, project management or CV writing. These schemes were specifically praised by a number of bodies, including the REA, HEA and UKRO and has since been implemented for many additional student cohorts at partner universities.

Topical Workshops

The network also organizes workshops on specific R&D areas that are covered in the network's different work packages, including particle sources (2013), novel acceleration techniques (2013) and laser technology (2014). Between 16-18 November 2014 a "Scientists Go Industry" workshop explored a slightly different area. It was hosted by the Helmholtz Association in Berlin with thirteen invited speakers from industry and the commercial world talking about their own career pathways and what their work entails. This provided the Fellows and external delegates with an insight into the full range of job opportunities available for them outside of academia. The event was a sell-out showing that there is an appetite for investigating such alternative career paths. The speakers stepped up to the mark to paint a bright picture of the spectrum of career pathways available with each session generating plenty of questions and some lively discussion. The presentations are available from the workshop website as a resource for any physicist pondering their future [10].

The penultimate events for LA³NET took place in Mallorca at the end of March 2015 with a 2-day long Topical Workshop on Beam Diagnostics kicking off a week dedicated to lasers and accelerators. The first day saw presentations about the state of the art in optical diagnostics, beam profile and emittance measurements using optical radiation, laser wire scanner R&D, Compton backscattering and the use of optical techniques for ultra-short bunch diagnostics. On the second day longitudinal measurements of ultra-short Bunches, novel sensors and technologies and advanced diagnostics technologies were covered [11].

Wednesday welcomed the opening of the LA³NET Conference on Laser Applications at Accelerators [12]. This event brought together around 70 experts to discuss the state of the art in the network's R&D area. All LA³NET Fellows presented the outcomes of their research in form of talks and the conference also featured presentations by research leaders from around the world. Sessions were organized along the network's research work packages and triggered many interesting and stimulating discussions.

Finally, the project will host an outreach symposium in Liverpool on 26 June 2015 [13]. There, the network will present its research results to a very wide audience to help promote researcher careers in the field of accelerator science and technology.

SUMMARY

The LA³NET project is one of the largest Marie Curie initial training networks ever funded by the European Union. It has been training 19 early stage researchers in an interdisciplinary area and organized numerous events for the wider scientific community. This paper gave 3 examples of recent research results by LA³NET Fellows. Stretching across beam generation, acceleration and diagnostics, the network provides a unique framework for international cooperation across sectors.

Identified as a European 'success story' by the REA as part of formal reviews in a number of key areas, including Fellow R&D, international dissemination, project management and coordination, the project is providing a high quality training program to its Fellows, giving them an excellent basis for their future careers.

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