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Laser Technology and Applications 2012

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***Abstract*—The research and technical achievements in the area of lasers are summarized every three years by the National Symposium on Laser Technology held in the Baltic See Resort Świnoujście near Szczecin, Poland. The paper presents a review of the main symposium subjects tracks debated during this key national laser event in September 2012. There are shown development tendencies of laser materials and technologies and laser associated branches of optoelectronics in this country, including the efforts of academia, governmental institutes, research businesses and industry. The symposium work are divided to two branches: development of lasers and laser applications, where the laser systems operators and laser users present their achievements. Topical tracks of the meeting are presented, as well as the keynote and invited subjects delivered by key representatives of the laser industry. The STL 2012 was a jubilee meeting held for the X^{th} time.**

***Keywords*—lasers, laser technology, lasing materials, optoelectronics, laser theory, laser design, laser components, kinds of lasers, semiconductor lasers, VCSEL, laser applications, photonics, nonlinear photonics, active optical fibers, optical fiber lasers, high power lasers, high intensity lasers, laser atomic clocks**

I. Introduction

EVERY three years the organization team of then Technical University of Szczecin and now West Pomeranian University of Technology in Szczecin duly prepares a cyclic National Symposium on Laser Technology (STL). The 2012 STL was held in Świnoujście near Szczecin in September. The Symposium is intentionally held as a national event to enable a free exchange of research, technology, construction and application ideas. Here we present a review of the works presented during this key event of the local research, technical and application communities of lasers. The works carried on in this country today concern technology of laser materials, construction of new lasers and associated equipment as well as laser applications. Many technical teams participate in laser oriented European structural and framework projects, sharing and proliferating in this way the laser associated Intellectual Property. This conference summary paper was also published in the meeting proceedings.

Laser technology is an important practical tool, and simultaneously a driving force, of development for many branches of science, technology, medicine and industry. It embraces: optical and lasing material technology, laser construction, and laser applications. Materials are optical, optoelectronic, passive, active, nonlinear, crystals, semiconductors, glasses, and many more. Laser construction concerns optimization of existing solutions as well as searching for novel ones. There are researched materials, components, laser devices, manufacturing technologies and measurement techniques for laser parameters. The kinds of researched lasers include: semiconductor, photonic, gas, ion, solid state including DPSS, free-electron and others. Optical signals are subject to generation, amplification, synchronization, mixing, frequency multiplication, up and down conversion, forming into pulse shape, widening, narrowing, collapsing into solitons, etc. Applications of lasers concern such areas like: material processing, biology, industry, environment monitoring and protection, safety, medicine, etc.

Laser technology is intensely developing in this country since the sixties. The first laser was launched/fired in this country in 1969 nearly simultaneously at WAT and PW. The first research teams were formed at Military Academy of Technology WAT (prof. Z. Puzewicz) and at Warsaw University of Technology PW (prof. W. Woliński), as well as at the Adam Mickiewicz University in Poznań (prof. A. Piekara and prof. F. Kaczmarek). The domestic research and technical community of laser technology meets since 25 years during the national laser symposia. These symposia are organized traditionally in Świnoujście, under the auspices of Committee of Electronics and Telecommunications, Polish Academy of Sciences (PAN), Polish Committee of Optoelectronics, Association of Polish Electrical Engineers, Photonics Society of Poland, by the West Pomeranian University of Technology (formerly Szczecin University of Technology), in cooperation with Military University of Technology and Warsaw University of Technology. The jubilee tenth symposium was organized during the last week of September 2012. The paper contains a debate on chosen topical paths presented by national laser technology centers, University based, Research Institutes, Government Laboratories and Innovative Businesses, in Gdańsk, Białystok, Kraków, Wrocław, Poznań, Warsaw, Kielce, Gliwice and Toruń as well as some others. International cooperation of these communities is emphasized, especially within the large European FP7 research projects on laser technology and photonics. The aim of the conference was to summarize three year achievements of the national laser research community co-financed by the national science agencies and the EU [1]–[67]. The symposium sessions are organized in two major groups of topics: laser theories, simulations and analyses, laser materials, technologies, constructions, laser development; and laser applications from two points of view – by laser constructors and operators and mainly by laser users.

II. Optical Frequency Combs and Optical Atomic Clocks

The OFC (optical frequency comb) technology is developed in UW-IFT Warsaw and in PWr Wrocław by laser research

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teams using semiconductor lasers and optical fibers. Nonlinear effects are employed to convert nonlinearly the optical frequency comb from the telecom band to other bands like to the NIR or fiber telecom region. The combs are generated using amplitude modulation of a continuous wave laser as well as by a stabilization of the pulse train generated by a mode locked laser, also by super-continuum generation by deep self-phase modulation in nonlinear photonic crystal fiber. Combs spanning for more than an octave are used for ultra-precise measurements of reference phase and frequency. OFC with controlled base frequency f_o and separation (tooth spacing) f_r are used for mapping optical frequencies into the RF. This techniques is used for direct, thus very precise, measurements of the optical frequencies. Precise optical clock techniques, using OFC, are applied in measurement systems. An optical frequency is overlapped with a single tooth of the OFC on a photodiode resulting in a RF beating signal compared to the RF reference.

Ultimately precise measurement of time is a foundation for such technologies as broadband communication networks, GPS navigation, and many more. Optical atomic clock uses electronic transition frequency in the optical region of the EM spectrum of atoms as a frequency standard for a particular timekeeping component. Current atomic clocks use, near absolute zero temperature, atoms slowed down with laser radiation and probed in atomic fountain (cloud) in a cavity. The most accurate classical atomic clock, basing on single trapped ions and ultra-cold neutral atoms in free fall, has the frequency uncertainty 2.3×10^{-16} which may be transferred to ± 1 s per around 140MY. The OFC, which established a coherent link between optical and RF frequencies, is increasingly more regarded as a new emerging standard for ultra-precise time definition of superior precision. Atoms may be trapped in an optical lattice and serve as a quantum reference. The optical lattice clock shows a line-width one order of magnitude narrower than that observed for classical atomic clocks with superior stability.

