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Development of laser technology in Poland

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The paper presents chosen development threads of laser technology and associated branches of optoelectronics in this country. An occasion to summarize the work and show their current status is the 50 th anniversary of construction of the first laser. The first laser in Poland was launched successfully in 1969, almost simultaneously at WAT and PW. Domestic achievements in this area are summarized every three years by Symposium on Laser Technology held traditionally in Świnoujście. The work carried on in Poland concerns 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.

Keywords: hlasers, laser technology, lasing materials, optoelectronics, laser theory, laser design, kinds of lasers, semiconductor lasers, laser applications, photonics

1. LASERS AND LASER TECHNOLOGY

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. The 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, excimer, free-electron and others. Optical wave in laser technology is subject to generation, amplification, synchronization, mixing, frequency multiplication up and down, forming into pulse shape. Applications of lasers concern such areas as: material processing, biology, industry, environment monitoring and protection, safety, etc.

This year, there is the 50 th anniversary of laser discovery. Lasing phenomenon itself was predicted a few years earlier. Laser technology has been intensely developing in this country since the sixties. The first laser was launched in Poland in 1969. 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. F. Kaczmarek). The domestic research and technical community of laser technology have been meeting for 25 years at 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 ninth symposium was organized during the last week of September 2009. The paper contains a debate on chosen topical threads presented by national laser technology centers in Kraków, Wrocław, Poznań, Warsaw, Kielce, Gliwice and others.

2. NEW LASER MATERIALS

The researched laser materials include crystals like double wolframides doped with ytterbium, wanadides doped with lantanides and glasses, in particular glass optical fiber lasers of particular properties like high power ones. The researched materials that are pumped with a semiconductor laser, are subject to measurements of spectroscopic characteristics, in order to determine the conditions for light generation. The active cross sections for absorption of pump light and respective active cross sections for light emission are determined. There are observed relaxation processes for energy states of active ions and analysed parasitic processes. Possibilities for energy up-conversion from the IR spectrum to the visible are researched. The influence of dopant concentration on lasing characteristics is also evaluated. The work is carried in the Institute of Low Temperature and Structure Research of the Polish Academy of Sciences in Wrocław (INTiBS PAN).

Thin garnet layers are doped with transitional metal ions (Cr, Ni, Co). These ions possess broad emission spectral lines, that allow tunable generation in a wide spectrum. They are also used as sensitizers in systems doped with lanthanides. Tunable lasers based on transitional metal ions can potentially find application in amplifiers and optical generators and Q modulators of laser resonators.

Oxide crystals having stoichiometric Nd^{3+}ions, doped with Yb^{3+}ions, and illuminated with optical pump, exhibit photo-thermal phenomenon. Energy is exchanged between Nd and Yb ions. This effect can be maximized via the choice of the matrix material and concentration of active ions. The external result of the effect is a shift of the luminescence wavelength, which may be used for optical switching. The work is carried in Institute of Electronic Materials Technology (ITME).

3. SEMICONDUCTOR LASERS

Semiconductor lasers are used as optical pumps in many devices and assemblies, as in the construction of hybrid lasers, for building of optical fiber lasers for numerable telecommunication applications. The lasers for telecommunications are strictly standardized because of costs and direct cooperation with standardized telecom oriented optical fibers. The parameters of optical pumps are as follows: single emitter, edge emitting, laser diodes, of the stripe width smaller than 100 μm, with a considerable length of the resonator, of maximum energy efficiency and high emitted power, with the biggest possible brightness or the smallest possible beam divergence. The beam divergence is critical because of small values of numerical apertures in telecom optical fibers. Semiconductor optical pumps are optimized for losses in the resonator and increase of the effective waveguide width and stabilization of the threshold current, which in turn stabilizes electrical and thermal laser parameters.

