INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2014, VOL. 60, NO. 2, PP. 187–192
Manuscript received October 30, 2013; revised November, 2013. DOI: 10.2478/eletel-2014-0023

LCLS – Large Laser Infrastructure Development and Local Implications

Ryszard S. Romaniuk

***Abstract*— The most powerful now in the world, American X-ray laser LCLS (Linac Coherent Light Source), has been working as a research and user facility since 2009. It is further developed to LCLS II machine at the Stanford National Accelerator Laboratory SLAC in Menlo Park CA. In a certain sense, LCLS II is a response to the EXFEL machine and a logical extension of LCLS. All these machines are light sources of the fifth generation. EXFEL is expected to open user facility in 2016, at a cost of over 1 mld Euro. LCLS II, which design started in 2010, will be operational in 2017. The lasers LCLS, LCLS II and EXFEL use SASE and SEED methods to generate light and are powered by electron linacs, LCLS by a warm one, and EXFEL by a cold one. The linacs have energies approaching 20 GeV, and are around 2 - 3 km in length. EXFEL linac uses SRF TESLA microwave cavity technology at 1,3GHz. A prototype of EXFEL was FLASH laser. SLAC Laboratory uses effectively over 50 years experience in research, building and exploitation of linear electron accelerators. In 2009, a part of the largest 3 km SLAC linac was used to build the LCLS machine. For the LCLS II machine a new infrastructure is build for two new laser beams and a number of experimental stations. A number of experts and young researchers from Poland participate in the design, construction and research of the biggest world linear and elliptical accelerators and FEL lasers like LCLS (Stanford), EXFEL (DESY) and CEBAF (JLab), and a few more. The paper concentrates on the development state-of-the-art of large laser infrastructure and its global and local impact, in the competitive world of R&D. LCLS infrastructure implications in Poland are considered.**

***Keywords*— USA laser programs, x-ray lasers, free electron lasers, FEL, electron linac, accelerators, electron beams, high energy photon beams, DESY laboratory, large research mega projects, LCLS, LCLS II**

I. INTRODUCTION

LCLS Laser [1] and its upgrade has a large impact not only in SLAC but also globally and locally. In Poland there are accelerator and laser communities interested in participation in the large machine development but also work with the infrastructure as users. Global laser infrastructure stimulates not only global but also local developments in the field, what leads to establishing a kind of worldwide FEL laser network. This kind of EuroFEL network exists in Europe [2]. Part of EuroFEL is expected to be planned POLFEL infrastructure [3,4]. EuroFEL, created by European infrastructure owners, cooperates globally with large laser infrastructures worldwide, mainly in Japan and the USA, especially with LCLS and CEBAF.

The paper tries to show state-of-the-art of the LCLS infrastructure activities and development, and is a part of a cycle of papers on large laser and accelerator endeavors in Europe and the USA. This paper was presented during the WILGA 2013 Symposium [5-11], and was published in Polish version in Elektronika [12]. Other papers from this cycle concerned the developments of the CMS detector, European fusion program, ILC collider and were focused on local impact of these projects in Poland. It is commonly believed in the national research and technical communities, participating in the European and global infrastructure development projects, that these projects are the fastest tool of dissipating the newest and most advanced technologies [13-24].

Experts and young researchers from this country are actively participating in building of the biggest world linear and circular accelerators and FEL lasers like: LCLS (Stanford), EXFEL (DESY), CEBAF (JLab), ALBA (Spain) and numerable other ones, including JET and ITER fusers/tokomaks. The number of young researchers from Poland participating in the scientific and technical activities directly and indirectly around the described infrastructures is astonishingly high. The numbers go in tens and soon in hundreds. Thus, one of the aims of this cycle of papers is to present closer these infrastructures, emphasize their impact in Poland, and bring to consciousness these numbers to the Polish policy makers in the field of national science, research and technology. Long term participation of these hundreds of young researchers in these global experiments will have a grave and lasting effect on the future research in Poland in a number of key technologies [25].

