Military
University
of Technology

Institute
of Optoelectronics

INSTITUTE OF OPTOELECTRONICS

# Annual Report 2015

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## Institute of Optoelectronics
Military University of Technology

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# PREFACE

In 2015, first time in its history, the Institute of Optoelectronics has accomplished all scientific, educational and organizational capacities of an academic faculty. In the research–development group, being persistently our main area of activity and source of funds, we have carried out above 80 projects including 12 international projects financed by 7PR EU, NATO, EDA H2020-EU, SF) and above 70 projects financed by Ministry of Science and Higher Education, Ministry of Defense, National Centre for R&D, National Science Centre and other national economic institutions. We have submitted 8 patent applications . The most R&D projects have been carried out in the framework of scientific-industrial consortia. Our business partners were large industry concerns , small and medium enterprises and high-tech companies. Above half of our budget was derived from R&D projects for the benefit of the national security and defense. The most important projects are ones within the frameworks of Strategic Program "New Systems of Weapon and Defense regarding Directed Energy", Program TYTAN "Advanced Individual Warfare Systems" , Program PIORUN "Modernization of portable, anti-aircraft missile GROM" and programs dedicated to precise munition, active defense or detection of biological warfare agents. The assistance and consultation of our specialists provided to the Auschwitz-Birkenau State Museum and Chancellery of the Sejm have also an important social impact.

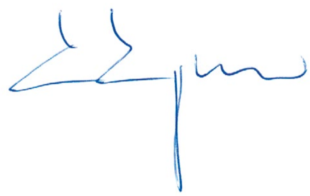
The very important form of scientific activity of IOE is international collaboration. For several years we have been participating in scientific programs of EU, EDA and NATO. Moreover, we have been conducting a number of common projects according to bilateral agreements with teams from several countries all over the world. In this year we have commenced two projects from Horizon 2020.

In 2015 council of IOE have conducted 6 PhDs and 3 habilitations proceedings and started one proceeding for a title of professor. The President of Poland has granted the title of professor to our meritorious colleague, academic teacher Henryk Madura, outstanding specialist in infrared technology and thermal imaging.

On the initiative of Council of IOE, Professor Wiesław Leonard Woliń-

ski, member of Polish Academy of Science, tutor of a few generations of optical engineers in Poland was honored by the Senate of Military University of Technology with the title of doctor honoris causa.
Our two young scientists: Mjr Przemysław Wachulak, D.Sc. and Marta Domańska-Michalska, PhD. were the winners in OPUS 9 and SONATA 9 competitions financed by National Science Centre.
In year 2015 we have intensively enriched our education offer and activity. The first group of students has started the 1-st stage of studies on the newly organized specialization: space and satellite engineering. Our students have continued 2-stage studies on electronics and telecommunications and could have started regular Ph.D studies in electronics. In the framework of Erasmus Mundus Joint Doctorate (EMJD) Program – Extatic 5 foreign doctoral candidates from Italy, Ghana, Pakistan, Ethiopia and Sudan have been preparing in our Institute their PhD. dissertations.
The professors of IOE have gained important awards and distinctions. In August Minister of Defense Tomasz Siemoniak has awarded Ret. Col. Prof. Henryk Madura entry to the Honor Book of Polish Army. Prof. Mieczysław Szustakowski was honored with I Medal of Warsaw Technical University commemorating centenary of its renewal during conference "Integrated optics – sensors, sensing structures and methods" in March 2015.
In April we participated in OPTONexpo – Polish most important conference and exhibition in area of photonics, optoelectronics and laser technology. In May the IOE has hosted for the second time international teams of scientists working on terahertz technology and making joint measurements during NATO RTO SET-193 Field Trials. In July on request of Chief of Department of Defense against Mass Destruction Weapons, the IOE has conducted a training in stand-off detection of chemical and biological contaminations for CBRN Joint Assessment Team. Foreign specialists from JFC Brunssum, JCBRN Defense COE, Armed Forces of Czech Republic and Hungary have participated in this training as well. In June, designed in IOE , LIDAR system for medium-range stand-off detection of biological hazards passed successfully for the second time a 2-week tests in military technology training facility DPG (Dugway Proving Ground) in Utah, US. The first tests took place in DPG in 2013.
In conclusion year 2015 was for IOE the time of successes and dynamic progress, a year full of achievements and important changes in scientific and educational activity. The good development and accomplishments attained in year 2015 allow us to look optimistically into the future of our Institute.

**płk dr inż. Krzysztof Kopczyński**



Dyrektor Instytutu Optoelektroniki

# 1.
# ORGANIZATION STRUCTURE AND SCIENTIFIC TASKS OF INSTITUTE

**Table 1.1.** Distribution of divisions and scientific groups

Organizational structure of the Institute of Optoelectronics in 2015 comprises 4 Divisions, Accredited Testing Laboratory and the Biomedical Engineering Center with 16 research groups (see Table 1)

| Division | Group | Leader |
|---|---|---|
| Laser Technology Division | Laser Matter Interaction Group | prof. H. Fiedorowicz |
| | Solid State Lasers Group | prof. A. Zając |
| | Fiber Lasers Group | J. Świderski, D.Sc. |
| | Laser Optics Group | prof. J. Jabczyński |
| | Laser Application Group | J. Marczak, D.Sc. † |
| Optoelectronic Technologies Division | Laser Teledetection Group | M. Zygmunt, PhD Eng. |
| | Optical Technology Group | Col. K. Kopczyński, PhD. Eng. |
| | Laser Nanotechnology Group | B. Jankiewicz, PhD. |
| | Optical Spectroscopy Group | M. Kwaśny, D.Sc. Eng |
| | Biochemistry Group | A. Padzik-Graczyk, D.Sc. |
| Optoelectronic Systems Division | Optical Signal Detection Group | prof. Z. Bielecki |
| | Security Systems Group | prof. M. Szustakowski |
| | Quantum Electronics Group | prof. Z. Puzewicz |
| Infrared Technology and Thermovision Division | Thermal Detection and Thermovision Group | prof. H. Madura |
| Accredited Testing Laboratory | | J. Janucki, PhD. Eng. |
| Biomedical Engineering Center | | M. Łapiński, D.Sc. , M.D. |

At the end of 2015, the staff of the IOE consisted of above 200 employees including 104 scientific workers, 12 professors, 13 D.Sc's, and 63 PhD.'s. Thirty-nine of these scientific workers were <35 years of age, among whom 34 were Ph.D. students. The Council of the Institute (comprising 11 professors and 11 D.Sc.'s) can award a D.Sc (doctor habilitatus) and Ph.D. degrees in electronics.

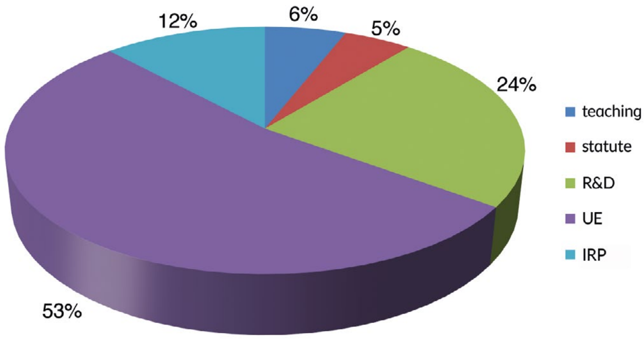



**Figure. 1.1.** Distribution of financial sources of the IOE in 2015

The structure of the finances was not changed in the 2015. The activity in research- development has remained the main d source of incomes, however the activity in the education field was increased significantly. The R-D works, conducted in the framework of 89 projects, were financed from several sources (see Fig. 1.1., Appendix 2). The research results have been presents in 246 scientific publications and reports including 60 articles published in the journals included in the JCR list.

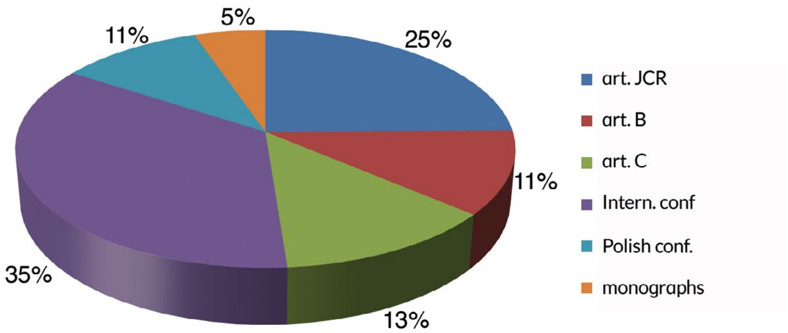



**Figure. 1.2.** Distribution of publications of the IOE in 2015 (total number, 246)

In Chapters 2 - 5 the selected results of R-D works conducted in 2015 were presented.
Below the competence areas, scientific topics and main achievements of divisions were presented

# 1.1. LASER TECHNOLOGY DIVISION

Laser Technology Division conducts fundamental and application studies related to the development of laser sources, laser-plasma soft X-ray (SXR) and extreme ultraviolet (EUV) sources, as well as studies carried out with the use of lasers in military technology, materials engineering, measuring techniques, medicine, and art renovation. The division carries out research on the broad subject of diode pumped lasers (LPD), including: the design of optical systems, resonators, and LPD pulse designs for special and industrial applications; characterization of new active centres and nonlinear crystals; systems of nonlinear radiation conversion that include parametric generation and supercontinuum generation; and studies on the spatial distribution of laser beams. Highly qualified staff, modern laboratories, and extensive equipment ensure a high level of research and education.

**Research Topics:**

- Development and testing of high-efficiency stable sources of laser radiation and their applications in military, technology, and metrology equipment
- Development and testing of pulsed, tunable LPD generating in the 1 - 3 µm spectral range, and their applications in military, technology, and metrology equipment
- Research on fibre-based near- and mid-infrared lasers and supercontinuum sources
- Development, testing, and construction of power supplies and parameter control systems for laser sources
- Development of laser-plasma SXR and EUV radiation sources
- Application of laser-plasma radiation sources in material testing, microscopy, surface engineering, microtreatment, and nanolithography
- Research on the interaction of high energy laser pulses with matter for military technology and nanotechnology
- Research on the process of laser ablation and applications of laser technology in art renovation
- Research on Laser Directed Energy Weapons Systems

**Achievements in last years:**

- diode pumped neodymium lasers Nd:YAG, Nd:YLF, Nd:YVO4, Yb:YAG, Yb:LUAG, lasers generating eye-safe radiation (Er:YAG, Tm:YLF, Tm:YAP, Tm:fiber, Ho:YAG, Ho:YLF), a series of nonlinear radiation conversion systems (OPO, harmonic generation, Raman lasers)
- unique all over the world high-power mid-infrared supercontinuum sources
- novel fibre lasers and amplifiers operating at 1.55 µm and 2 µm

- Creation of micro- and sub-micro-periodic structures on different surfaces, including biocompatible materials, using laser induced interference lithography
- Development and commercialization of technology for art renovation using laser ablation applied to sedimentary rock, gypsum, museum and construction ceramics, animal bones, elephant ivory, fabrics, metal braid, varnishes, and wood
- High-efficiency laser-plasma SXR and EUV radiation sources and their application in pulse radiography, microscopy, micro-treatment, and polymer surface modification

# 1.2. OPTOELECTRONIC TECHNOLOGIES DIVISION

The Optoelectronic Technology Division conducts fundamental and application studies related to the development of optoelectronic materials and technologies for applications in security systems, defence, environmental protection, medicine, and industry. The division is involved in the advanced construction and implementation of complex optoelectronic systems and devices including systems of point and remote detection of hazardous chemicals and biological materials. Fundamental studies carried out in the division mainly involve materials and nanomaterials engineering, optical spectroscopy, materials characterization using advanced research methods, plasmonics, and biotechnology.