Optical atomic clock and optical metrology with cold atoms are enablers of new technologies for time reference. To measure time with high accuracy, optical and optical-atom effects are utilized. Optical frequency masters use trapping mechanism. Application of ultra-cold μK atoms allow for ultra-precise spectroscopy and measurement of the frequencies of optical transitions with relative uncertainty of 10^{-18}, thus two orders of magnitude more precise than offered by classical atomic clocks. In other words, the optical frequency of 300 THz is measured with accuracy of mHz. Optical clocks with cold atoms consist of an atomic trap in which a cloud of atoms is controlled in a particular quantum state, cooled down and permanently trapped; ultra stable laser of the line-width less than 1 Hz to sample the resonant frequencies of the atoms; optical frequency comb for precise measurements of distances between particular components of the spectrum. The work is done at UJ in Kraków in cooperation with UW – Warsaw and UMK – Toruń.

III. Ultra Fast Laser Science

Ultra fast science, strongly combined with laser technology, is the study of physical phenomena that occur on short time scales ranging from picosecond to attoseconds. Short laser pulses are enablers in the study of fundamental mechanisms at this time scale including interactions in matter. Especially interesting are ultrafast interactions and processes in novel materials – ultrafast materials science, but also ultrafast nano-magnetism, atomic and molecular dynamics, light induced chemical reactions, nanoscale and biomolecular imaging. Ultrafast science is inherently associated with short wavelength and high pulse intensity lasers. Attosecond pulses are generated using high harmonic generation (HHG) method and sub optical cycle timescale dynamics. Attoseconds in time are, in turn, associated with femtometers in geometrical dimensions. Femtometers in space and attoseconds in time, in combination with optical atomic clocks, setting very precise phase, time and frequency reference frames, allow to observe not only the intra-molecular chemical processes with great time accuracy and geometric precision but also intra-atomic processes. The dimensions of concern inside a proton are of the order of 0,1 fm.

IV. Graphene and Other Laser Materials

Graphene, an allotrope of carbon, paves actively, though not without essential difficulties, its way in electronics and in photonics applications. Here, among the national laser scientists, there is an interest in optical properties of grapheme for applications in optoelectronics, components, optical communications, laser technology, and photonic integrated circuits. Graphene exhibits a saturable absorption under strong excitation in the visible and IR. This effect is used for mode locking in fiber lasers, with graphene based saturable absorber. Ultrafast response of fiber embedded graphene layer is tuned electrically. Giant non-linear Kerr coefficient of graphene is a subject to applied research. Photonic components with propagated solitons are designed with graphene as a medium. Graphene interaction with the EM field is very strong which initiates applied research on fiber coupled free graphene ultra-sensors of the properties of gases and vacuum. Graphene quantum dots of sub 100 nm radius are researched for optoelectronics components. Recently an interest was evoked by a silicon analog of graphene – the silicene. Silicene is manufactured, unlike the graphene, with the aid of laser sputtering and using the self organization techniques of individual atoms. This new allotrope form of silicon is also of interest to laser technology.

The works on graphene applications in laser technology and optoelectronic/photonic components are carried out at Silesian Uni. Technology (T. Pustelny), Wrocław Uni. Technology (K. Abramski), ITME (J. Baranowski, Z. Jankiewicz) and some other places. Graphene is a two dimensional sheet of single layer atoms. Crystalline structure of graphene stems from covalent bonds between C atoms in sp2 hybridization. The sp2 hybridization gives strong and short s bonds in the graphene plane. These bonds are responsible for good mechanical properties of graphene. Apart of s bonds, graphene has resonant p bonds which stem from perpendicular p orbitals to the graphene plane. The p bonds are responsible for electron structure of graphene, thus determine its electrical and optical properties. The valence and conduction bands which are determined by p electrons are degenerated in K points of the Brillouin sphere, which results in zero width of the energy gap. Optical transfers between energy bands are direct. There is a linear dependence between energy of electrons and holes energy on their wave vector. The electrons and holes behave in a relativistic way in graphene. Thus a particular characteristic of the graphene is that the absorption is nondependent on the wavelength, the absorption is constant, from the visible to THz. Graphene is used as a saturable absorber in lasers with self synchronization of modes. It is expected to be applied as an active matrix in quantum THz generators.

V. Quantum Cascade IR Lasers

QCL – quantum cascade IR lasers are unipolar semiconductor lasers with intraband transfers. Classical semiconductor lasers use inter-band transfers. The length of generated radiation, practically, does not depend on the material but on geometry of quantum wells building the active region. QCL may be widely tuned from the NIR, via MIR to FIR. QCL are routinely done from GaAs and InP. Cascade type of radiation generation, i.e. accumulation of optical power from each well, leads to bigger power beams. QCL are used in THz spectroscopy systems like gas pollutions, molecular spectroscopy, short range telecom in open space, and trans-illuminators of dielectrics. Technological experiments and experimental production of THz QCL laser chips is done at ITE Warsaw (M. Bugajski).