Semiconductor lasers are bipolar components with a p-n junction, directly polarized. This junction is an active region of a laser. Lasing action bases on inter-band transitions of carriers. The length of generated wave depends on kind of material and width of the energy band. Quantum cascade lasers are a new class of semiconductor unipolar components (as opposite to bipolar). Lasing is a result on intra band transitions of electrons (as opposite to inter-band ones). The active region is a multiple quantum well. The generated wavelength depends on the geometry of the quantum wells. Materials such as AlGaAs and InP give the possibility to generate waves from IR to THz. There are investigated pulse components, working with Peltier stack, for MIR. They generated 1W of optical power in 240K. The work is carried in Institute of Electron Technology in Warsaw(ITE).

Gallium nitrides GaN,InGaN, AlGaN are used to build semiconductor lasers, for the following applications, that require high optical power: writing optical information and data, printing, optical laser projectors, laser displays. To obtain high optical power, at not very big exciting current densities, and at not very high requirements for beam quality, laser matrices with multi-emitter construction are used. Individual lasers in the matrix may couple together via the optical field in the substrate, which leads to the work mode in a single transverse mode of the resonator and results in a high power emission of a very narrow spectral line. A coherence of the emitters is obtained when they are positioned close enough to each other in the matrix. The work is carried in Institute of High Pressure Physics of the Polish Academy of Sciences (IWC PAN).

4. PHOTONIC CRYSTAL LASERS

Semiconductor and glass lasers are also built of 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 linewidth, possible increase in the rate of digital modulation.

5. OPTICAL FIBER LASERS

Fast optical fiber lasers development was due to progress 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 and Warsaw University of Technology (WUT).

Optical fiber lasers find broad applications in photovoltaics, optical fiber communications, medicine, cosmetics, material processing, welding, industry, imaging systems, and in research. Optical fiber lasers can work in single-wave and multi-wave modes, fit for optical communications WDM standard. Shaping of the multi-wave spectrum is done via a change in the mutual polarization states of the emitted and pumping signals.

Optical fiber lasers are built in a cascade geometry, the master oscillator and power amplifier configuration (MOPA). The cascade is used for pulse work mode. It is easier to control low power semiconductor or optical fiber laser starting the cascade, than a high power laser finishing the cascade. The parameters to be controlled are pulse repetition frequency, time duration and shape of the pulse and wavelength. The cascade consists of a source (semiconductor or optical fiber) and two or three optical fiber amplifiers. The first stage of the cascade is a preamplifier of very high amplification and optimized very low noise. The second stage uses optical fiber with a double cladding for maximal pumping. The third stage of the cascade is either a multimode fiber or a single mode with very large effective modal area.

6. HYBRID, ION AND GAS LASERS

This not very single meaning term 'hybrid' is used for a serial connection of two or more different lasers where the first one pumps the next one. The pump is usually an optical fiber laser (or a number of lasers), and the output beam of the hybrid cascade is generated by a volume laser. Hybrid lasers emitting in this part of the NIR spectrum which is safe for human eye, i.e. 1.4-2.2 μm are used for pulse atmospheric lidars, tuned spectrally for particular absorption lines of substances in the atmosphere like water vapor, carbon dioxide, hydrocarbons. The mentioned wavelengths are generated in matrices doped with thulium and holmium (optical fibers and crystals YLF, YAG). A tunable laser $Ti{:}Al_20_3$ pumped with a pulsed neodymium laser may possess internal resonator conversion to the second harmonic.

There is also carried work on gas lasers: He-Xe excited by RF method and ion lasers Ar-Kr.

7. EYE SAFE LASERS

Various types of a laser equipment work with an open, free space accessible beam. These are the following applications of lasers: distance meters, goniometers, level meters, area confiners, area protection. Working with an open beam, the devices have to protect the safety of the user and accidental persons coming into the working area. The highest radiation intensity, not causing damage to human eye is in the spectral range 1.6-1.65 μm. This range is usually called a "eye safe". The radiation is totally stopped at the surface of cornea and does not penetrate deeper. Eye safe lasers embrace: glass:Nd^{3+} pumped by semiconductor laser diode, Nd lasers with Raman shifter in a form of methane gas chamber, and new solutions – optical parametric oscillators (OPO) from KTP crystal positioned inside Nd Laser, and hybrid lasers Er:YAG pumped with optical fiber laser doped with erbium. The work is carried in Military Academy of Technology (WAT).