II. SLAC FEL LASER LABORATORY

LCLS-SLAC is a very important R&D accelerator and laser as well as user oriented infrastructure having profound impact on local and global research communities, including the research groups from Europe and Poland. The X-ray and tunable laser infrastructure serves very actively as a development laboratory for future accelerator – laser machines, as well as a research tool in many various branches of science. LCLS is located in the National Accelerator Laboratory co-financed by DoE and run at the University of Stanford in Menlo Park campus, CA. SLAC laboratory was established in 1962 and runs research in the experimental and theory area of elementary particles, using electron beams. Area of research embraces: atom physics, solid state physics, chemistry, biology and medicine. The source of electron beams is synchrotron SSRL and free electron laser LCLS. Additionally SLAC Laboratory has accelerator research infrastructure designed for tests of new and advanced accelerator techniques FACET - Facility for Advanced Accelerator Experimental Tests.

The author is with Warsaw University of Technology, Poland (e-mail: rrom@ise.pw.edu.pl).

The biggest ad most powerful now in the Word American X-ray laser LCLS - Linac Coherent Light Source, is working since 2009 as a user and machine research facility, and is further developed to LCLS II. This is the light source of the fifth generation. In certain sense the LCLS is an infrastructure which is predecessor in certain abilities of the European XFEL, now under construction in DESY Hamburg. EXFEL is expected to be commissioned in 2015/2016, and turn to user facility, at a total cost of over 1 mld Euro. The LCLS II, which design started in 2010 will be commissioned in 2017. LCLS, LCLS II and EXFEL lasers use all SASE and SEED methods to generate light, and are powered by powerful electron linacs of teen GeV energy. The LCLS is powered with warm linac while EXFEL with a cold one. Both linacs are over 2 km in length. The EXFEL linac uses superconducting technology SRF TESLA of resonance frequency 1,4 GHz. A prototype of EXFEL is FLASH laser. The SLAC laboratory uses its over 50 years of experience in building and exploitation of linear electron accelerators. In 2009, part of the biggest 3 km electron linac was used for building of LCLS machine. For the LCLS II machine a new infrastructure is built for two new laser beams.

III. FEL LCLS Laser

Now, the LCLS has the following parameters: 1 km linac, energy of electron beam – 2 -14 GeV, undulator length 100 m; range of proton energy 250 eV – 10 keV; pulse length 1 – 100 fs; number of photons in the pulse – 10^{10} – 10^{13}; number of coherent photons in the pulse – 10^{9}; pulse energy 6 mJ; timing between optical and X-ray pulse – 10 fs; method of X-ray generation – SS-SASE; X-ray pulses are transform limited; full longitudinal and transverse coherence of the pulse; beam sharing; 6 different specialist experimental stations; 600 users on the average per annum from 30 countries; acceptance on the average 1 from 4 grant applications for the beam time.

The first in the world, the Angstrom laser LCLS was constructed and commissioned in April 2009 in SLAC by the Consortium of three laboratories: LLNL, SLAC and Argonne. SLAC Laboratory is run by Stanford Uni. and financed by DoE. Laser uses a part of three km electron linac as a powering source for the undulator. Apart from the linac and LCLS the SLAC Lab has the SSRL, which is a synchrotron light source of the third generation. The LCLS is a FEL which uses 1/3 of the linac length. The laser generates a coherent light beam in the X-ray region – soft and hard. The peak brightness of the beam is around 10 orders of magnitude bigger than in conventional synchrotron sources. Pulse duration time is changed in the range 500 – 10 fs. By means of such beam, the light source may image the structure and dynamics of matter on the atomic level of dimensions and time periods. The light source of the fourth generation works in the spectral range of 1 - 22 Å and is correlated with several user laboratories working in the area of biology, material engineering, and other ones. Laser beam is shared in time between these laboratories.

Availability of FEL lasers, and in particular the unique LCLS machine, which in many respects and technical parameters is the first in the world (time and space coherence, beam intensity, brilliance, wavelength), has opened a new era, indeed, of interaction research between the hard X-rays of high intensity and matter. Many practical applications of X-rays require thorough understanding how electrons in the matter interact with intense X-ray radiation. The research run on the LCLS machine reveal the nature of the electron response of a free atom to X-ray beam of extreme values of intensity, wavelength and fluence, which are respectively: $I=10^{18}\,\mathrm{W\,cm^{-2}}$, and $\lambda=1.5–0.6\,\mathrm{nm}$, also $F\sim10^{5}$ X-ray photons on $Å^{2}$. For such fluences, during the irradiation of a target from neon gas, and with a ingle fs pulse, the absorption of a few photons ionizes the atom completely. Photo ejection of the electrons from the internal electron orbits in the atom forces temporarily total induced transparency of the gas target. Such transparency, caused by vacancies in the internal orbits, may be induced in all material systems, for such values of intensities and fluencies of the X-ray beam. Qualitative comparisons, theoretical and direct laboratory ones between materials of atomic, molecular and complex – crystalline, amorphous, structures allow for precise determination of the beam parameters (fluence, pulse duration time) and material characteristics. Extension of the modeling of the influence of the X-ray beam on complex systems is necessary in biological applications.