**Research Topics:**

- Physics and optics of new types of lasers, in particular those with potential applications in military laser technology systems
- Coherent and incoherent optical detection
- Design of refractive, reflective, and diffractive optical systems
- Optical beam shaping
- Integration of military optoelectronic systems
- Measurement methods and standards for calibration, testing, and standardization of military optoelectronic equipment
- Spectroscopy methods for remote detection of atmospheric pollutants and contaminants, including chemicals and biological materials
- Optical point and stand-off detection of biological and chemical agents
- Laser range-finding
- Measurement of laser speed
- Laser-plasma ion sources for nanotechnology and materials research
- Laser-assisted fabrication of thin films and nanostructures using a pulsed laser deposition (PLD) method
- Measurements of spectral characteristics of optical components
- Optical technology of special laser and infrared elements and components
- Thin film technologies
- Plasmonic nanostructures for use in the detection of chemicals and biological materials
- Spectroscopy in the UV-Vis-NIR range, Raman, Surface Enhanced Raman Scattering, and fluorescence spectroscopies
- Biomaterials
- Analytical procedures for determination of microelements and biologically active compound content in various samples
- Cancer therapies and diagnostics
- Optoelectronic components for space research

**Selected Achievements in last years:**

- LIDARs for stand-off detection of chemical and biological agents
- Laser rangefinders
- Laser speedometers
- Laser shooting and ballistic simulation systems
- Fire detection and explosion suppression systems
- Optoelectronic systems for fire control
- Laser communication links
- UV dosimeters
- UV Solar Blind radiometers
- Laser radiation warning systems
- Optoelectronic solutions for cancer diagnosis

# 1.3. OPTOELECTRONIC SYSTEMS DIVISION

The research and development activities in the Optoelectronic Systems Division focus on applications of new optoelectronic detection systems, fibre and terahertz (THz) technologies in medicine, environment monitoring, and critical infrastructure protection.

**Research Topics:**

- Design of low-noise, highly responsive photoreceivers working in the extreme ultraviolet to long-wavelength infrared radiation range
- Construction and investigation of devices for vapour preconcentration and thermal decomposition of explosive materials
- Design of free space optical transceivers that operate in the longer infrared wavelengths
- Investigation of ultrasensitive optoelectronic sensors for dangerous gases
- Development of air sampling units for breath analyses of people, using laser absorption spectroscopy
- Design of special current drivers for semiconductor lasers used in laser absorption spectroscopy or free space optic setups
- Development of fibre sensors for electronic protection of large objects
- Design, consulting, and commissioning of electronic protection systems for critical infrastructures
- Measurement methods and systems for investigating thermal imaging cameras, TV cameras, night vision devices, laser devices, and multisensor observation devices
- Measurement of the spectral signatures of dangerous materials (explosive materials, drugs) and characterization of composite materials using THz spectroscopy
- Investigations of integrated radar-camera systems for airport and seaport security
- Development related to the modernization of the homing heads of GROM short-range anti-aircraft missiles and P-22 medium-range water-to-water missiles
- Simulation studies of missile homing head subsystems working in the real configuration of the head, simulation of missile flight dynamics (also in the presence of organized jamming)
- Development, modernization, and manufacturing of training systems for operators of mobile short-range anti-aircraft missiles
- Modernization of missiles along with industry, laboratory, and field tests of developed equipment and participation in the modernization of equipment by the manufacturers

**Selected Achievements in last years:**

- Development of optical sensors for trace detection of explosive materials
- Ultra-sensitive sensor of NO2
- Commercialization of a fibre system for perimetric protection of special objects
- Fibre optic sensor for protection of museum collections
- Single-photon sensor to protect and monitor the integrity of the fibre-optic link
- Integrated platform radar-camera for protection of military facilities
- Integrated maritime port security system
- Protection system against pirate ship attacks
- Modernization of anti-aircraft missiles
- Modernization and commercialization of a seeker's detection module for the P-22 water-water type missile
- Development and commercialization of controls and measurement equipment for laboratory and field tests of short-range anti-aircraft missiles

## 1.4. INFRARED TECHNOLOGY AND THERMOVISION DIVISION

The research carried out by the Infrared and Thermovision Technology Division covers non-contact temperature measurements, thermovision measurements, and infrared technology used in devices developed for the Polish Armed Forces. In recent years, the statutory tasks were dedicated to thermographic and spectroradiometric measurements of objects and the development of integrated optoelectronic sensor systems for military applications. The current research of the division focuses on the development of thermovision cameras with cooled and uncooled array detectors.

**Research Topics:**
Military applications of infrared technology:

- Thermo-detection systems for intelligent ammunition
- Multisensor detection systems
- Infrared sensors for protection systems
- Detection systems for infrared objects
- Thermovision cameras with cooled and uncooled detectors
- Thermovision cameras for individual soldier equipment systems
- Thermovision and infrared pyrometry of infrared radiation
- Thermovision measurements and thermal image analysis
- Development and fabrication of infrared pyrometers
- Development and fabrication of infrared radiation sources
- Calibration and standardization of infrared pyrometers
- Characterization of thermovision cameras, visible light cameras, and laser rangefinders
- Testing of thermo-detection components and assemblies
- Measurement of spectral characteristics of infrared detectors
- Measurement of angular characteristics of infrared sensors
- Climatic measurements of infrared detection systems
- Modelling of infrared radiation detection processes
- Simulated operation of thermo-detection systems and devices
- Determination of multispectral signatures of infrared objects
- Determination of the operating range of thermo-detection devices

**Selected Achievements**
**The recently completed targeted projects in collaboration with Przemysłowe Centrum Optyki S.A. resulted in the development of:**

- CTS-1 thermovision sight
- KT-1 camera with cooled detector for fire control systems
- LOP-1 rangefinder-observation binoculars

# 1.5. ACCREDITED TESTING LABORATORY

The Accredited Research Laboratory functions in accordance with quality management systems of research, meeting the requirements of standard PN-EN ISO/IEC 17025, since 1997. The management system is documented and has been issued a certificate (No. AB 109) by the Polish Centre for Accreditation. The results of tests performed by the laboratory are recognized by the International Laboratory Accreditation Cooperation/Mutual Recognition Arrangement (ILAC/MRA).

**Measurement procedures:**

PB-01 – Measurement of laser pulse energy
PB-02 – Measurement of the power of continuous laser radiation
PB-03 – Analysis of the irradiation distribution in laser beam cross sections
PB-04 – Measurement of laser radiation pulse duration and determination of its asymmetry factor
PB-05 – Verification of correction factors and the nonlinearity of laser energy and power meters
PB-06 – Measurement of the absorption coefficient of optical materials
PB-07 – Assignment of safety classes for laser devices
PB-08 – Measurement of parameters related to thermal imaging devices, including: signal transfer function; components of the 3D noise model; components of the simplified noise model, including 1/f noise, non-uniformity, and noise equivalent power; signal-to-noise ratio; modulation transfer function and contrast transfer function; minimum resolvable temperature difference; and field of view
PB-09 – Measurement of parameters related to TV, LLLTV cameras, and night vision devices, including: signal-to-noise ratio, modulation transfer function, contrast transfer function, spatial resolution, minimum resolvable contrast, and field of view

The laboratory has collaborations with national and foreign scientific centres in the area of optoelectronic metrology. The laboratory research team participated in several international EUREKA projects and developed and pursued their own research projects funded by the Ministry of Science and Higher Education. The laboratory is also working closely with business entities on the development and implementation of projects in the area of optoelectronic measurement systems and automation, which include:

- Material testing using laser-induced plasma spectroscopy
- Electronic sensors for measuring physical quantities
- Laser power and energy meter calibrators
- Microprocessor control systems and data processing of measurements

# 1.6. BIOMEDICAL ENGINEERING CENTER

The mission of the Biomedical Engineering Centre (BEC) is to conduct research in the field of biomedical engineering as well as to design innovative technologies and medical equipment. BEC is implementing the project as a part of the 5.1 IE OP under the name of “Development of the Cluster – the Centre of Biomedical Engineering”. The aim of this project is the diffusion of innovation from the Military University of Technology as well as other research institutions to companies associated with the cluster. The cluster was established by 44 companies: enterprises, research organisations, scientific institutes, universities and the business support institution. Currently BEC is in the final stage of personnel training as well as organizing and launching of new research laboratories.

**Research Topics:**

- Development of technology for diagnostics and therapy of cancer and cardiovascular diseases with use of photodynamic therapy
- Design of technology for detection of harmful microorganisms that could become a cause of nosocomial infections
- Assessment of antimicrobial activity and biocompatibility of graphene flakes
- Analysis of proliferation rate and differentiation of human bone marrow-derived mesenchymal stem cells upon irradiation from LED sources with different wavelengths
- Study on biological effects of low-frequency and microwave frequencies HPM pulses on the mammalian cells at molecular level
- Design of information systems for and therapy of cancer.

# 2. RESEARCH ON PLASMA PHYSICS AND LASERS

## 2.1. INVESTIGATIONS OF PHOTOIONIZED PLASMAS: ELECTRON TEMPERATURE

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**Figure 1.** Emission spectrum obtained for Kr photoionized plasma in the EUV range, accumulation of 4000 pulses. Intensity scale adjusted to the spectral lines except the most intense one corresponding to the $4s^24p^4\,{}^1D_2 - 4s^24p^3({}^2P°)4d\ {}^1F°_3$ transition. Its intensity in relation to the other lines is shown in the sub-image.

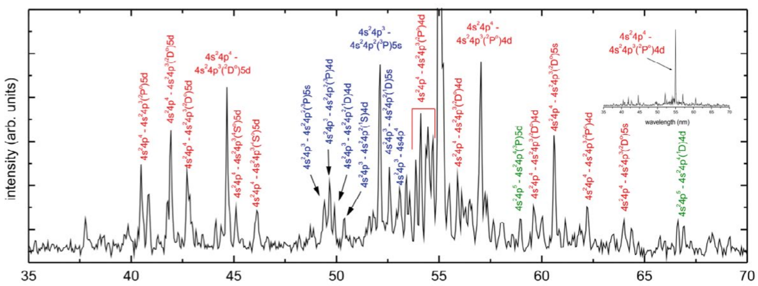
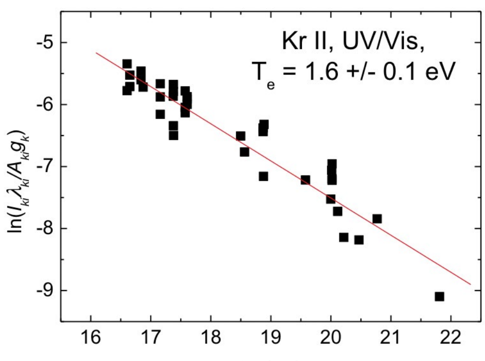



**Figure 2.** The Boltzmann plot based on spectral lines originating from Kr II ions, measured in the UV/ VIS range, $T_e = 1.6 \pm 0.1$ eV



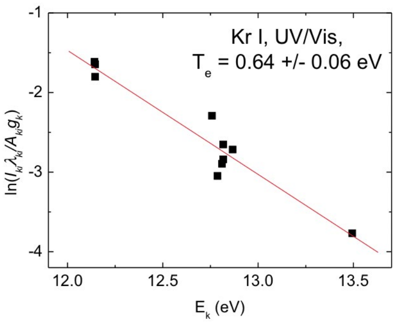



**Figure 3.** The Boltzmann plot based on spectral lines originating from Kr atoms measured in the visible range, Te = 0.64 ± 0.06 eV

Laser produced plasma EUV (extreme ultraviolet) sources developed in Institute of Optoelectronics can be used for different types of investigations. The EUV collector employed for focusing of the radiation enables to obtain a power density at the level of $10^7$W/cm$^2$. It is the ionizing radiation allowing to perform different kinds of investigations concerning interaction with solids or gases. As a result of interaction of intense EUV beam with gases, photoionized plasmas are produced. This kind of investigation was carried out and emission spectra of plasmas produced in different gases were obtained. The spectra were recorded at the wavelength range 10 ÷ 100 nm using a toroidal grating spectrograph (McPherson, Model 251) and at the 200 ÷ 780 nm range using the Echelle Spectra Analyzer ESA 4000. The spectral lines were used for construction of Boltzmann plots allowing for estimation of the plasma electron temperature. It is so called low temperature plasma with $T_e \approx 1$ eV. Its electron density at the level of $10^{16} \div 10^{18}$ cm$^{-3}$ is a few orders of magnitude higher comparing to plasmas used in various technologies.