Generation/detection of THz wave by lasers can be achieved now using two essential methods, respectively in time and frequency domains. Time domain method uses optical rectification effect, while the frequency method uses optical frequency mixing. The basic problem is construction of a laser generating a double single mode beam of tuned frequency. The biggest application perspective in this area have quantum cascade lasers with external resonant cavity, which generate two tunable beams in the MIR spectral range. Increasing the wavelengths subject to generation of differential frequency by optical mixing, leads to increase/amplification of this process due to the increase of the mutual coherence path. The quantum cascade lasers are build with a double amplifier and inbuilt, in the laser structure, an optical, resonant, nonlinear component. The lasers generate and mix internally two longitudinal frequency modes in the MIR range, what as a result of mixing gives an output THz wave. The obtained beam power is now around tens of μW in the temperature of 80 K and around 1μW in 300 K.

VI. Photonic Integrated Circuits

The major research on the photonic integrated circuits (PIC) is concentrated around the fiber optic communication systems and applications. Increasingly strong interest is drawn recently by biomedical and photonic computing fields. Several architectures of PICs are tested like: AWG (arrayed waveguide grating), DFBLD with EAM – distributed feedback laser diode integrated with electro-absorption modulator, and other ones combining several functions. Since PIC devices require a variety of different materials, unlike the VLSI IC, material choice and optimization for PIC functionalities is a subject of research. The research on InP PIC is expected to simplify optical system design, reduce power consumption and space occupation, increase the reliability, maximize system functionality, widen service flexibility, simplify network operations and reduce cost. Until recently, however, the practical usage of PICs has been quite modest. There is a considerable tendency, supported by the research results, that this situation will change essentially. Practical potential of PICs is very big. So far, the solution were confined to combining the source with the modulator and the detector with the de-multiplexer. Much more complex architectures include not only complex passive signal distribution, for example for quadrature signal detection, but also optical/photonic computing. Addition of all-optical full-featured digital signal processors onboard a PIC, doing such tasks as mathematics, optical Fourier transforms, and inverse transforms, has the potential of speeding the DSP tasks several orders of magnitude, due to the inherently parallel processing in the optics domain.

The theoretical and experimental work on photonic integrated circuits is carried out at IMIO WUT (R. Piramidowicz, P. Szczepanski, M. Malinowski). PICs consist of many optical passive and active components, integrated on a common, most frequently, semiconductor base. This integration now is at the stage of very early electronic ICs. The development tendency is to increase the number of individual components integrated on a single chip. Now this number only rarely crosses over 100. The maximum number ever is several hundred. These PICs allow to construct more complex photonic devices. The advantages of photonic integration are obvious: miniaturization, less material and energy consumption, ruggedness, easy standardization, sure parameters, low cost, increased functionality and efficiency. The work aims at some generalization in the universal description of architecture of today's and near future PICs.

VII. Active Optical Fibers, Fiber Amplifiers and Lasers

Active optical fibers, as well as optical fiber lasers and amplifiers are subject to intense research. Classical erbium doped active optical fibers of high quality are of standardized uniformity and reliability. They are obtained from a number of vendors in a large variety spanning from classical telecom fibers to specialty ones of simpler or advanced design, for particular sensing and optical data processing purposes. They are usually hermetically coated for significant advantage with respect to mechanical ruggedness and resistance to hydrogen induced optical losses and attenuation degradation. These fibers, used for optical amplifiers, are dimensionally and modally compatible with standard SM (single mode) telecom optical fibers. They exhibit inherently low splice loss when coupled with trunk telecom oriented optical fibers. The research goes on special material specialty active optical fibers. These include ultra-low-loss multicomponent glasses, halide and chalcogenide glasses, polymer active fibers, and microstructured active fibers (photonic crystal) made of glass and polymer.

There are a few technological centers in this country that manufacture high quality optical glasses and optical fibers serving as matrices for active optical ions. They are located in Białystok (BUT), Lublin (UMCS), Kraków (AGH) and Warsaw (ITME and WUT). The glasses are doped with rare earths and with transition metal ions to make classical EDFA active optical fibers and fibers for ASE sources and Raman amplifiers. Optical glasses are manufactures for fibers showing luminescence in the spectral region of 1,7 – 2,1 μm. Broad luminescence lines are obtained by simultaneous doping of the glass with several lanthanides. There are presented requirements for the technical conditions and luminescent properties of optical fiber glass matrices doped with ion pairs and ion triplets: Tm3+/Ho3+, Yb3+/Ho3+, Yb3+/Tm3+, Yb3+/Er3+/Tm3+. The types of glass matrices, and their mechanical parameters – deciding of the phonon energy, for fiber core and cladding have some influence on the overall optical properties of the photonic device, pumped with high power LEDs. Constructions of active optical fibers with efficient optical power coupling from the pump to the useful amplified beam are presented. Some of these constructions include asymmetric double clad fibers and multi-core single mode fibers with a phased super-mode.

Semiconductor and glass lasers are also build from structural materials – photonic crystals. For photonic crystal optical fibers (passive and active) the matrix is glass, while for semiconductor lasers from photonic crystals the matrix is AlGaInAs/InP. Photonic crystals for lasers have several advantages for telecommunications applications like: wide work area in a single mode regime (theoretically endless, non-confined), possible reduction of threshold current, possible increase in emitted optical power in the fundamental mode, narrowing of the spectral line-width, possible increase in the rate of digital modulation. Fast optical fiber lasers development was due to the advances in technology of ultra-low-loss active fibers with double cladding, which facilitates optical pumping, and due to spectrally and geometrically fit optical semiconductor pumps. Optical fiber lasers have different characteristics from a family of volume lasers. The lengths of active optical fiber made of glass or photonic crystal vary from a few tens of centimeters to a few tens of meters. The aggregated volume of active material is small. The transverse dimension of fundamental mode is also small, which results in critically low power levels leading immediately to nonlinear effects, and then to the destruction of the structure. Now, optical fiber lasers radiate approximately 10 kW of continuous wave (CW) optical power at the beam quality factor $M^2 \approx 2$. For pulsed wave (PW) lasers, the radiated energy in a ns pulse is around 10 mJ, thus relatively not large. The work on optical fibers and fundamental confinements concerning the quality of the beam are carried out at Military Academy of Technology (WAT) and Warsaw University of Technology (WUT).