Imaging in the space (Angstroms) and time (femtosecond) atomic scales is done with the usage of the laser femto-camera. There are made sequences of images from different phases of the laser pulse interaction with the nano-object. A kind of a molecular movie is recorded showing molecular movements during its chemical changes and reactions. This research leads to the knowledge on photosynthesis mechanisms and virus structures. Mastering of an artificial photosynthesis may lead to new methods of energy production, storage, management and economy, as well as to food production. Identification of viral transformations in the real time leads to the knowledge on their immunity to antibiotics, and also their roles in formation of tumors.

Albumen crystallography is a subject of intense research by means of FEL lasers (Nobel Prize in 2006 for R.Kornberg). Albumen structure may be determined from the diffraction image Laue spots. Locations of individual atoms are to be determined in molecules containing several tens of thousands of atoms. Availability of X-ray beam of the parameters offered by LCLS opens completely new path to the research of biological molecules and particles, which can not be crystallized.

Infrastructures of the LCLS laser includes user laboratories: AMO – atom and molecular optics; CXI – coherent X-ray imaging; MEC – matter in extreme conditions; SXR – material engineering of soft X-rays; XCS – roentgen correlation spectroscopy; XPP – X-ray pump-probe technology. User laboratories search answers to the really fundamental questions. How atoms and individual molecules react to the X-rays? How the electrical and magnetic properties are generated in complex materials and how chemical reactions evolve at the surface? How do react atoms and chemical complexes to excitation? Is it possible to disentangle precisely atomic structures of biological complexes (in their natural life states), which may not be crystallized and which easily are destructed during prolonged radiation exposition? Is it possible to observe and register atom movements in non-ordered materials and fluids during the changes of their equilibrium states? How the matter properties change, when it is taken to a state far away from the equilibrium?

AMO laboratory uses soft x-ray pulsed beam from LCLS. Gas, atomic, molecular or nano-particle (albumen crystalline or viruses) interaction region is irradiated with a pulsed beam. The region is subject to electron and ion spectroscopy. There are used large area detectors for x-ray diffraction measurements. The researched effect are: time-resolved photo-ionization, x-ray diffraction in nano-crystals, and single pulse imaging of non-reproducible objects.

CXI laboratory uses hard x-ray pulsed beam from LCLS. There are imaged single sub-micrometer particles and bio-molecules structure is determined with the usage of nano-crystals. Nearly ideal, full transverse coherence of the LCLS beam enables imaging of single particles with high resolution. Short duration time of the imaging pulse confines the radiation damage, which are difficult to be reduced with synchrotron sources. The samples are introduced into the laser beam in a static or dynamic ways by means of relevant injector in a stream of fluid. Coherent diffraction imaging is used to research the images of nano-crystallites.

MEC laboratory researches transient states in matter in extreme conditions. These extreme states are generated by wavelength tunable pulsed x-rays. The interaction is investigated of a few simultaneous beams, the main from FEL and supplementary from a few conventional optical high power or high energy/intensity lasers. Measurement apparatus embraces: Thomson x-ray scattering spectrometer, XUV spectrometer of high resolution, Fourier interferometer and VISAR system. The vacuum chamber for these experiments has large volume giving the laboratory additional flexibility for research of hot dense matter physics, high pressure research, shock waves and physics of high energy densities. Some experiments are predicted on vacuum nonlinearity.

SXR laboratory is active in soft x-rays. Research concerns x-ray emission, coherent imaging, resonant scattering, and photo-electron spectroscopy. Research embraces the effects of: catalysis, magnetism, correlated materials, laboratory astrophysics and biological structures. The SXR experimental line is equipped in monochromator for photon energies in the range 0,5 keV to 2 keV. Such energy range covers the K and L edges of resonant excitations of elements of the second and third order. The monochromator also provides radiation non-monochromatic. SXR laboratory is combined with AMO in series and samples may be tested first in XAS in the transmission mode.