# 2.2. PULSED CAPILLARY CHANNEL GAS PUFF TARGET

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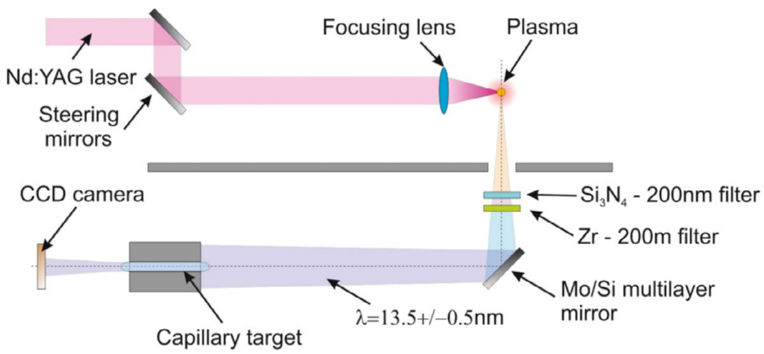


**Figure 1.** Experimental arrangement for EUV backlighting imaging of a capillary channel target

Characterization measurements of a pulsed capillary channel gas puff target, developed for applications in laser-matter interaction experiments, were carried out.

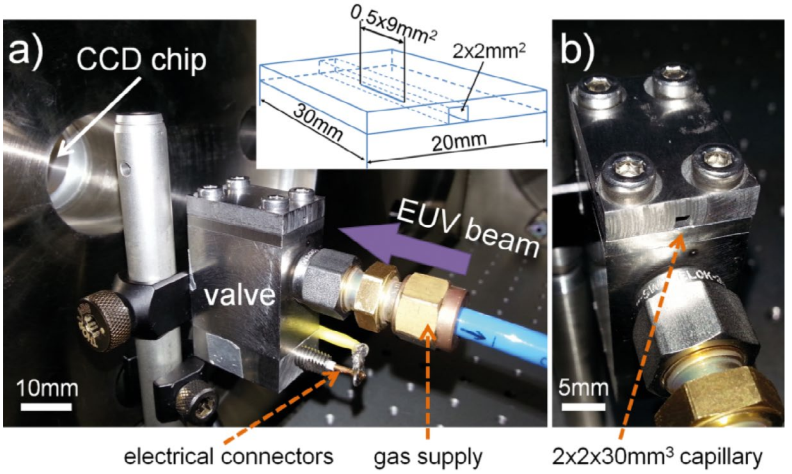


**Figure 2.** Photograph of the valve equipped with capillary nozzle a) and zoomed for the capillary b).

The target is produced by pulsed injection of gas through a slit-shaped nozzle into a capillary channel and has been characterized by extreme ultraviolet (EUV) radiography at 13.5nm wavelength.

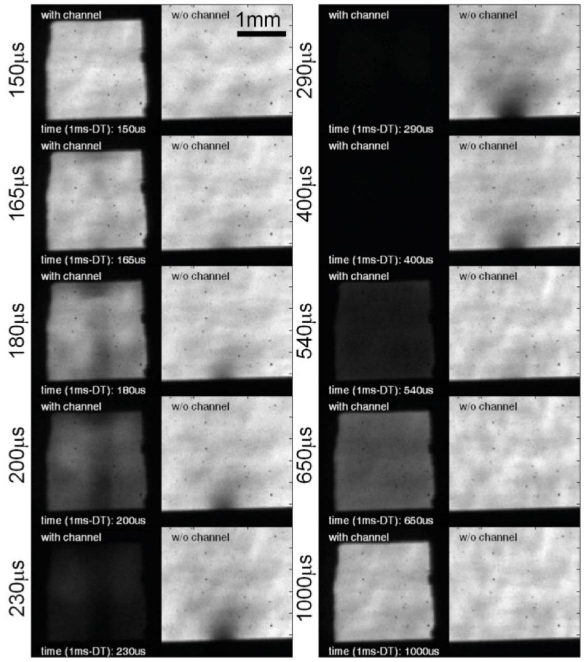


**Figure 3.** Sequence of EUV shadowgrams (raw transmission data) for the capillary channel target (left images) and without the cover plate forming a capillary – free expansion case (right images) for various delays (1ms-DT), representing delay time before arriving of the EUV pulse Experimental conditions: argon pressure $P_{Ar}$=0.1bar, PW=40ms. Each frame was recorded in ~3ns

Time dependent gas flow effects and flow shaping by capillary walls were visualized. Density measurements for argon were performed on axis for variable timing conditions and variable backing pressures. This target, due to its advantages, might be an interesting alternative for lower repetition rate and higher energy laser-matter interaction experiments.

# 2.3. GAIN-SWITCHED AND PASSIVELY MODE-LOCKED THULIUM FIBER LASER OPERATING AT 2 µm

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An all-fiber gain-switched and mode-locked (GS-ML) thulium-doped fiber laser (TDFL) operating at 2 µm was developed. The TDFL was resonantly pumped by 1.55 µm pulses delivered by a home-made fiber MOPA system whereas passive mode-locking was provided by a SESAM which was characterized by the saturation fluence of 65 µJ/cm2 and modulation depth of 12%. The system operated at 50 kHz and emitted gain-switched pulses with duration of less than 200 ns and output average power of up to 22 mW. The sub-pulses recorded within the gain-switched pulse envelope were regular, stable and had a repetition rate of 89 MHz, corresponding to the cavity round trip time, which indicates that the oscillator operated in fundamental mode-locking. The laser operated at 1999 nm with a 3-dB bandwidth of 0.29 nm.

a) b)

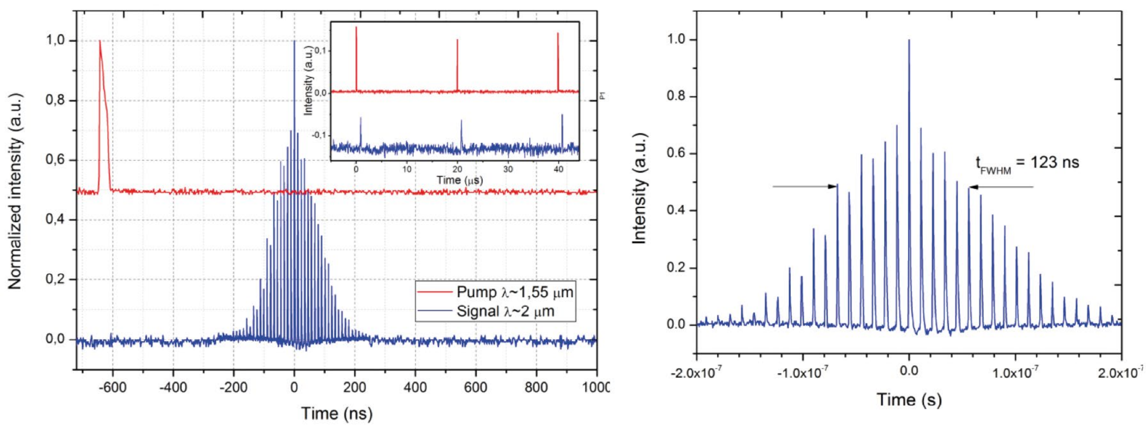


**Fig. 1.** Pulse waveform on oscilloscope: upper trace - pump pulse at 1.55 µm, lower trace - output pulse at 2 µm; inset, output pulse train of the GS-ML fiber laser (a), measured temporal GS-ML pulse (b)

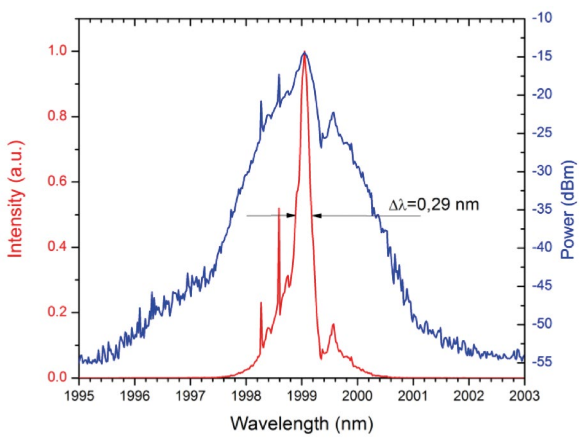


**Fig. 2.** Laser spectrum (linear and dB scale) of gain-switched and mode-locked pulses

It is the first time simultaneous fast gain-switching and mode-locking of TDFL with a 100% modulation depth was demonstrated. The patent-pending laser can be used as a seed in a MOPA configuration, leading to higher pulse energy and peak power, which is crucial for OPO or supercontinuum generation in the mid-IR.

# 2.4. HYBRID, CONTINUOUS-WAVE AND Q-SWITCHED HO:YLF LASER DEVELOPER IN MOPA CONFIGURATION

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The compact setup of a Ho:YLF laser pumped by a high power Tm:-fiber laser was developed and examined in both continuous-wave (CW) and Q-switched operation. In a continuous-wave operation, the research in an oscillator scheme was done for a crystal of 0.5 at. % Ho dopant concentration and the length of 30 mm for various output coupler transmittances. At room temperature, the maximum CW output power of 24.5 W for 82.5 W of incident pump power, corresponding to slope efficiency of 35.4 % was achieved. The highest slope efficiency of 81.6 % with respect to the absorbed pump power was obtained. Trying to fully utilize the pump power unabsorbed by the active crystal in an oscillator stage, an amplifier system based on two additional Ho:YLF crystals was developed. A two-stage amplifier system yielded an output power of 30.5 W. For a Q-switched operation, for the maximum incident pump power and the pulse repetition frequency (PRF) of 1 kHz, pulse energies of 18.5 mJ with a 22 ns FWHM pulse width corresponding to 841 kW peak power in the amplifier system were recorded. Carrying out the measurements of the laser spectrum, for various out-coupling transmittances, we observed laser generation at wavelengths in the range of 2050 and 2060 nm with a beam quality parameter of $M^2$ better than 1.1.