VIII. Material Processing

Material processing, apart from medical applications, is the largest application field of lasers. A variety of laser systems are used for material processing like: tunable femtosecond lasers, diode pumped solid state Nd:YAG Q-switched lasers, fiber lasers, CO_2 lasers. Conventional applications include: drilling of metal and ceramics, welding, cutting, surface treating and/or modification, texturing, marking, engraving, patterning, cleaning, rapid prototyping in metals and ceramics, shock peening. The fields of micro and nanofabrication embraces: lab-on-a-chip, fiber sensors, 3D periodic patterns for display and LCD; micro/nano 3D structures for manufacturing fuel cell screens, matrix for ceramic metal composites, carbon nanotube mesh, bone grafts; ultrafast laser micromachining of coronary stents to enhance drug coating and endothelial cell growth; thin film fabrication and patterning of superconductive materials for microelectronics. In biomedical and defense applications, these are: multi-photon and spectral-lifetime imaging and LIBS. In micro and nano-scale fabrication and material processing, lasers aim at high quality and no-heat affected zone, and high precision.

A lot of different techniques of material surface modifications are using lasers. In this country the research in this area is performed in a few centers like in Kielce and predominantly at AGH in Kraków, but also Silesian Uni. Technology in Gliwice and at some other centers. The area of laser surface modification is an extremely large field of laser applications. In modern materials, the surface layers are composites, for example, of titanium nitrides in the metal matrix. Hardness of the surface layers and erosion wear resistance depends strongly on parameters of laser processing and parameters of the processing atmosphere like partial pressure of the nitrogen-argon gas mixture. Titanium alloy is used for the blades of turbofan engine in steam turbines. The fatigue strength is there a key parameter determined mainly by the internal stresses in the nitrated surface layers. The quality of surface processing depends on the beam shape. Application of high power laser diodes not only makes the technological system more rugged, robust, miniature and more reliable and power efficient, but allows to form the multimode, beam in a rectangular form instead of an elliptical (SS YAG and gas lasers) with high uniformity of power distribution. Uniform intensity of laser radiation is very profitable during the surface re-melting and alloying because the treated material is heated uniformly what results in uniform penetration depth and uniform thickness of the surface layer. The works also concern laser hardening, re-melting and enriching steel surface with chromium, tantalum, tungsten and silica, remelting of Stellit 6 and making thin film layers of CeO_2, Bi_2O_3, Al-Fe-C, Mg-Al, TiC by laser ablation. Laser technology enables a precise deposition, by ablation or evaporation methods, of multilayer films on the surface of heavy loaded machine parts. At the total thickness of approximately 1 μm, the layer can be built of a few hundred of nanometer sub-layers (now a few tens). Interlaced thin layers of different hardness create a monolith layer of great adhesion and much more resistant to cracking, yet very hard. The used material systems are for example Ti/TiN, Cr/CrN, TiN/CrN, but also may consist of polymer, ceramics and metal layers mutually interlaced. There are researched and optimized mechanical properties of such meta-material super layers for applications in the machine industry. Apart of increased mechanical ruggedness, they exhibit a property of self lubrication.

IX. Laser Based Ultrasensitive Metrological Systems

Lasers are used in ultrasensitive metrological systems. Laser based compact and/or integrated interferometric circuits are increasingly frequently used in a number of photonic metrological systems. The example is an ultra-precise interferometric positioning. The systems of an automatic positioning of masks and inspection of semiconductor wafers, based on laser interferometry, will require, during the next decade, a resolutions better than 0,1 nm. The respective lithography will use a standard dimension in the order of a few nm. It requires intense research on stable metrological lasers, of ultra-low noises, with precise control systems, detectors and interpolation methods. The work is carried in Lasertex in cooperation with Wrocław University of Technology (PWr). Other laser based precision metrological systems are developed at Silesian Uni. Technology (T. Pustelny). These include: Raman spectroscopy, scanning laser confocal microscopy, two-photon microscopy, laser microscopy with phase detection, fluorescent microscopy of interference contrast, holographic microscopy and optical microscopy of atomic forces, as well as photoacoustic spectroscopy.

X. Medical Lasers in Therapy, Treatment and Optical Diagnosis

Medical lasers are massively used in therapy, treatment and optical diagnosis. This huge field is mastered on the clinical level, in outpatients departments throughout the country, but also still at the research level. Novel laser surgery procedures are under development in combination with endo-techniques and imaging. This concerns in particular optical fiber lasers in combination with photodynamic therapy but also endo-venous laser therapy and cancer cells detection. Lasers in medicine aim generally at bloodless surgery.

Methods and laser based and/or photonic apparatus used for medical diagnostic were presented from several research centers and clinical hospitals. The research on next generation of laser based medical equipment is carried out at WAT in cooperation with WUM, Warsaw (A. Zajac, J. Kasprzak). Optical diagnostic methods use non-coherent radiation, covering UV, VIS and IR spectra, and fully coherent radiation of long and short coherence lengths. Short coherence length white light radiation based equipment evokes special interest because of direct interaction with human vision system. The diagnostic result is an image, different in each case of a different method. Thus, image processing is an inherent part of these technologies. Separate and important group of methods is optical tomography, including OCT. Other tomographical methods are of concern too including: PET, X-ray tomography, ultrasound scanning tomography in combination with optical methods and image processing. Laser technologies in medical diagnostics are on the developing curve.