XCS laboratory of x-ray correlation spectroscopy allows for observations of dynamical changes of large atom groups in condensed matter systems in wide time scales. Observations are carried out using coherent x-ray scattering and correlation spectroscopy of x-ray photon. Dynamics of equilibrium and non-equilibrium states is tested in non-ordered materials and modulated materials.

XPP laboratory serves for generation and research of transient states of excited matter with short pulse from optical laser. Hard x-ray pulse probes this state of master, and in particular its structural dynamics, initiated by optical pulse. Optical pump is tuned in wide area of space, time, profiles, frequency, intensity and fluence, in order to evoke relevant excited states. Structural changes, induced by the laser pulse, are researched by means of roentgen scattering. Hardware measurement channel embraces: generation and delivery of optical and x-ray pulses to the sample, preparation of the excited state in the probe, detection of the pattern of x-ray scattering.

LCLS infrastructure supports research projects of four categories: electron beams, x-ray beams, conventional lasers, end stations – user laboratories. Beam research is associated with their generation, diagnostics and manipulation. Research with conventional lasers concerns extension of spectral range to UV and THz, and timing diagnostics. Research on the end laboratories for beams concern techniques of sample delivery to the exposition region, detectors and data analysis.

Current achievements of the LCLS infrastructure research program, launched in 2009, concerned introduction of a new x-ray self-seeding technique, which replaced conventional SASE technique without seeding. The X-ray SS SASE technique allowed for ten fold reduction of the photon bandwidth and improvement of photon energy stability of two orders of magnitude. Other, efficiently introduced technique was mutual correlation between optical and x-ray pulses of very high accuracy, now equal to 10 fs. This technique and range of offered accuracy is required in the optical pump and x-ray probe and in nano-crystallographic techniques. A common diamond monochromator is used, with double crystal and large offset for both photon beams.

IV. DEVELOPMENT OF LCLS RESEARCH AND USER INFRASTRUCTURE

Research in accelerators and beams

There are carried out simultaneously a few infrastructure development projects, spanning the next five years 2013-2017. CATHO project is directed for the improvement of cathode reliability in the electron RF gun. XTCAV project concerns a transverse transmission resonant cavity for X band, which acts actively as ultra fast streak/track camera providing information from a pulse to a pulse of the temporal structure of X-ray radiation. Developed techniques of cross-correlation provide synchronization of optical and X-ray pulses. Other projects concern the self-seeding of hard x-rays and soft x-rays, spectrometry of single hard x-ray pulse, optical laser – x-ray laser timing, multi bunch x-ray pulses, DELTA type undulator, conical undulator for high power radiation, splitting of the hard x-ray beams, and others. The basic aim of the research is to obtain a pulsed and well controlled x-ray beam, of much better improved parameters than only high intensity and short pulse. What is really necessary: precise stabilization of pulse intensity between pulses, control of pulse length, obtaining of large energy resolution, polarization resolution and control, availability of multicolor x-ray pulses of controlled and changeable delay, etc. These research and development directions for x-ray lasers and beams go along a similar path as some time ago did the conventional optical lasers and beams.

Improvement of the quality of x-ray pulses leads to precise control of phase space in the photon beam. Spontaneous seeding alone does not give such a control. Self-seeding is necessary, because the external seeding for x-rays is not yet used. The beam should be longitudinally coherent, then it is determined as transform limited, and in the pulse there is confined uncertainty between its length and energy. Such pulses are generated in the SS SASE process. A separate issue is soft x-ray beam polarization. Circular polarization is build in the undulator of a special DELTA construction. Other infrastructure development projects concern generation of multiple x-ray pulses by the multiplication method and increase of laser power to the level of TW. TW-FEL requires additional undulators.

Laser research

Application of LCLS infrastructure to laser research leads in two directions: widening of the spectral range of generated wavelengths in both directions – short and long waves, i.e. gamma rays and THz beams, and timing diagnostics of lasers. LCLS infrastructure has three signal sources: differential frequency generator DFG giving a wave of THz frequency 15 – 20 THZ - which is equivalent to 20 -15 µm; optical rectifiers made of lithium niobate $LiNbO_3$ for bandwidths 1,0 – 1,5 THz; and on DAST for bandwidth 2,0 – 2,5 THz. In combination with DAST material, over 1MV/m field intensity was obtained. DAST material is pumped in MIR spectral region and requires application of OPA, transmission line for THz wave, beam focusing and diagnostics, and THz and x-ray beams overlapping. The research concerns efficiency increase of the conversion process, control of bandwidth generation, and tuning of the wavelength. Widening of the generated bandwidth concerns meV energy levels from the THz waves and KeV energy levels from the EUV waves. Timing research concerns the possibility to generate attosecond pulses.