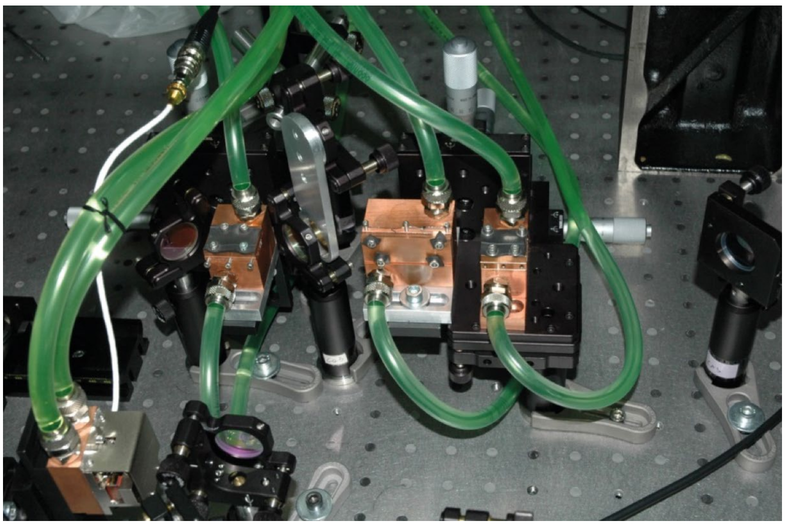

**Photo 1.** Picture of the laboratory scheme of the Ho:YLF-MOPA laser

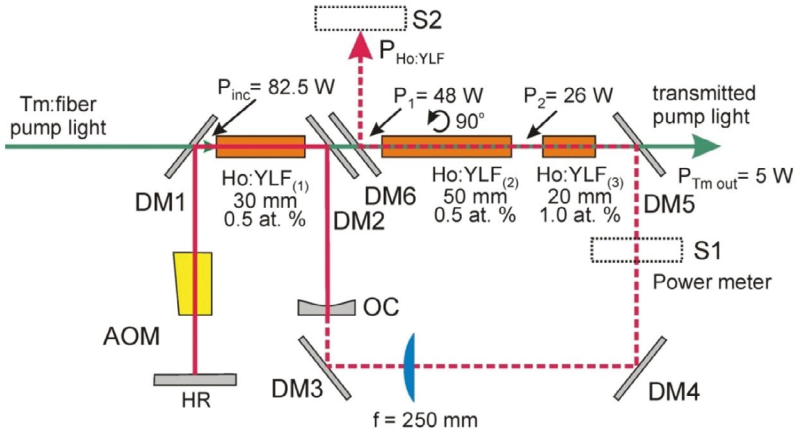


**Fig. 1.** Experimental setup of the Ho:YLF-MOPA laser, pumped by a high power Tm:fiber laser

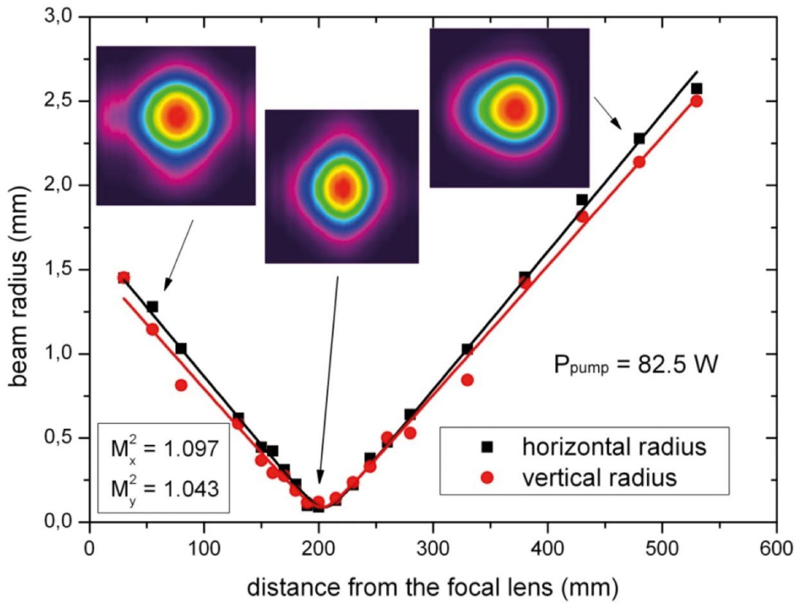


**Fig. 2.** Beam propagation factor measurement of a CW Ho:YLF-MOPA laser beam. The insets show 2D spatial profiles of the amplified laser beam

# 2.5. PULSED, YB DOPED LASERS SIDE-PUMPED BY HIGH POWER 2D LASER DIODE STACKS

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The semi-analytical model to design lasers side pumped by means of 2D laser diode stacks was developed and applied to design Yb lasers (see Fig. 1). The elaborated model enables determination of 2D inversion profile (see Fig. 2), effective gain and reabsorption loss inside mode area, stored and extracted energy density for a wide class of gain crystals, shapes of gain elements and pump beam shaping optics etc.

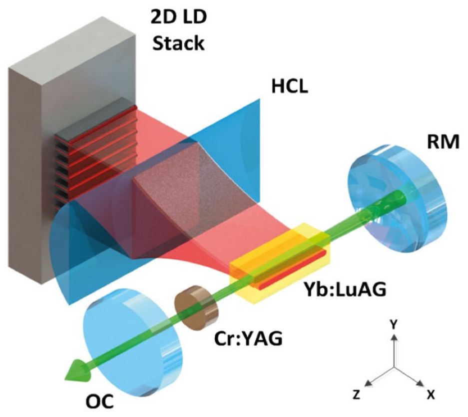


**Fig. 1.** Scheme of side pumped slab laser

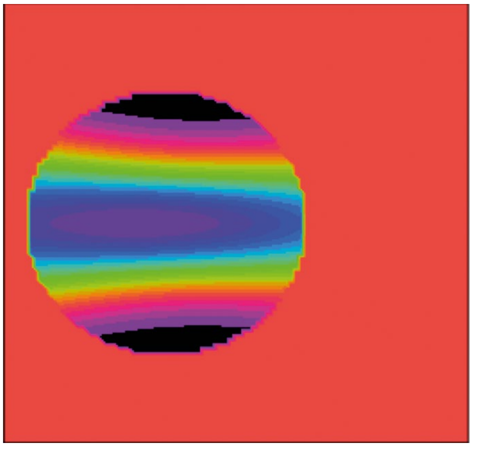

**Fig. 2.** 2D inversion distribution inside slab

We have elaborated the laboratory model of such laser system with 2D LD stack pump unit offering up to 0.8 J of energy in 1 ms duration at 970 nm wavelength. According to model predictions, such lasers can operate in room temperature applying only passive cooling to control of LD stack temperature. We have checked both Yb:YAG and Yb:LuAG crystals with different doping levels generating at 1030-nm wavelength. In free running regime we have shown the energies of 160 mJ for Yb:YAG and above 100 mJ for Yb:LuAG with slope efficiency about 20% in near fundamental mode. In passive Q-switching by means of Cr:YAG, 10 mJ energy and 2.5 MW peak power were demonstrated for the best case of Yb:LuAG laser. The output energy in such a case was limited by damage threshold of laser elements. The indications how to overcome or mitigate that drawbacks were formulated. Lasers of such type could provide the real alternative to 'old-schooled' lamp pumped Nd lasers, as well as, novel Yb lasers designed in 'thin-disk' architecture.

# 2.6. MONOLITHIC PULSE MICROCHIP LASER OPERATING AT 1.5 µm

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Monolithic pulse microchip laser $Er^{3+}$,$Yb^{3+}$:glass/$Co^{2+}$:$MgAl_2O_4$ operating in eye-safe radiation range was designed and developed. On the basis of the microchip a laser head was build which can be successfully applied to laser range finders.

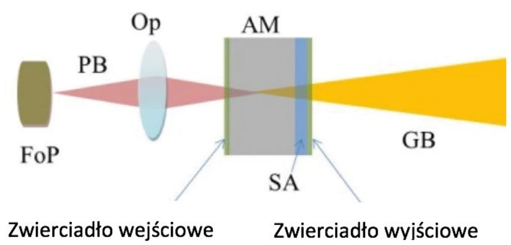


**Fig. 1.** Outline of the developed monolithic microchip laser; FoP - fibre of the pumping laser diode; PB – pumping beam; Op - optics; AM – active medium **$Er^{3+}$,$Yb^{3+}$:glass**; SA – saturable absorber **$Co^{2+}$:$MgAl_2O_4$**; GB – generated beam

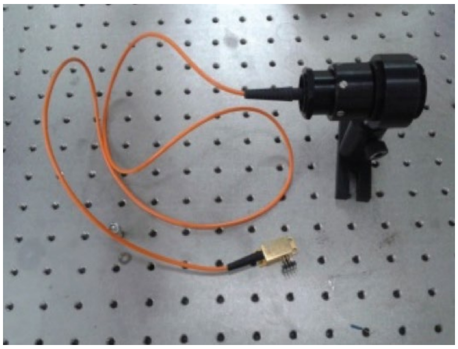

**Fig. 2.** Photo of the laser head with the pumping laser diode

The generated radiation is characterized by: peak power , pulse duration , pulse energy , slope efficiency η=5,31% and threshold , pulse repetition rate depends on the pump power and for =375 mW is equal to 735 Hz.
$M^2$ parameter of the generated beam amounts to $M^2_x$=2.77 and $M^2_y$=2.27.

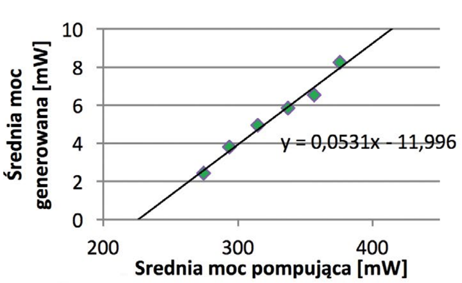


**Fig. 3.** Average output power versus the average pump power incident on the active medium with linear approximation

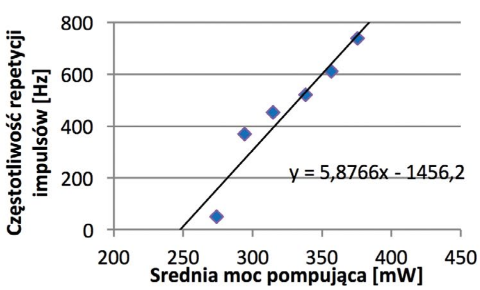


**Fig. 4.** Pulse repetition rate versus the average pump power incident on the active medium with linear approximation

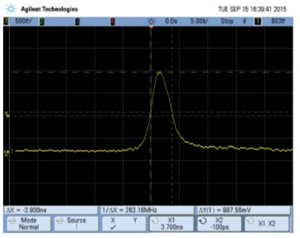


**Fig. 5.** Pulse shape generated by the laser head

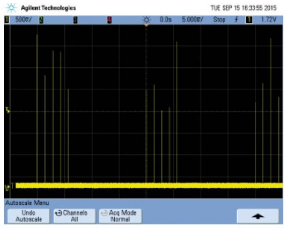


**Fig. 6.** Pulse train generated by the laser head for =735 Hz repetition rate


**Fig. 7.** Spectrum generated by the laser head

# 3. APPLICATIONS OF OPTOELECTRONIC TECHNIQUES IN MEASUREMENTS

## 3.1. LASER INDUCED BREAKDOWN SPECTROSCOPY (LIBS) IN ANALYSES OF ART WORKS

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Laser induced breakdown spectroscopy (LIBS) is used to determine chemical composition and structural analyses of any objects in solid, liquid or gas phase. Shortly, it relies on using high peak power, focused laser energy to cause the ablation of a small amount of surface material, resulting in plasma that emits both continuous and linear radiation, which is then analyzed to identify elements. Calibration and gradual ablation deliver knowledge about elemental concentrations and object's stratigraphy.

**Fig. 1.** The crowns from Skrzatusz Sanctuary: left – Jesus Christ crown, right – Blessed Virgin Mary crown

Diagnostics of art works using LIBS technique are conducted more than 15 years in the Laboratory of Lasers Application (IOE MUT). Recently, wide research program included identification analyses of two crowns (17$^{th}$ century) from the Shrine of Our Lady of Sorrows in Skrzatusz (fig.1), and collection of five oil paintings presenting the family of King Jan III Sobieski from Wilanów Museum (fig.2).

LIBS data usually contain multiple spectroscopic variables, which allows to apply statistical methods, delivering information about most important properties of analyzed objects and correlation between different measurement points. So called factorial (FA) and principal components (PCA) analyses have shown that the bodies of both crowns are likely to have been made from the same silver alloy with small additions of copper, zinc, lead and tin. The presence of mercury under a thick layer of gold reveals that an amalgam technique was used to cover the silver with gold. The other components of the crown, which were later additions, were made of different alloy compositions, with the largest variance being in the metal stone settings.

**Fig. 2.** Collection of five oil paintings of King Jan III family, Museum of King Jan III's Palace at Wilanów

In case of five oil paintings from Wilanów, PCA statistical analyses were performed on the set of lithium and barium content in painting grounds (fig.3). Results suggest similarity in the ground composition, e.g. in Wil.1685 and 1686 paintings (King and Queen on a horse), which correspond also to the similarity of complete LIBS elemental spectra at the stratigraphic depths after subsequent 41-50 and 51-60 laser shots.

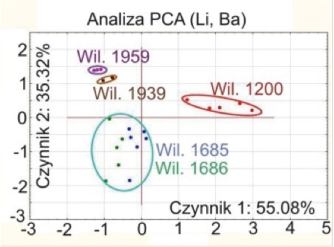


**Fig. 3.** The PCA results of Li and Ba content in paint ground

# 3.2. IMAGING BY RAMAN SPECTROSCOPY AND FTIR

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Biological samples are characterized by the complex structure and chemical composition. A study of this type of material is based on an analysis of the bioelements that occur in very low concentrations. Among the many analytical techniques optical spectroscopy methods work very well in cell and tissue studies of biological origin. The main advantages of spectroscopic methods are: low invasiveness, low destruction and the ability to detect pathological changes in the tissues at an early stage of their creation. Spectroscopic methods are relatively quick and allow in vivo testing, so one can skip the stages of sampling and preparation of samples for analysis.