8. TERAHERTZ LASERS

Generation 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 has quantum cascade lasers with external resonant cavity, which generates two tunable beams in the MIR spectral range. Increasing the wavelengths subject to generation of differential frequency by optical mixing, leads to increase of this process due to the increase of mutual coherence path. The quantum cascade lasers are built 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 1 μW in 300 K.

Terahertz photo mixer is a nonlinear photonic component, in which optical switching in optical material is performed by means of two interfering laser beams, with THz frequency. Periodic intensity of the interfering beams switches the optical key. The effect is amplified by a THz dipole resonant antenna. The generated THz beam is collimated in the material by a silica lens of high resistivity. The radiated beam out of the material (into the free space) is collimated by a polymer lens or by parabolic mirrors. The beam, after penetrating through the investigated object, is detected by a dedicated semiconductor or bolometric matrix, or by an analogous terahertz photo-mixer – excited by identical two laser beams, as in the transmitter. The photo-mixer receiver is an analog to homodyne coherent detection in the radio frequency (RF) range. One of the materials, where the photo-mixing is realized is low temperature GaAs.

9. OPTICAL MASTER CLOCKS

To measure time with high accuracy, optical and optical-atom effects are utilized. Optical atom clock, similarly to microwave cesium master oscillator, consists of three major components: atom master resonator for reference frequency, a laser tuned to the frequency of master oscillator and optical frequency comb. The atom reference clock uses cold μK, trapped, slowed down optically and magnetically strontium atoms. The expected accuracy of the optical reference clock is in the order of 10^{-18}, thus bigger than obtained in the cesium clock. The optical frequency of 300 THz is measured with accuracy of mHz. This work is carried at Jagiellonian University in Kraków (UJ).

10. LASER BASED REMOTE SENSING

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 by 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).

11. LASER DEFENCE AND WEAPON

The European Defence Agency (EDA), under the management of Javier Solana, has turned recently to a very considerable and effective disposition center of the increased European funds in the area of safety. The logistics of the EDA projects and grants is similar to the framework FP system. WAT participates in a number of laser projects embracing laser, directed beam, weapon for destroying rackets and shells, discovery of a sniper, building of a modern helmet with passive and active sensors, building of a an individual safety and protection system for a soldier, tele-detection of improvised explosives, detection of biological weapon by means of laser induced fluorescence, detection of molecularly modified polymers combined with explosive materials.

The sniper discovery system is a hybrid one, consisting of an active laser lidar to find the components of sniper aiming optics, infrared and thermo vision sub-system, miniature radar of low range and acoustic data acquisition and imaging. The system is capable of creating a composite image of the analysed scene. The methods with the creation of a composite image of a very noisy and complex scene are very efficient.

12. 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).

13. LASER LAYER DEPOSITION

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. 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 from increased mechanical ruggedness, they exhibit a property of self lubrication.

14. PHOTODYNAMIC DIAGNOSIS AND THERAPY

For diagnosis and therapy 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.

15. EUROPEAN INFRASTRUCTURAL LASER PROJECTS

The extremal light infrastructure (ELI) project concerns building of a system with exawatt laser generating ultrashort pulses of 10 fs, and power 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, 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: multibeam 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. 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, 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 built 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 multiplicate 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. 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.

16. CONCLUSIONS AND CLOSING REMARKS

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 are local actions 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, material processing.

The laser technology is slowly but systematically developing. Active teams enter into European networks and projects, gaining access to big laser infrastructure creating the system of ERA – 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 built around this large laser.

Large research infrastructure (here laser) 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 the class of nations contributing to the common pool of laser research. Such an infrastructure is to be shared inside ERA system. We have nothing to share actively. 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. These efforts should be coordinated at various levels.

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