Detector research

There are carried out works on new generation of detectors. There are developed prototypes of detectors of small pixels and very low noises able to reconstruct single photons. Such detectors are predicted for the x-ray photon correlation spectroscopy, building of crystalline x-ray spectroscopes, and for general aims of imaging with photons of energy above 2 keV. Further development of detectors requires considerable increase of counting frequency per pulse per pixel combined with keeping of high sensitivity for a single photon signal. Large signal detectors are necessary to build a diffractive measurement system for nano-crystallography. In the range of soft x-rays there is necessary a universal detector capable of discrimination of single photons up the carbon edge. Apart from single detectors, there are built pixel cameras of large angular resolution, and sub-nanosecond timing for soft x-ray photons. Detector assembly is done with minimal separations between the pixels.

Sample delivery to beam

System of sample delivery in the x-ray beam interaction region is an area of intense studies. Solid-state, liquid and gaseous samples are injected into the beam in a standardized way. Gas targets include albumen nano-crystals, sprays, aerosols of biological matter. Liquid targets include liquid solutions of molecular systems. Samples are transported in most cases to the vacuum area what complicates considerably the delivery system. There was established a design group which aim is to simplify and high standardization of the gas, liquid and solid-state sample delivery to the x-ray beam.

V. LCLS II - 2025

The first light from the LCLS II infrastructure will be generated in 2018, and the machine development is strictly written up to 2015. Infrastructure development predicts building of a second injector and a nondependent linac of 1 km in length. Two new undulators provide simultaneously soft and hard x-ray radiation to a new experimental hall, which contains one experimental station. Together, the new experimental halls will have six stations. Further development predicts addition of a new undulator for hard x-rays and new experimental stations to the LCLS-I machine. Summing this up, the modernization of LCLS infrastructure till 2025 predicts, in comparison with the current situation, the following changes: two nondependent injectors giving more flexibility to the machine working conditions, increase of the number of undulator sources up to four, tripling of the number of nondependent experimental stations up to 12, nondependent work modes with soft and hard x-rays, extension of the spectral range of photons – 250 eV – 18 keV; soft and hard pulses from the self seeding, improvement of pulse parameters – 10^2 times in brilliance, 10^2 times smaller bandwidth, 10^1 times increase in pulse power, full control of polarization of soft pulse, manipulation of the x-ray pulse – splitting, delay, combining, many colors; improvement of x-ray detectors – sensitivity to a single photon; extended dynamical range; bugger number of pixels, smaller pixel dimensions; timing of the pump – probe system – 10 fs.

The priority directions of research predicted now for the LCLS-II infrastructure are:

- new effects in advanced materials – considered also as quantum materials, atomic research, electron and spin research in the area of soft x-rays;
- dynamics of chemical reactions, natural and artificial – designed molecular photochemical transformations, provoking artificial reactions, electron and atomic research in the area of hard x-rays;
- structure of albumen nano-crystallites, and structure of non-crystallizing albumens – techniques of nano-crystallization, atomic research, advanced diffraction research of nano-systems and systems spuriously non ordered.

Quantum materials

Condensed matter may be formed into exotic, rare and stable or quasi stable quantum states by the control of chemical composition and application of external field interactions. This leads, for example to the extension of the current silica and metal technologies. Such materials show useful properties such as: high temperature superconductivity, combination of semiconductor and semi-magnetic properties at low losses, gigantic magneto resistance, switchable multiple-ferrolectricity, etc. These features stem from ordered charge, spins and orbitals in electronically distinguishable micro domains. These domains fluctuate in space and time in the range of many orders of magnitude for both scales time and space. LCLS-II infrastructure is optimized to research precisely these new effects, particularly in the critical range of photon energies, around meV, nanometer range of dimensions and femtosecond area of time durations for observed effects. The necessary research tool is well defined, stable, pulsed x-ray beam of strictly controlled parameters and changeable polarization, pulse time duration, pulse energy, and pulse color. Response of the material is researched in time domain – by time resolved method of resonant, inelastic x-ray scattering RIXS. The response signal may be amplified with the usage of stimulated processes. The aim is to understand the mechanisms of generation in the material of new features and new effects and control of these processes and parameters and new phases of quantum materials. Quantum materials are the hope for obtaining such parameters and features like: cloaking, perfect heat insulation, minimization or maximization of friction, radiation immunity, and many more.