**Photo 1.** For imaging with Raman technique spectrometer Nicolet IS-50 Raman/FTIR was used with excitation wavelength of the laser 1064 nm and DTGS detector. At the same time Raman is coupled with ATR-IR module for recording spectra in the infrared range

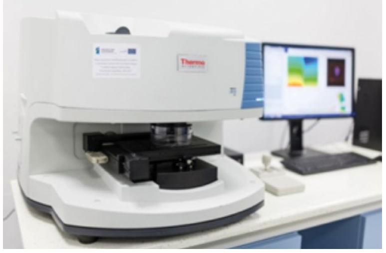

**Photo 2.** For mapping with infrared absorption technique (FTIR) Nicolet iN10 microscope was used equipped with DTGS and MCT detector, movable table that allows a precise location of the mapped area. Interchangeable adapters allow to fit the measurement techniques (DRIFT, ATR, transmission) to the kind of samples analyzed

In the Raman spectrum the one band is visible around 960 $cm^{-1}$, which is characteristic for $PO_4$ group originating form hydroxyapatite, the main tooth material. The intensity of this band determines the phosphates content in the sample. Tooth decay is the quantitative change of the phosphate content (the loss) hence the maximum amount of phosphates is observed in the healthy enamel and lower in caries area. Anthocyanins are a large group of plant pigments, which in accordance with pH of environment, may be seen as red to purple. These dyes are found in flowers, fruits, leaves, stems, and less commonly in the roots and wood. In cells they are located in vacuole in the form of granules of varying size, but cell walls and the pulp tissue does not contain anthocyanins. The characteristic construction of $C_6$-$C_3$-$C_6$ result in identification of these compounds in a range of 1604 $cm^{-1}$ assigned the aromatic ring.

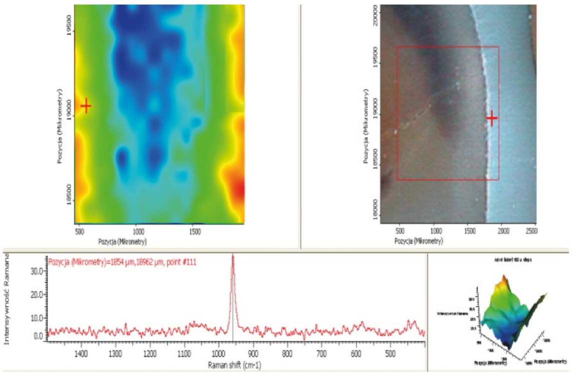


**Fig. 1.** Tooth image recorded with Raman technique

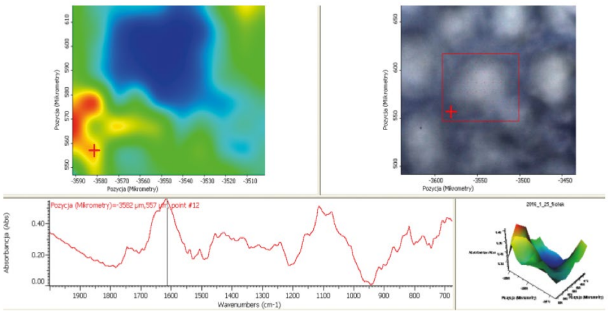


**Fig. 2.** Flower petal image recorded with FTIR technique

# 3.3. TERAHERTZ SCANNING OF POLIETHYLENE COMPOSITES

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Polyethylene composites, which are manufactured as plates with a thickness of approx. 10-20 mm, are used as material for the ballistic protection of vehicles, helmets and bulletproof vests. They consist of a number of about 50-mm thick layers of fibers (diameter approx. 20 mm) made of UHMWPE. The fibers in successive layers are arranged perpendicular to each other. During interaction of a projectile with the structure a chamber and vast delamination occur (Fig. 1). Knowing the location of these delamination, their size and thickness is essential to determine the quality of material and further research. Terahertz radiation from the range of 0.1-3 THz perfectly passes through the polyethylene structures and facilitate their accurate analysis and three-dimensional visualization.

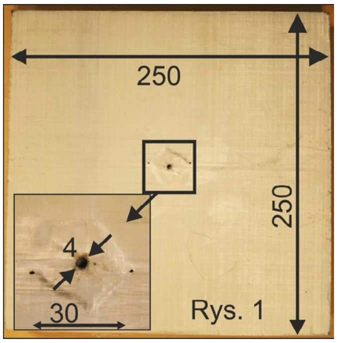



**Fig. 1.** Photo of polyethylene composites with the delaminated defect area induced by projectile

To measure the sample we used the TDS system operating in the reflection configuration. The TDS technique bases on generation and detection of the 0.5-ps-long pulse of electromagnetic radiation (Fig. 2). THz impulse propagating in a multilayer structure encounters the interfaces between the layers with different refractive index and is partially reflected. The remaining part propagates further in the structure. As a result, one obtains a series of pulses delayed relative to each other by twice the propagation time in the individual layers. Scanning the sample point by point facilitates to create the internal structure and the position of delamination

Vertical (Fig. 3) and horizontal (Fig. 4) cross sections of the structure present the inlet channel of the projectile, centrally located chamber, radially spreading delamination, and other features.

By means of the developed signal processing of ambiguous THz waveforms reflected from the interior of the sample we can unambiguously determine the distribution of delamination and size of the chamber (Fig. 5).

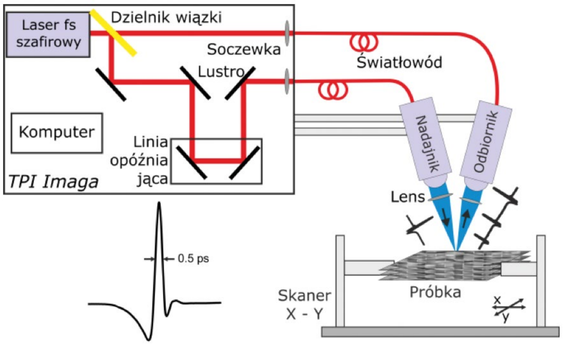



**Fig. 2.** Optical scheme of measurement set-up

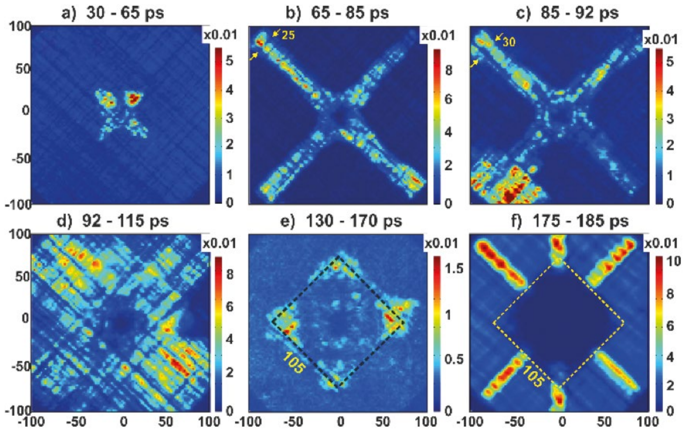
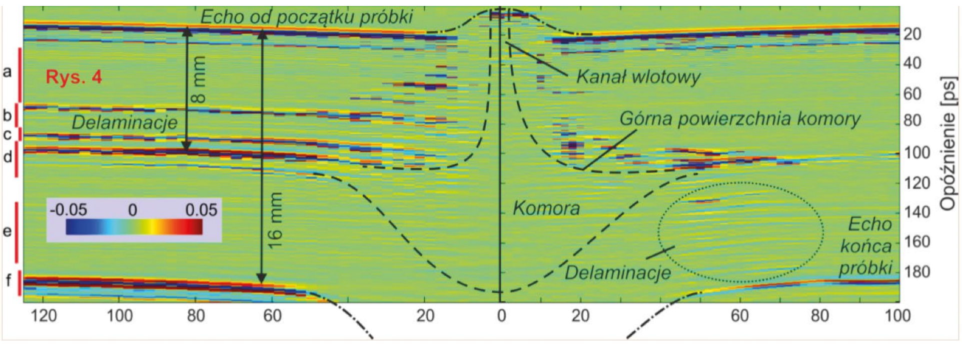



**Fig. 3.** Vertical cross sections of the structure

**Fig. 4.** Horizontal cross sections of the structure



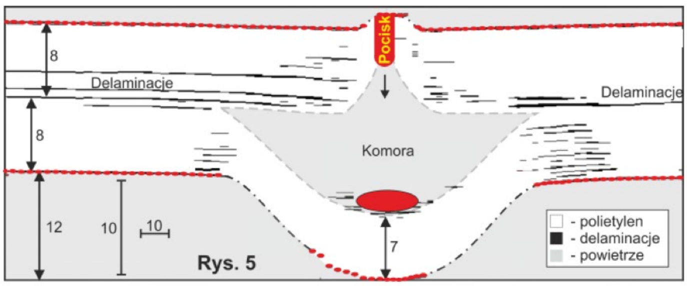




**Fig. 5.** Distribution of delamination in the sample

# 3.4. IMAGE FUSION METHOD FOR DETECTION OF CONCEALED OBJECTS

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**Fig. 1.** Image Fusion process. THz image (left), VIS image (centre) and fused image (right)

Security of public transport systems and public places has become a major challenge. Assuring safety of crowded public places like e.g. airports is one of the most serious social issues. One of aspects of the problem is detection of potentially dangerous objects hidden under person's clothes. Detection of concealed threats such as weapons, explosives or chemicals is essential in this context. Terahertz (THz) band has lately become very interesting for scientists mainly because of its specific properties. One of potential application of THz devices is security area. Imaging devices working in the THz range can be used to detect objects hidden under clothes. Since most of commercially available THz cameras provide low quality images, great potential of image processing techniques for both quality improvement and detection of threats is expected. Our goals are to detect objects hidden under clothes and provide the recipient with clear and understandable visualization. There is a great potential in using multispectral surveillance imagers in security systems thus we investigated the possibilities of concealed object detection by screening people using non-invasive cameras working in visible and terahertz ranges. We applied image fusion methods in order to achieve understandable visualization presenting a visible image of a person with marked localization of hidden item. Image fusion allows us to combine the most interesting elements of images two spectrums into one image. During the investigations, a passive THz camera operating at 250 GHz as well as visible light camera were used.

# 3.5. MEASUREMENTS OF POLARIZATION STATE LONG-WAVE INFRARED RADIATION

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Innovative device has been developed for the measurements of the polarization state of electromagnetic radiation in far infrared spectral band. It's the same part of electromagnetic spectrum commonly used by thermal cameras. Contrary to a conventional thermal camera solution, the developed device performs the analysis and visualization of polarization state of recorded thermal radiation coming from observed objects, which allows for the detection of their characteristic properties. Principle of operation of the presented device relies on a well-known phenomenon of partial polarization of electromagnetic radiation when reflected or scattered from certain surfaces. The developed device detects and measures the basic properties of partially polarized IR radiation using specially designed optics, detection modules with focal plane array detectors and a real-time data processing subsystem made of FPGA circuits and microprocessors. Prototype model of the device is presented in Fig.1.