For diagnosis and therapy, the laser radiation and an active dye like porphyrine can be used. The dye is gathered via complexing reaction with the lipoproteins in pathological places. The diagnosis seeks for these places via activating illumination of the skin, body cavities or using endoscopic techniques. The therapy uses higher illumination power to release single oxygen atoms from the dye, which poison very locally the changed tissue. The method is used in dermatology, ophthalmology and other disciplines of medicine.

XI. Lasers in Technologies of Double Applications

Lasers are favorably used in technologies of double application. Eye safe lasers are researched at WAT (Military Academy of Technology in Warsaw) for multiple applications including safety and security areas and other ones in environment, agriculture, chemical, biological and medical fields. Making the construction of a laser applicable in both fields, defense/security and other one, opens a wider possibility for manufacturing and marketing, as well as releases the demands for key laser parameters. The applications include: laser reference level equipment for construction industry and civil engineering; laser ranging and pointing devices for marine and airborne industries, space technologies, but also civil engineering and biomedical fields, as well as remote sensing, etc. Laser based remote sensing systems are applied practically in fire alarm systems for large forest areas, as well as in national parks and reservations.

Laser driven teledetection (remote sensing) is an area of double usage, in the safety and defence technology, as well as in monitoring and protection of the environment. The remote detection methods perform simultaneously data acquisition and analysis. To monitor remotely threats such as gases, aerosols, fumes, dust, there are used two methods with either a remote or a local sensor. The measurement without a contact with the polluted threat area is realized in an active or passive way. There are used lidars or multispectral thermovision. Narrow band optical filters are adjusted to the absorption ranges of expected gases or other pollutants. The measurement system estimates the changes in beam transmission along the analyzed path inside the polluted area. The measuring characteristics of the lidar depend on the range of the penetrating beam, extension of the monitored area, field of view, and the rate of beam scanning. The measurement technique with usage of the local sensor (or a network of sensors) requires data readout by a wired or wireless method. The work is carried out in Military Academy of Technology (WAT).

XII. HiPER, ELI, E-XFEL – European Infrastructural Laser Research Projects

HiPER and ELI as well as E-XFEL are massive European Infrastructural Laser Research Projects. The research teams for this country (WAT, PW, IFPILM, IF PAN, PWr and others) participate in several European, international and global laser system development projects. The projects of concern include

ELI, HIPER, E-XFEL, FLASH. Some researchers from this country are also cooperating with such large laser experiments like LIFE, NIF, ALMA, etc.

The extreme light infrastructure (ELI) project concerns building of a system with exawatt laser generating ultrashort pulses of 10 fs in duration, and power desity as high as 10^{23}W/cm^2. The laser will be used for: research of light interaction with matter, generation of high energy charged particles, generation of X-ray pulses, relativistic compression of optical pulses in order to obtain the light intensities above 10^{25}W/cm^2 and light pulse durations in the range of atto- and zepto-seconds (10^{-21} s). The project LaserLab Europe is a research network grouping laboratories possessing infrastructures with pulse lasers of high power. The aim is to coordinate the research efforts and cost spending to obtain synergy effect. The subjects of relevance are: attosecond lasers and their applications, high power and medium energy lasers, laser acceleration of particles, lasers in medicine, and femtosecond X-ray sources.

HIPER project concerns construction of the European laser infrastructure for thermonuclear fusion and extreme states of matter. The aim is to build a laser demonstrator capable of producing power from fusion of deuterium and tritium to helium, which is a highly exothermic reaction. The project is complementary to ITER which uses superconducting pulse plasma tokomak. The test system for fusion consists of two lasers: multi-beam nanosecond laser of around 1 MJ energy, and picosecond laser of 100 kJ energy and 10 PW power. The laser set is supplemented by a femtosecond research laser of 1 TW power. High power and high energy lasers are of special interest to the laser fusion research community. The European Union equivalent of the American NIF (National Ignition Facilty) is just the HiPER experiment (High Power laser energy research facility). These systems aim at an experiment of laser-driven inertial confinement fusion (nuclear fusion). Other European experiment in this area is Laser Magajoule. Teams from WAT and IFPiLM in Warsaw participate in several subprojects of these experiments.

In a more traditional way, high power lasers are used for: material processing like welding, cutting, drilling, soldering, marking, surface modification; large scale laser displays; remote sensing, medical applications like surgery; military applications like beam antimissile weapon; laser-driven particle acceleration, laser driven plasma generation, laser induced nuclear transmutations and neutron generation. The researched lasers are usually pumped by high power matrices of laser diodes. High enough wall plug efficiency is investigated for these lasers. Mitigation methods for damage in optics are researched for Q-switched lasers of very high optical intensities. Relevant optical nonlinear effects are applied to build high power fiber lasers like stimulated Raman scattering, Brillouin scattering and four wave mixing. Power scalability is of research concern for high power lasers, with the optimal choice of scalable architectures.

Laser induced thermonuclear fusion experiments are now a reality. In July 2012, after 15 years of work, the NIF at LLNF obtained a nearly target parameters of its 192 laser fusion system. The parameters of the pulse delivered to the DT target were nearly 2 MJ of UV light energy and over 500TW of peak power. The aim is to ignite hydrogen fusion fuel in laboratory conditions and produce more energy than supplied to the target. In ignition experiments, the H in the fuel capsule must be compressed to the density bigger 100 times than the density of Pb. The NIF center is heading for full operability and providing experimental access to user communities of matter research under extreme conditions. LIFE project (laser inertial fusion energy) is one among a few more ones involving precision coordinated laser beams of these parameters. One of the key issues during the construction and tests of the LIFE system was manufacturing of flaw-less optics and hardening the large optical components to high level of optical radiation.