Molecular, photochemical transformations

Disentangling the details of atomic transformations on the molecular level, and obtaining the insight and possibility of control over chemical reactions is necessary for further improvement of the life quality of us all, the human beings. These processes take place in femtosecond time scale in local catalytic reaction centers. Sampling of these effects require high time and space resolution and taking into account the chemical specificity – going now far beyond the current measurement abilities, especially these which are accessible with the use of synchrotron radiation sources, and even FEL sources of the first generation with non-ideal pulsed beam. Control of chemical reactions leads to the possibility of synthesis of completely new classes of materials, building of effective and compact systems of energy gathering and storage and its release – usage by, for example, only manipulation of a particular chemical bound. This leads to the ability to influence key biological reactions and organism functions. LCLS infrastructure gives the possibility to research by x-ray methods triggered reactions by optical photons. This creates the possibility to develop artificial biological processes, which run with increased efficiency. Optical pulse triggers a process, which evolution is then sampled and observed by strictly determined in time, space and energy and fully controlled x-ray pulses. The following atomic movements are traced by the method of ultrafast nano-crystallography and diffusion scattering techniques of hard x-rays. Soft spectroscopies allow for observations of very subtle changes in local bonds around the chosen atoms in selected functional groups. There are used techniques of stimulated Raman scattering for soft x-rays with the transform limited pulses of various colors and polarizations.

Structure determination of micro and nano biological objects

Fighting certain types of diseases requires determination of structures of viruses or albumen complexes. To research these structures, there are used methods of anomalous diffraction of a singe wavelength SAD or anomalous diffraction of multiple waves MAD. These methods are characterized by very precise control of the spectral intensity distribution of the pulse. To obtain high measurement resolution there are used photons of energy over10 keV, or above the edge of Se and Br. There are registered full photon trajectories, their all reflections, what minimizes the need for over-sampling. Over-sampling is a considerable confinement in the case of research of proteins difficult for preparation samples and crystallization. Non periodic biological objects, such as viruses, should be imaged with a single pulse. This is possible, but at the cost of smaller resolution.

VI. LCLS IMPLICATIONS IN POLAND

National project POLFEL is a potential participant of the EuroFEL R&D network. EuroFEL is a potential partner of the LCLS infrastructures and any networking activities associated with SLAC FELs. The planned Polish VUV CW FEL may be built at the NCNR in Swierk near Warsaw, using TESLA technology. The project is positioned on the European list of infrastructural priorities ESFRI. The POLFEL project realization is associated with the European financial perspective 2014-2017. The TDR draft document was prepared for the planed machine [26]. There are also planned numerable infrastructural initiatives accompanying the big machine like: test laboratories for particular sub systems like RF CW gun, cold mass, injector development, etc. The machine is also expected to be one of the satellites of the E-XFEL infrastructures. Such reasonable networking of European and global FEL activities guarantees its optimal usage and development. There is no doubt, that the LCLS accelerator and laser complex and its development to LCLS II has a profound influence on the local activities in the debated area in this country.

VII. CONCLUSIONS

Commissioning of the full LCLS accelerator – laser complex as a very effective user and machine development laboratory requires considerable simplification of the user and operator interfaces, training of users and operators and construction of dedicated and standardized experimental set ups. Users and machine experts from this country are also active in these processes. This paper was prepared using public and Intranet materials from the LCLS, and other FEL web pages, as well as from LCLS users, relevant talks and presentations. Some fragments of the text were quoted from these resources [1-4,26].

VIII. ACKNOWLEDGMENTS

The author would like to thank POLFEL (NCBJ), FLASH and EXFEL (DESY), and TIARA (CEA), EuCARD (CERN) management for cooperation. Within these networked cooperation the experts from WUT are working at the realization of the FLASH and the EXFEL, and are using LCLS facilities.