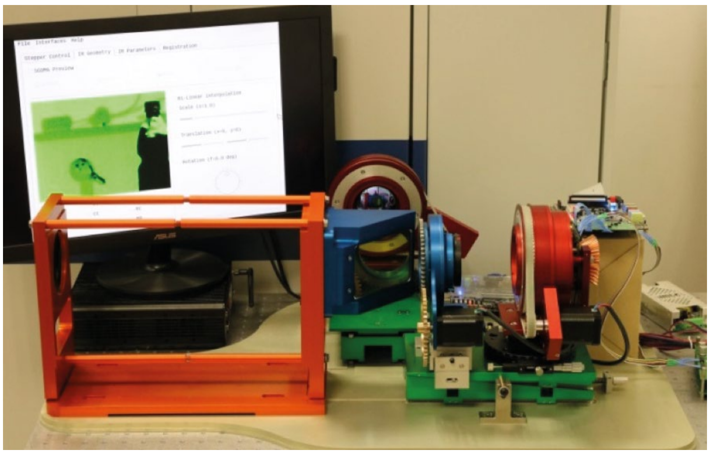

**Fig. 1.** Prototype system for the measurement and visualization of polarization state of infrared radiation

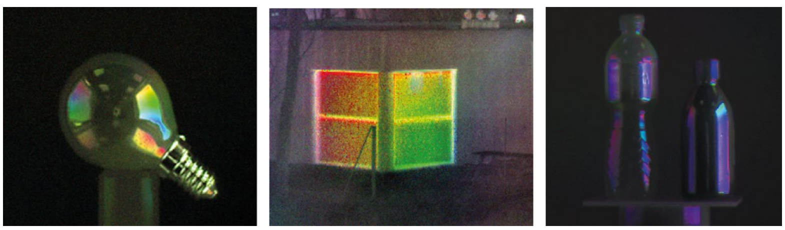

**Fig. 2.** Sample visualizations of recorded polarization states

During the research project also a method was developed for the visualization of polarization state using color image representation. Color describes the orientation angle whereas saturation corresponds to the magnitude of polarization effect. The results are shown in Fig.2.

# 4.

# NANO AND BIO TECHNOLOGIES

## 4.1. MODIFICATION OF POLYMERS FOR APPLICATION IN BIOMEDICAL ENGINEERING USING A LASER PLASMA EUV SOURCE

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Correct tuning of polymer surface properties is beneficial for various applications in bio-implants, artificial muscles and diagnostic devices. The surface properties can be modified by the surface functionalization and fabrication of nano- and micro-structures on it. The degradation of bulk material has been reported for traditional chemical, plasma, and ultraviolet irradiation based surface modification techniques. However the strong mechanical properties of these materials are considered as an imperative for their use in biomedical engineering applications. This limitation can be avoided by using extreme ultraviolet (EUV) that is absorbed within a very thin (less than 100 nm) layer of the polymer.

In this study a compact laser plasma EUV source based on a double-stream Kr/Xe gas-puff target, irradiated with a Nd:YAG laser pulse (3ns/0.8J) at 10 Hz was used. The EUV radiation at the wavelength of about 10 nm was focused onto a polymer sample using a gold-plated grazing incidence ellipsoidal mirror. Several polymers were irradiated by EUV radiation under different experimental conditions and SEM, AFM, XPS, and water contact angle goniometry were used to characterize the changes of the physical and chemical properties. Thenceforth cell culture studies were performed to determine EUV surface modification potential in biomedical engineering.

It was shown that the EUV surface treatment strongly modified the surface properties, introducing nano and micro-structuring, controlled multi-scale surface roughness, controlled wetting beha-

vior and functionalization of the studied polymers. The cell culture studies by using L929 mouse fibroblasts and Human Umbilical Vein Endothelial Cells (HUVEC) demonstrated enhanced biocompatibility and hemocompatibility of EUV modified PTFE polymers to be used as bio-implants for cardiovascular devices. The EUV modified polymer substrates were successfully used to identify cancer cells depending upon their metastatic potential on the basis of pleomorphic phenotype. The EUV surface modification was successfully employed as a single tool for controlling the wetting behavior by increasing hydrophobicity or hydrophilicity for applications in separation devices and artificial muscles. The results presented in this work were the basis of the doctoral dissertation entitled „Application of laser plasma extreme ultraviolet (EUV) source in biomedical engineering" defended by Inam Ul Ahad in 2015.
Project was realized under the Erasmus Mundus Joint Doctoral (EMJD) Programme EXTATIC. Investigations have been performed in collaboration with Advanced Processing Technology Research Centre, Dublin City University in Ireland, Biomedical Engineering Laboratory, Warsaw University of Technology, Laboratory of Biophysical Microstructures, Institute of Nuclear Physics in Krakow and Institute of Motor Vehicles and Transportation Military University of Technology.

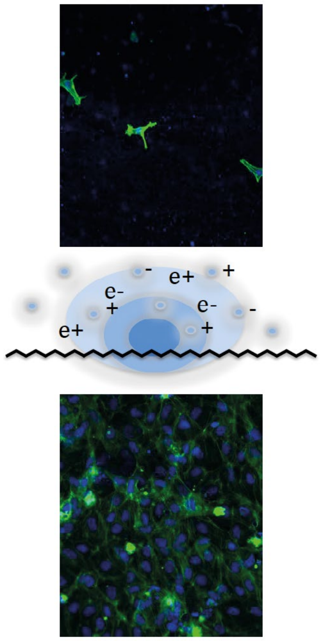


**Fig. 1.** HUVEC cell adhesion on pristine (above) and EUV modified (below) PTFE surface after 48 hours cell culture.

# 4.2. LASER MANUFACTURING OF MICROSIEVES FOR BIOENGINEERING APPLICATIONS

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Matrices of microholes (microsieves), fabricated using different materials, such as polymers, silicon and metals, are necessary in many technological applications, among others in microfluidic systems and filtration-separation techniques. Simple processes of fast drilling of thousands of holes per cycle with low processing expenses are desired. The ideal tool in this case is a laser beam with a proper energy density and a high pulse repetition rate, operating without contact with the material in an easy-to-automate and fast process of position control (fig.1). Experiments were performed using picosecond Nd:YAG laser, emitting 60 ps pulses with a repetition rate of 1 kHz at a wavelength of 355 nm (third harmonics), which was coupled to a galvanometric scanner, equipped with F-theta lens with a focal length of 163 mm. Kepler's telescope, expanding the laser beam to 25 mm (8x) was inserted at the output of the laser head.

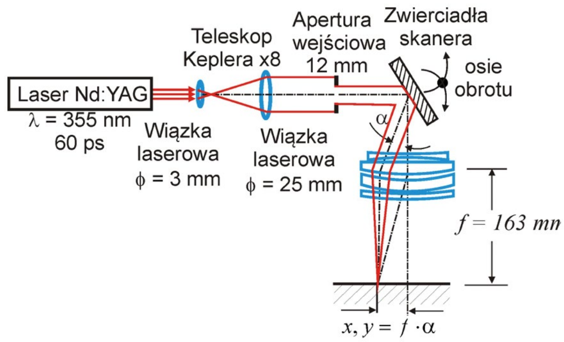


**Fig. 1.** Scheme of experimental arrangement

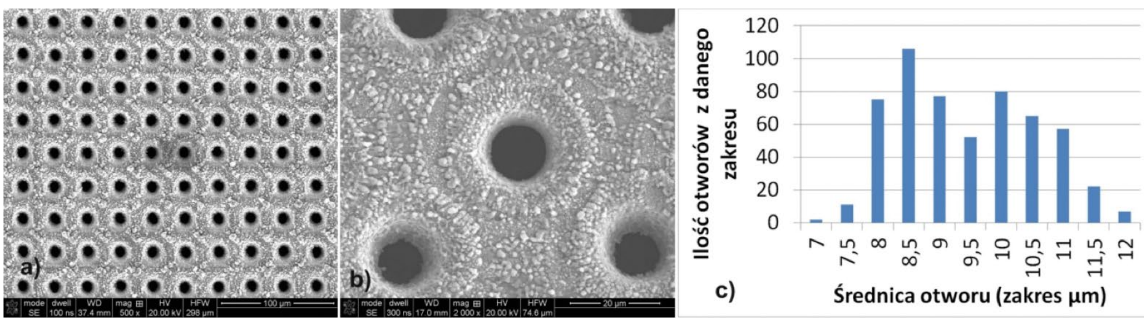


**Fig. 2.** a) SEM image of holes in square microsieve; b) Magnified SEM image of holes in involute microsieve; c) Exemplary result of hole diameter distribution measurement

Square and involute distributions of holes in Ni and Al foils were formed with an overall dimension of 3 mm. Examples of SEM images are shown in fig.2a and 2b. Distance between adjacent holes was 25µm to 100µm, which meant fabrication of up to 10,000 openings per microsieve. The square sieves were fabricated using percussion drilling with five laser shots per hole, in foils with a thickness of 50 µm. Samples of involute microsieves were perforated in foils with a thickness of 7 mm, using “on the fly” method with different scanning velocities. Each hole was drilled with a single laser pulse. Final transmission of optimized sieves with regular pore diameters (see fig.2c) and periods of 100, 75, 50 and 25 µm was equal to 1%, 2.5%, 5% and 22%, respectively. Exceptionally short processing times of 1 second for sieves with 900 holes and below 10 seconds for sieves with 10,000 holes were obtained using techniques of “on the fly” laser drilling and percussion laser drilling. Fabricated microsieves are used in the research on filters and microfluidic devices for bioengineering applications, including separation of circulating tumor cells.

# 4.3. SIMPLE LASER INTERFERENCE LITHOGRAPHY WITH PRISM OPTICS FOR PERIODICAL MICROMACHINING OF BIO-SCAFFOLDS

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Direct Laser Interference Lithography (DLIL) is increasingly applied for shaping of material surfaces and for changing their properties. DLIL applications in bioengineering for shaping biocompatible scaffolds for tissues using patterned materials with enhanced mechanical properties and selectively influencing the growth and development of cells are particularly interesting. DLIL technique uses at least two superimposed laser beams that create an intense interference field which is further reproduced by ablation on the processed surface. It does not require any preparation of treatment area except cleaning, and the only requirement is a sufficient absorption of material and high enough power density of radiation above the predetermined treshold. There are a lot of methods for dividing a laser beam into an arrangement of many interfering beams, but, in many applications, the simplest, efficient and precise are prism-based methods. The great advantage of these methods is an easy way of the beam partition to the interference components by proper selection of the prism geometry as well as by shaping a characteristic period of the interference structure through the control impinging radiation divergence (Fig. 1).

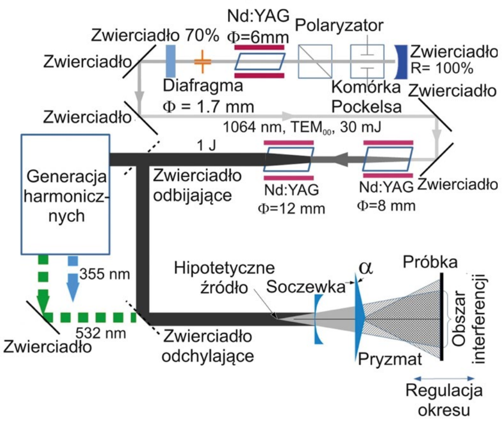


**Fig. 1.** Scheme of experimental arrangement based on prism interferometer

The important type of cells necessary for providing a fully functional tissue-like vessel wall are the vascular endothelial cells. Therefore, the adhesion and growth of endothelial cells were tested on a dotted grid, created in a diamond-like carbon (DLC) layer on a silicon wafer (Fig. 2a). In the cardiovascular field, DLC is employed for blood-contacting implants and interventional devices, such as heart valves, vascular prostheses, dialysis membranes and rotary pumps for ventricular assistance, stents and guidewires. The performed studies have indicated a directional migration (proliferation) towards the dimples and an increased number of cells in such patterned areas in comparison to the smooth DLC surfaces (Fig. 2b,c).