The E-XFEL project concerns construction of an European X-ray laser FEL. Test precursor for this machine is FLASH laser. The laser is under construction in DESY and will start operation in 2013. The shortest wavelength in the fundamental mode will be around 0,05 nm. There is predicted an efficient work of this machine at least in the fifth harmonic. The laser is powered by a 3 km superconducting electron linac of TESLA type, working at 1,3 GHz, with niobium resonators. The resonators work with 35 MV/m EM accelerating field.

The EuroFEL project is an European FEL infrastructures network. The network is build now around the E-XFEL project. The idea is to build a network of smaller FELs, complementary with E-XFEL. The smaller machines would create preparatory community for E-XFEL experiments. The network would multiply access to FELs in Europe.

PolFEL project is, from assumption a part of the EuroFEL network, devoted to building a national FEL complementary with the E-XFEL. The predicted localization of PolFEL machine is The Andrzej Soltan Institute for Nuclear Studies (IPJ) in Świerk, now the National Center of Nuclear Research (NCBJ-NCNR). The work mode would be CW and PW. Machine tuning would cover THz to vacuum ultraviolet (VUV) regions.

EuLasNet is an European laser network organized inside the Eureka initiative. It gathers laser businesses in Europe. It is oriented to applications of lasers in research, industry, metrology, medicine, environment protection, protection of high cultural values. EuLasNet groups national laser networks. In Poland the relevant organization is PolLasNet. Polish Laser Community is organized in the Laser Club, gathering around a hundred of laser experts from academia, industry and government, most of them involved in international cooperation, thus, adding a lot of synergy to the mutual cooperation. Cooperation at such wide network of international laser research projects allows for fast and accurate exchange of expertise in the area of laser science and technology.

XIII. Potential of Laser Technology in this Country

Potential of laser technology in this country was a subject of a panel and community discussions during the STL2012 Symposium. There were drawn some general, but informal conclusions. The laser research potential of this country is large, but its usage is modest. There are around 20 bigger research teams localized in academic centers, governmental institutes and firms, which carry out research and technical work on the construction and applications of lasers. A few of these teams possess bigger research and technical potential. Most of them participate in the European infrastructural and framework projects and/or have international cooperation. The work has current character, and with the exception of only a few examples, these undertakings are local actions only of relatively low budget.

The major topical areas in the laser technology, of relatively bigger funding, with the involvement of national teams are: technology of semiconductor lasers, solid state lasers and gas lasers, construction of laser components; and in the area of laser applications. These are remote sensing, safety, environment monitoring and protection, medicine and cosmetics, and material processing. Laser technology in this country is systematically developing. Active teams enter into European networks and projects, gaining access to big laser infrastructure creating the system of European Research Area.

As far, the critical threshold of building own big national laser infrastructure of European dimensions, combined with international laser centers was not overcome. It seems that the national research and technical laser community should insist on building such a large infrastructure in this country. A number of national laser centers seem to be ready to undertake this initiative and withstand the effort. Building of a big laser infrastructure in Poland is closely combined with participation of a bigger and bigger number of Polish teams in such projects like: ELI, HIPER, E-XFEL, FLASH, ALBA and similar. One of the most interesting and promising possibilities is building of POLFEL. A modern technological park may be build around this large laser research infrastructure leading to the development of local hi-tech industry.

Laser research infrastructure (as well as any other type of modern research infrastructure) fulfills a number of important global and local functions. Confining the considerations to domestic aims, one may mention: amplification of national laser centers, focusing of national and European expert power, possibility to build technological park around big infrastructure of unique character, training of young experts and specialists, and many more. Lack of such large infrastructure of European extent (and even plans for its building) clearly shows that Poland consciously surrenders in this area and resigns from ambitions to belong to a class of nations contributing to the common pool of laser research. This accession efforts should be coordinated at various levels. Such an infrastructure is to be shared inside the ERA system. We have nothing to share actively today. The strength of positive values to possess large infrastructure is so big that it is a duty of the national laser community to keep trying to build one in this country. The aim of the STL periodic symposium and this type of discussion is to proceed along this way.

XIV. Conclusions

The European research community of laser science and technology, including high energy and high power lasers and laser physics is well structured due to common realization of large EC projects. These projects are: ELI, HiPER, FLASH and E-XFEL and some others. Laser research community in this country participates actively in most of these European-scale projects, with large benefit to all sides. The national laser research and commercial market is developing at a very fast pace. The STL 2012 summarized well the current developments and achievements of this vivid community. The next National Laser Technology Symposium is predicted for 2015.