REFERENCES

[1] SLAC Linac Coherent Light Source: lcls.slac.stanford.edu

[2] European FEL Network: www.eurofel.org

[3] R.Romaniuk, POLFEL – A free electron laser in Poland, Photonics Letters of Poland, 1 (3), pp.103-105 (2009)

[4] R.S.Romaniuk, POLFEL – laser na swobodnych elektronach w Polsce, Elektronika, vol.51, nr 4, str. 83-87 (2010)

[5] R.S.Romaniuk, Photonics applications and web engineering: WILGA May 2013, Proc.SPIE 8903, art.no.890303 (2013)

[6] R.S.Romaniuk, Accelerators for society: succession of European infrastructural projects: CARE, EuCARD, TIARA, EuCARD2, Proc.SPIE 8903, art.no.890320 (2013)

[7] R.S.Romaniuk, European X-Ray Free Electron Laser (EXFEL): local implications, Proc.SPIE 8903, art.no.8903OP (2013)

[8] R.S.Romaniuk, Accelerator science and technology in Europe 2008-2017, Proc.SPIE 8903, art.no.89031P (2013)

[9] R.S.Romaniuk, Europejski laser rentgenowski, Elektronika, vol. 54, no. 4, str.149-154 (2013)

[10] J.Gajda, R.S.Romaniuk, Laser technology and applications 2012 – a preview, Proc.SPIE, vol. 8454, art no. 845418, 2012

[11] R.S.Romaniuk, Fizyka fotonu i badania plazmy, Wilga 2012, Elektronika, vol.53, nr 9,2012, str. 170-176

[12] R.S.Romaniuk, Lasery rentgenowskie LCLC i LCLS II – SLAC, Elektronika, vol. 54, no. 4, str.66-69 (2013)

[13] R.S.Romaniuk, EuCARD-2, Elektronika, vol. 54, no. 3, str.114-119 (2013)

[14] R.S.Romaniuk, Akceleratory dla społeczeństwa TIARA 2012, Elektronika, vol. 54, no. 3, str.108-112 (2013)

[15] R.S.Romaniuk, Technika akceleratorowa i eksperymenty fizyki wysokich energii, Wilga 2012, Elektronika, vol. 53, Nr 9, 2012, str. 162 – 169

[16] R.S.Romaniuk, Accelerator science and technology in Europe: EuCARD 2012, Proceedings SPIE, vol. 8454, art no. 84540O (2012)

[17] R.Romaniuk, Accelerator infrastructure in Europe EuCARD 2011, International Journal of Electronics and Telecommunications, vol.57, no.3, pp.413-419, 2011

[18] R.Romaniuk, EuCARD 2010 accelerator technology in Europe, International Journal of Electronics and Telecommunications, vol.56, no. 4, pp.485-488, 2010

[19] R.Romaniuk, EuCARD i CARE - Rozwój techniki akceleratorowej w kraju, Elektronika, vol.49, nr.10, 2008, str. 12-17

[20] R.Romaniuk, K.Pozniak, Metrological aspects of accelerator technology and high energy physics experiments, Measurement Science and Technology, vol.18. no.8, art.no.E01, 2008

[21] P.Fąfara, K.T.Pozniak, R.S.Romaniuk, et al., FPGA-based implementation of a cavity field controller for FLASH and X-FEL, Measurement Science and Technology, vol.18, no.8, pp.2365-2371, 2008

[22] T.Czarski, K.T.Pozniak, R.S.Romaniuk, et al., Superconducting cavity driving with fpga controller, Nuclear Instruments and Methods in Physics Research A, vol.568, no.2, pp.854-862, 2006.

[23] T.Czarski, K.T.Pozniak, R.S.Romaniuk, et al., TESLA cavity modeling and digital implementation in fpga technology for control system development, Nuclear Instruments and Methods in Physics Research A, vol.556, no.2, pp.565-576, 2006

[24] T.Czarski, K.T.Pozniak, R.S.Romaniuk, et al., Cavity parameters identification for TESLA control system development, Nuclear Instruments and Methods in Physics Research A, vol.548, no.3, pp.283-297, 2005

[25] R.S.Romaniuk, Visions for the future of particle accelerators, Proc.SPIE 8903, art.no.890324 (2013)

[26] PolFEL Technical Design Report (TDR), NCBJ, Warsaw-Świerk, 2012