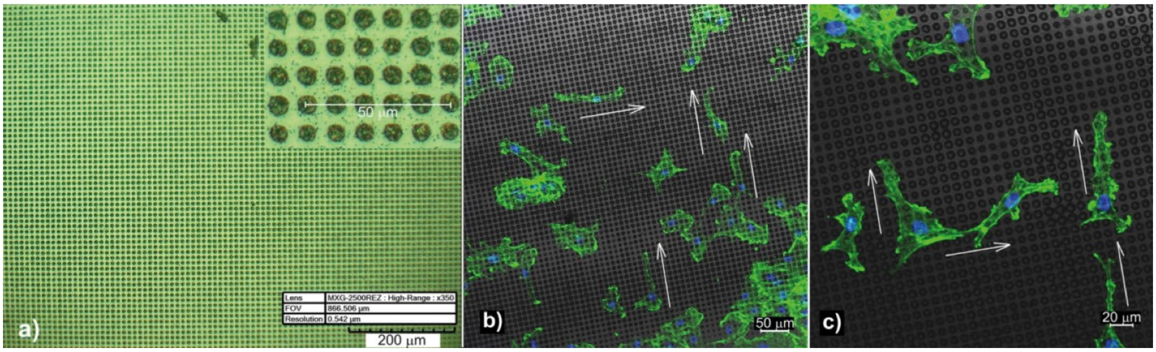


**Fig. 2.** a) Photograph of an interference pattern obtained by overlapping of 4 laser beams while illuminating a thin DLC layer on a silicon substrate; b,c) Confocal laser scanning microscope images of endothelial cells growth on dotted structures from a)

# 4.4. LASER DECORATION BY FUSING COLOUR CERAMIC LAYERS WITH GLASS PRODUCTS

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By reducing costs and time of the production process and by introducing significant improvements in technological processes, laser fusing of colour ceramic agents with ceramic or glass products arouses great interest, thereby substituting the typical process of furnace firing for decoration of small series of products. Glass substrate of a decoration allows use of two configurations of the optical scheme in the technological process – laser irradiation from the side of fused ceramic layer as well as from the side of glass substrate. Presented results are mainly related to experimental determination of utility features and advantages of both solutions.

Tests were performed with an extensive range of colour agents developed at the Institute of Ceramics and Building Materials in Warsaw, and with commercial glass substrates, delivered by the industrial company - Ceramika Tubądzin II Sp. z o.o. The processes were researched and optimised using computer-controlled ytterbium-doped diode-pumped fibre laser systems: GLPM 10 from IPG Inc, USA (10 W, 532 nm) and SP-100C-0020 from SPI Lasers UK Ltd (100 W, 1070 nm), coupled with "galvo" type beam scanners RLC1004 from Raylase GmbH, Germany.

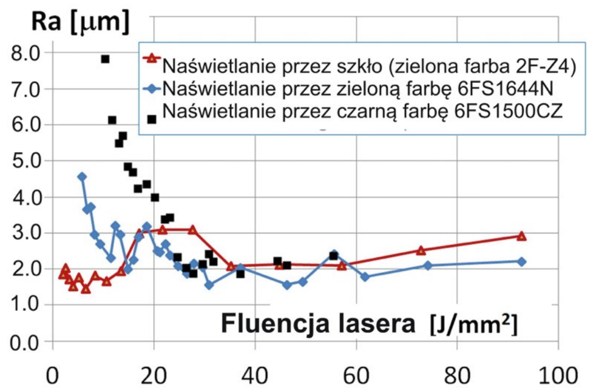


**Fig. 1.** Dependence of Ra roughness parameter on laser fluence and direction of laser irradiation

A main advantage of sample irradiation through the glass layer is the low value of roughness parameters for low values of laser fluence causing minimization of microcracks of product surface. Fig. 1 illustrates a comparison of the dependence of roughness parameter Ra on laser fluence for both optical configurations used. In the summary of all tests conducted using both fibre lasers, definitely better results are obtained for laser operating at a wavelength of 532 nm rather than 1070 nm. It corresponds to a higher absorption of colour agents in the visible part of spectrum. Examples of fused decoration images are shown in Fig. 2.

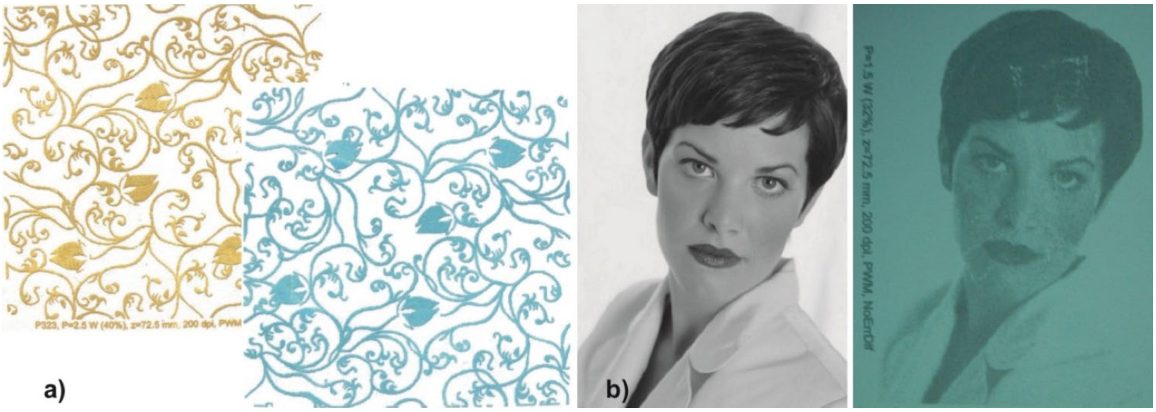


**Fig. 2.** Examples of laser fused colour decoration. a) image of vector ornament (Corel Draw); b) bitmap image (left side) and its laser projection before washing off the excess of green paint (right side)

# 4.5. SYNTHESIS OF “CORE-SHELL “ PLASMONIC NANOSTRUCTURES

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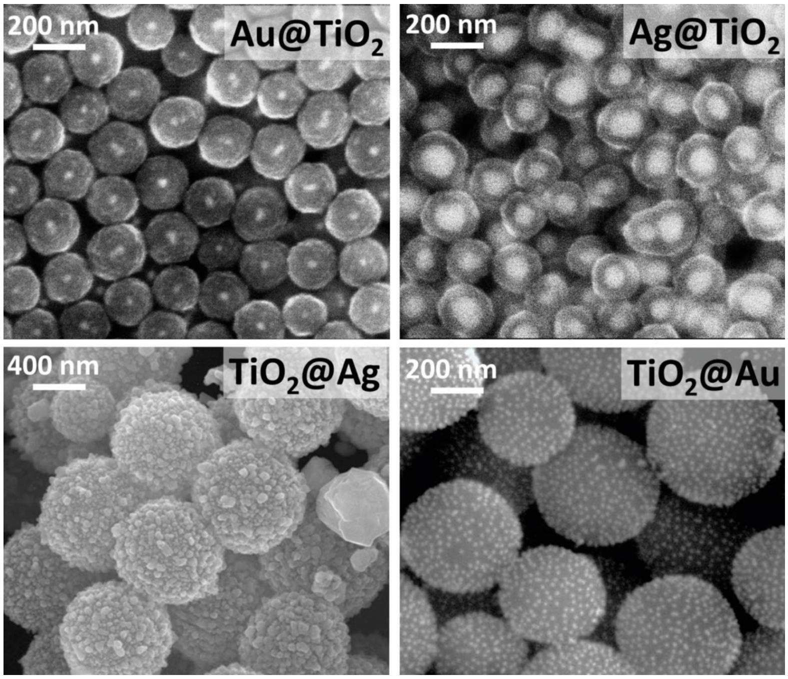


**Fig. 1.** The SEM images of $TiO_2@Au$, $Ag@TiO_2$, $Au@TiO_2$ and $Ag@TiO_2$ core-shell structures, which have been synthesized in IOE MUT

In 2015, we continued our research studies on the chemical fabrication, characterization and applications of various types of plasmonic nanostructures. The main efforts were focused on studies on the fabrication and characterization of core-shell nanostructures, based on titanium dioxide and noble metals, having great potential for application in photocatalysis and photovoltaics. As a result of carried out work, the methods for the synthesis of core-shell structures $TiO_2@Au$, $Ag@TiO_2$, $Au@TiO_2$ and $Ag@TiO_2$, including structures shown in the pictures above, were developed. The synthesized nanostructures were tested for their efficiency in the process of photocatalysis. These structures have also been used to build simple photovoltaic cells.

Research studies focusing on the surface-enhanced Raman spectroscopy (SERS) were devoted to the use of this technique in the detection and identification of bacterial endospores. Our research results have shown that this is a complex task and the results depend on many factors, including the type of SERS substrate and the excitation wavelength used in the measurements. The use of Raman imaging also showed that the measurement results are dependent on the position of spores on the SERS substrate and their spatial orientation. The extension of IOE MUT Raman system made in 2015, will allow in the near future to use for studies on SERS of bacteria ultrafast Raman imaging and 3D imaging, among others.

# 4.6. FLUORESCENCE IMAGING IN BIOENGINEERING

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Fluorescence imaging is used to evaluate the viability of cells, localization of endogenous and exogenous fluorochromes. Amino acids are source of endogenous fluorescence in UV spectrum human cells and tissues. In mineralized structures fluorescent properties has hydroxyapatite - main component of bone. The laser scanning system LSM 700 combined with confocal microscope Zeiss Axio Observer.Z1 has an extensive illuminator system (consisted of lasers with a wavelength of 405nm, 488nm, 555nm, 639nm, Colibri panel with LEDs 365nm, 470nm, 590nm, halogen lamp HAL 100). It allows to observe intracellular processes in cell cultures in real time (monochrome camera AxioCam MRC5) at a given temperature, humidity, and $CO_2$ concentration (incubation chamber Pecon XLmulti S1), fluorescence imaging of biological preparations, accumulation of fluorochromes analysis in in vitro conditions.

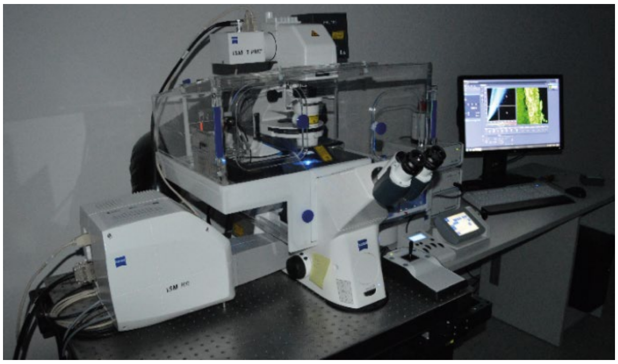

**Photo 1.** The laser scanning system LSM 700

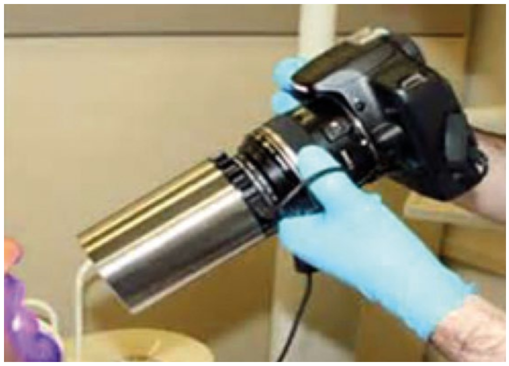

**Photo 2.** QLF-D system

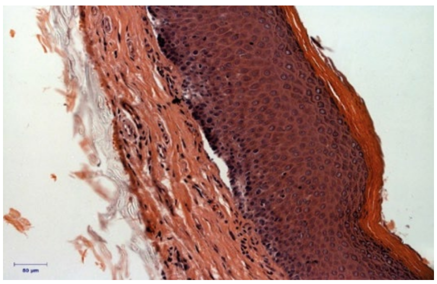

**Photo 3.** Fragment of the floor of the mouth; AxioCamera MRc5

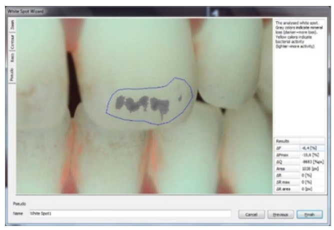

**Photo 4.** Example of green and red fluorescence analysis. The green one at white spot analysis shows us the fluorescence loss in each pixel in the selected area, which means caries. Red fluorescence reveals bacteria and plaque localization

QLF-D system (Quantitative Light-induced Fluorescence) is more sensitive than the reflection method of the enamel evaluation and permits to get the screening of the teeth in a short time. It is based on the method of imaging fluorescence at an excitation wavelength at 405 nm. Analysis of the green fluorescence allows detection of outbreaks of caries and demineralization of the tooth surface, while the red area shows us the localization of bacteria and plaque.