References

[1] "Laser Technology Symposium," [http://www.stl.zut.edu.pl].
[2] R. Romaniuk, "Manufacturing and characterization of ring-index optical fibers," *Optica Applicata*, vol. 31, no. 2, pp. 425–444, 2001.
[3] R. Romaniuk and J. Dorosz, "Multicore single-mode soft-glass optical fibers," *Optica Applicata*, vol. 29, no. 1, pp. 15–49, 1999.
[4] J. Dorosz and R. Romaniuk, "Fiber Optics Department of Biaglass Co. twenty years of research activities," *Optica Applicata*, vol. 28, no. 4, pp. 267–291, 1998.
[5] ——, "Multicrucible technology of tailored optical fibress," *Optica Applicata*, vol. 28, no. 4, pp. 293–322, 1998.
[6] R. Romaniuk, "Tensile strength of tailored optical fibres," *Opto-electronics Review*, vol. 8, no. 2, pp. 101–116, 2000.
[7] ——, "Capillary optical fiber – design, fabrication, characterization and application," *Bulletin of the Polish Academy of Sciences: Technical Sciences*, vol. 56, no. 2, pp. 87–102, 2008.
[8] R. Romaniuk, et al., "Optical network and fpga/dsp based control system for free electon laser," *Bulletin of the Polish Academy of Sciences: Technical Sciences*, vol. 53, no. 2, pp. 123–138, 2005.
[9] A. Dybko, et al., "Assessment of water quality based on multiparmeter fiber optic probe," *Sensors and Actuators, B: Chemical*, vol. 51, no. 1–3, pp. 208–213, 1998.
[10] A. Dybko, R. Romaniuk, W. Wroblewski, and Z. Brzozka, "Efficient reagent immobilization procedure for ion-sensitive optomembranes," *Sensors and Actuators, B: Chemical*, vol. 39, no. 1–3, pp. 207–211, 1997.
[11] ——, "Applications of optical fibres in oxidation-reduction titrations," *Sensors and Actuators, B: Chemical*, vol. 29, no. 1–3, pp. 374–377, 1995.
[12] ——, "Polymer track membranes as a trap support for reagent in fiber optic sensors," *Journal of Applied Polymer Sciences*, vol. 59, no. 4, pp. 719–723, 1996.
[13] B. Mukherjee, et al., "Application of low-cost Gallium Arsenide light-emitting-diodes as kerma dosemeter and fluence monitor for high-energy neutrons," *Radiation Protection Dosimetry*, vol. 126, no. 1–4, pp. 256–260, 2007.
[14] R. Romaniuk and K. Pozniak, "Metrological aspects of accelerator technology and high energy physics experiments," *Measurement Science and Technology*, vol. 18, no. 8, 2008, art. no. E01.
[15] P. Fafara, K. Pozniak, and R. 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.
[16] A. Burd, K. Pozniak, and R. Romeniuk, et al., "Pi of the sky – all-sky, real-time search for fast optical transients," *New Astronomy*, vol. 10, no. 5, pp. 409–416, 2005.
[17] A. Burd, L. Mankiewicz, G. Wrochna, K. Pozniak, and R. Romaniuk, et al., "'Pi of the sky' – automated search for fast optical transients over the whole sky," *Astronomische Nachrichten*, vol. 325, no. 6–8, p. 674, 2004.
[18] W. Ackerman, et al., "Operation of a free-electron laser from the extreme ultraviolet to the water window," *Nature Photonics*, vol. 1, no. 6, pp. 336–342, 2007.
[19] T. Czarski, K. Pozniak, and R. 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.
[20] ——, "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.
[21] ——, "Cavity parameters identification for TESLA control system development," *Nuclear Instruments and Methods in Physics Research A*, vol. 548, no. 3, pp. 283–297, 2005.

[22] R. S. Romaniuk, "Petabit photonic internet," *Photonics Letters of Poland*, vol. 3, no. 2, pp. 91–93, 2011.
[23] P. Obroślak, K. Pozniak, and R. Romaniuk, et al., "Digital techniques for noise reduction in ccd detectors," *Photonics Letters of Poland*, vol. 2, no. 3, pp. 134–136, 2010.
[24] R. Romaniuk, "Wilga photonics and web engineering 2010," *Photonics Letters of Poland*, vol. 2, no. 2, pp. 55–57, 2010.
[25] ——, "Geometry design in refractive capillary optical fibers," *Photonics Letters of Poland*, vol. 2, no. 2, pp. 64–66, 2010.
[26] ——, "Modal structure design in refractive capillary optical fibers," *Photonics Letters of Poland*, vol. 2, no. 1, pp. 22–24, 2010.
[27] ——, "'the Photonics Letter of Poland' A new peer-reviewed internet publication of the Photonics Society of Poland," *Photonics Letters of Poland*, vol. 1, no. 1, pp. 1–3, 2009.
[28] G. Kasprowicz and R. Romaniuk, et al., "CCD detectors for wide field optical astronomy," *Photonics Letters of Poland*, vol. 1, no. 2, pp. 82–84, 2009.
[29] R. Romaniuk, "Wilga symposium on photonics applications," *Photonic Letters of Poland*, vol. 1, no. 2, pp. 46–48, 2009.
[30] ——, "POLFEL – A free electron laser in Poland," *Photonics Letters of Poland*, vol. 1, no. 3, pp. 103–105, 2009.
[31] T. R. Wolinski and R. Romaniuk, "Photonics Society of Poland established," *Metrology and Measurement Systems*, vol. 15, no. 2, pp. 241–245, 2008.
[32] R. Romaniuk, "Search for ultimate throughput in ultra-broadband photonic Internet," *International Journal of Electronics and Telecommunications*, vol. 57, no. 4, pp. 523–528, 2011.
[33] ——, "Photonics and web engineering 2011," *International Journal of Electronics and Telecommunications*, vol. 57, no. 3, pp. 421–428, 2011.
[34] ——, "Accelerator infrastructure in Europe EuCARD 2011," *International Journal of Electronics and Telecommunications*, vol. 57, no. 3, pp. 413–419, 2011.
[35] J. Dorosz and R. Romaniuk, "Development of optical fiber technology in Poland," *International Journal of Electronics and Telecommunications*, vol. 57, no. 2, pp. 191–197, 2011.
[36] R. Romaniuk, "Advanced photonic and electronic systems Wilga 2010," *International Journal of Electronics and Telecommunications*, vol. 56, no. 4, pp. 479–484, 2010.
[37] ——, "EuCARD 2010 accelerator technology in Europe," *International Journal of Electronics and Telecommunications*, vol. 56, no. 4, pp. 485–488, 2010.
[38] W. Wojcik and R. Romaniuk, "Development of optical fiber technology in Poland," *International Journal of Electronics and Telecommunications*, vol. 56, no. 1, pp. 99–104, 2010.
[39] J. R. Just, et al., "Highly parallel distributed computing system with optical interconnections," *Microprocessing and Microprogramming*, vol. 27, no. 1–5, pp. 489–493, 1989.
[40] R. S. Romaniuk, "Multicore optical fibres," *Revue Roumaine de Physique*, vol. 32, no. 1–2, pp. 99–112, 1987.
[41] ——, "Wilga Photonics Applications and Web Engineering, January 2012," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 845402.
[42] ——, "Astronomy and Space Technologies, Photonics Applications and Web Engineering, Wilga May 2012," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 845403.
[43] ——, "Accelerator Technology and High Energy Physics Experiments, Photonics Applications and Web Engineering, Wilga May 2012," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 845404.
[44] ——, "Photon Physics and Plasma Research, Photonics Applications and Web Engineering, Wilga May 2012," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 845405.
[45] ——, "Optoelectronic Devices, Sensors, Communication and Multimedia, Photonics Applications and Web Engineering, Wilga May 2012," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 845406.
[46] ——, "Biomedical, Artificial Intelligence and DNA Computing, Photonics Applications and Web Engineering, Wilga May 2012," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 845407.
[47] ——, "Accelerator Science and Technology in Europe – EuCARD 2012," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 84540O.
[48] J. Gajda and R. S. Romaniuk, "Laser technology and applications: a preview," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 845408.
[49] A. Zagozdzinska, K. T. Pozniak, and R. S. Romaniuk, "Heavy stable charged particles search by novel pattern comparator processor," *Proceedings of SPIE*, vol. 8454, 2012, art. no. 84540P.
[50] The CMS Collaboration, S. Chatrchyan, K. Pozniak, and R. Romaniuk, et al., "Commissioning of the CMS experiment and the cosmic run at four tesla," *Journal of Instrumentation*, vol. 5, no. 3, 2010, art. no. T03001.
[51] The CMS Collaboration, S. Chatrchyan, K. Pozniak, R. Romaniuk, and W. Zabolotny, et al., "Performance of CMS muon reconstruction in cosmic ray events," *Journal of Instrumentation*, vol. 5, no. 3, 2010, art. no. T03022.
[52] ——, "Performance and operation of the CMS electromagnetic calorimeter," *Journal of Instrumentation*, vol. 5, no. 3, 2010, art. no. T03010.
[53] ——, "Measurement of the muon stopping power in lead tungstate," *Journal of Instrumentation*, vol. 5, no. 3, 2010, art. no. T030o7.
[54] ——, "Identification and filtering of uncharacteristic noise in the CMS hadron calorimeter," *Journal of Instrumentation*, vol. 5, no. 3, 2010, art. no. T03014.
[55] K. T. Pozniak, R. S. Romaniuk, T. Czarski, and W. Geirgusiewicz, et al, "FPGA and optical network based LLRF distributed control system for Tesla-XFEL linear accelerator," *Proceedings of SPIE*, vol. 5775, pp. 69–77, 2005, art. no. 08.
[56] W. Giergusiewicz, W. Jalmuzna, K. Poznaik, and R. S. Romaniuk, et al., "Low latency control board for LLRF system – Simcon 3.1." *Proceedings of SPIE*, vol. 5948 II, pp. 1–6, 2005, art. no. 59482C.
[57] The CMS Collaboration, S. Chatrchyan, K. Pozniak, and R. S. Romaniuk, et al., "Performance of CMS muon reconstruction in cosmic ray events," *Journal of Instrumentation*, vol. 5, no. 3, 2010, art. no. T03022.
[58] T. Czarski, R. Romaniuk, and K. Pozniak, et al., "Cavity control modeling and simulations for Tesla linear accelerator and free electron laser," *Proceedings of SPIE*, vol. 5484, pp. 69–87, 2004.
[59] A. Dybko, W. Wroblewski, J. Maciejewski, and R. Romaniuk, et.al., "Fiber optic probe for monitoring of drinking water," *Proceedings of SPIE*, vol. 3105, pp. 361–366, 1997.
[60] T. Czarski, K. Pozniak, and R. Romaniuk, et al., "Tesla cavity modeling and digital implementation with FPGA technology solution for control system development," *Proceedings of SPIE*, vol. 5484, pp. 111–129, 2004.
[61] K. T. Poźniak, T. Czarski, and R. Romaniuk, "Functional analysis of DSP blocks in FPGA chips for application in Tesla LLRF system," *Proceedings of SPIE*, vol. 5484, pp. 130–138, 2004.
[62] W. Zabołotny, P. Roszkowski, K. Kierzkowski, K. Pozniak, and R. Romaniuk, et al., "Distributed embedded PC based control and data acquisition system for Tesla cavity controller and simulator," *Proceedings of SPIE*, vol. 5484, pp. 171–179, 2004.
[63] K. T. Poźniak, T. Czarski, and R. Romaniuk, et al., "FPGA based Simulator and controller for Tesla test facility," *Proceedings of SPIE*, vol. 5775, pp. 9–21, 2005, art. no. 02.
[64] P. Pucyk, T. Jezynski, K. Poznaik, and R. Romaniuk, et al., "Doocs server and client application for FPGA based Tesla cavity controller and simulator," *Proceedings of SPIE*, vol. 5775, pp. 52–60, 2005, art. no. 06.
[65] R. S. Romaniuk and J. Dorosz, "Measurement techniques of tailored optical fibers et al." *Proceedings of SPIE*, vol. 5064, pp. 210–221, 2003.
[66] R. S. Romaniuk, "Optical fiber transmission with wavelength multiplexing: faster or denser?" *Proceedings of SPIE*, vol. 5484, pp. 19–28, 2004.
[67] T. Filipek, K. Pozniak, and R. Romaniuk, et al., "Fast, synchronous distribution network of data streams for RPC muon trigger in CMS experiment," *Proceedings of SPIE*, vol. 5775, pp. 139–149, 2005, art. no. 15.