# 4.7. APPLICATIONS OF LASER-INDUCED FLUORESCENCE METHODS IN BIOMEDICAL ENGINEERING

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Laser induced fluorescence (LIF) is one of the most sensitive spectroscopic method. In the Laboratory of Lasers Application in Medicine unique measurement systems allow to measure bioluminescence different groups of materials: photosensitizers for Photodynamic Therapy (PDT), microorganisms, proteins, biological pollution of the atmosphere, laser crystals. The spectrofluorimetric Quanta Master QM-400 (Horiba) system is intended for the characterization of luminescent materials such as powders, solutions, thin films, crystals and nanomaterials. The spectral range of excitation and detection is between 200 to 2200 nm. The excitation sources are the pulse laser Nd:YAG Opolette 355 LD (225-2200nm) illuminator with xenon lamp (200-900 nm) and 980 nm laser to up-conversion measurement.

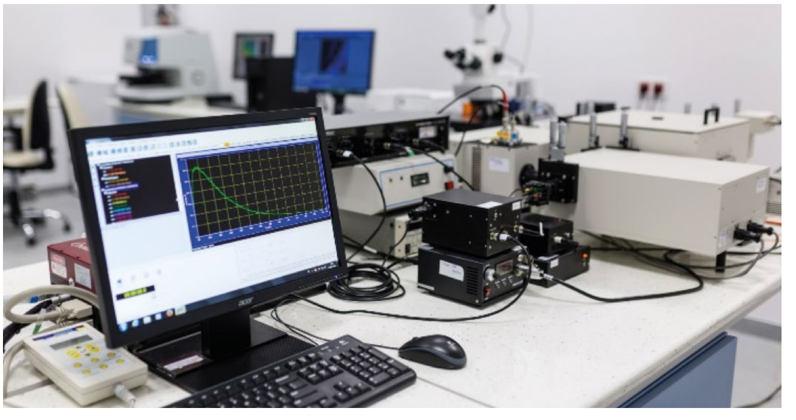

**Photo 1.** The spectrofluorimetric Quanta Master QM-400 (Horiba) system

Main applications of laser induced fluorescence: excitation spectra, emission spectra, time-resolved spectra, fluorescence and luminescence polarization anisotropy kinetics. System permits to determine the quantum yield. The system is integrated with a fluorescence microscope Zeiss Axio Imager. M2 and supersensitive camera for bioluminescence measurement.

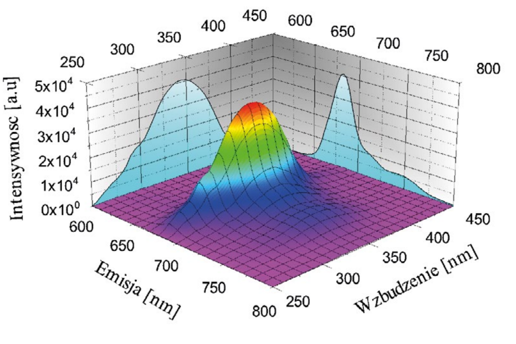


**Fig. 1.** Excitation-emission map of phthalocyanine

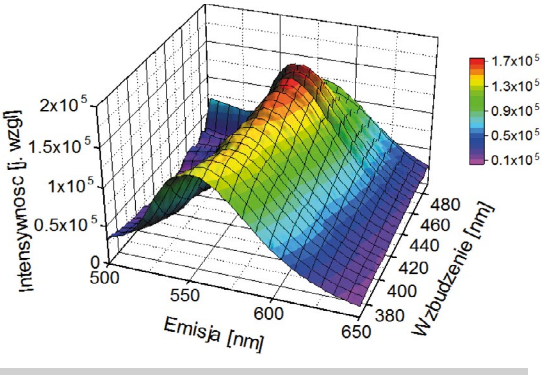


**Fig 2.** Excitation-emission map of amber

# 4.8. RESEARCH ON FLUORESCENCE PROPERTIES OF SIMULANTS AND INTERFERENTS OF BIOLOGICAL WARFARE AGENTS

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The database of fluorescence properties of more than 50 biological samples, including vegetative bacteria, bacterial and fungal spores, pollens, proteins, amino-acids, culture growth media, and also inorganic air pollutants has been created. These materials are simulants and interferents (naturally occurring substances that may give false alarms) of Biological Warfare Agents (BWA). Database consists of excitation-emission matrices, Laser-Induced Fluorescence (LIF) spectra, and fluorescence decay characteristics. This database, with addition of Principal Components Analysis (PCA) was used for design of BWA early warning systems. These systems were tested during international tests in campaigns in France, Sweden and USA.

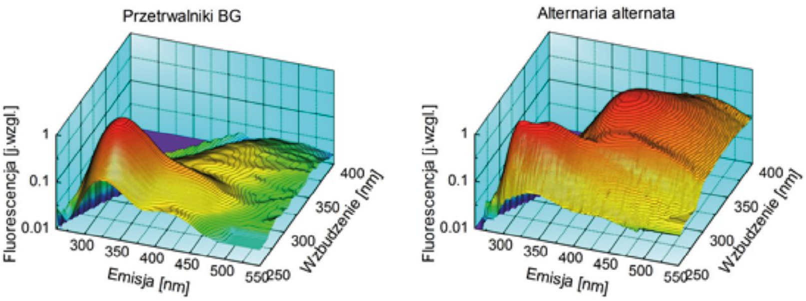


**Fig. 1.** Excitation-emission spectra of bacterial and fungal spores

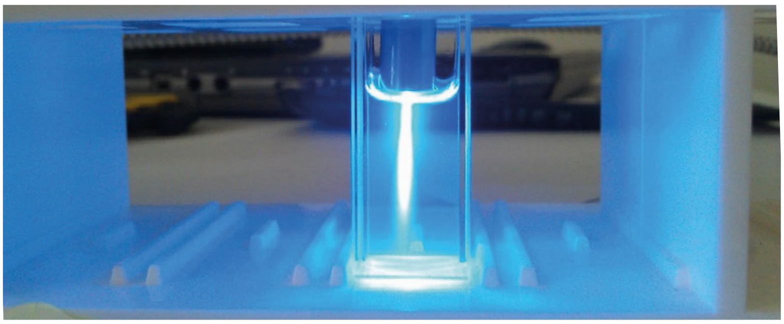

**Fig. 2.** Laser induced fluorescence of biological sample

# 5.
# OPTOELECTRONIC DEVICES AND SYSTEMS

## 5.1. EXTREME ULTRAVIOLET COMPACT MICROSCOPE WITH NANOMETER SPATIAL RESOLUTION

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Research, related to imaging in the extreme ultraviolet (EUV) spectral range was conducted using a laser-plasma EUV source. The microscope system was developed under LIDER/004/410/L-4/12/NCBR/2013 program. A compact, table-top EUV microscopy system was developed, which is based on a multilayer off-axis ellipsoidal condenser mirror and diffractive Fresnel zone plate lens objective.

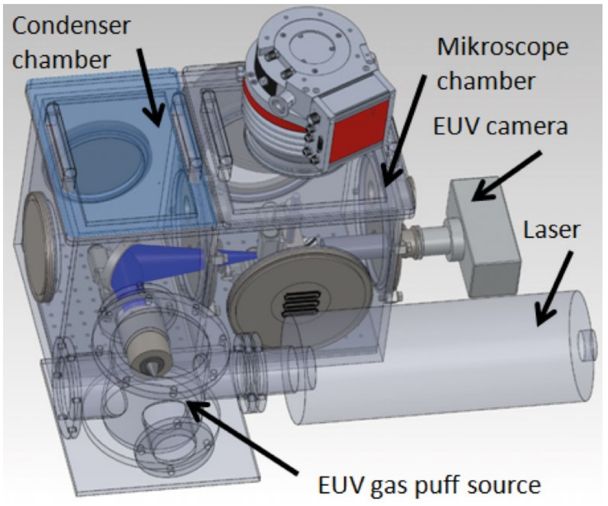


**Fig. 1.** 3-D visualization of the EUV microscope

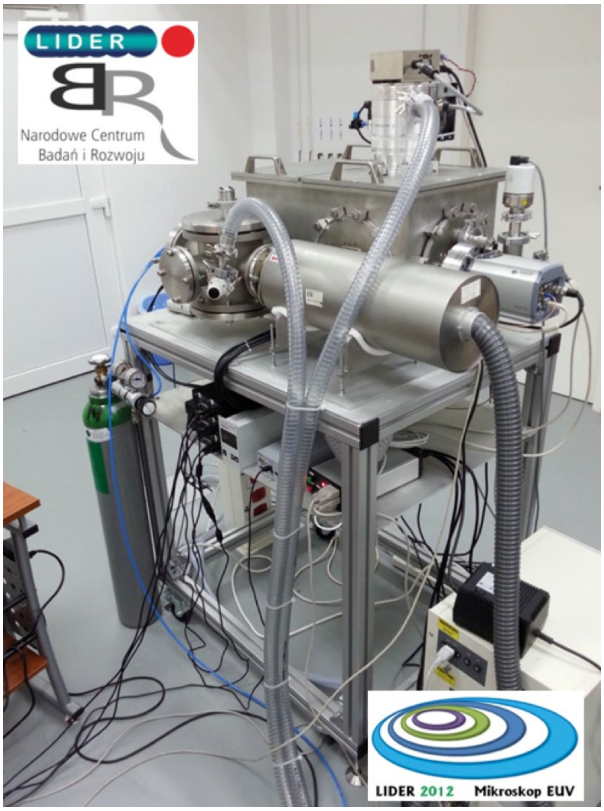


**Fig. 2.** Photograph of the EUV microscope

Detailed source and microscope optimization was carried in the course of studies. Using this microscope series of experiments were conducted, during which source parameters such as number of photons available, plasma size, emission spectrum from nitrogen/helium double stream gas puff target, as well as imaging of test objects for spatial resolution assessment were carried out.

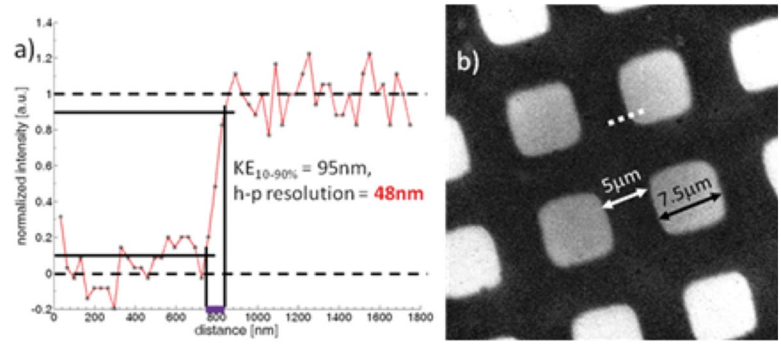


**Fig. 3**. Spatial resolution measurement using KE criterion a) - half-pitch spatial resolution of 48 nm. EUV image of the test object – copper mesh 2000 periods/inch b)

The microscope spatial resolution was measured to be 48 nm and the exposure time was from a few seconds up to 1 minute to acquire single EUV image with nanometer spatial resolution.

# 5.2. MULTISPECTRAL LASER REFLECTANCE PROFILOMETER

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The project concerning construction of the reflectance profilometer scanning head with optical transmitting and receiving systems of a new generation was completed. Multispectral laser scanner is an optoelectronic device, designed for use on aircraft platforms including unmanned. Its principle of operation is based on range-finding technique. As a source of radiation one used 4 semiconductors laser diodes of high power (850 nm, 905 nm, 2 x 1550 nm). With the multiplication of number of analyzed wavelength, it is possible not only to measure a distance from analyzed objects, but also intensity of a returning signal for each channel. Both returning signal intensity for all analyzed wavelength, as well as their mutual relationships arise directly from spectral characteristics of analyzed substance, and being their unique feature, provide the basis for identification. Obtained signals are compared with reflectance characteristics collected in specially created database for that purpose Based on the database the process of identification and analysis of terrain cover elements is made. For the needs of multispectral laser scanner one developed special software which illustrates collected data. Final information is presented by digital visualization implemented in both 2D and 3D format, creating Digital Elevation Model (DEM) as well as Digital Surface Model (DSM).

**Fig. 1.** Pictures of the reflectance profilometer head

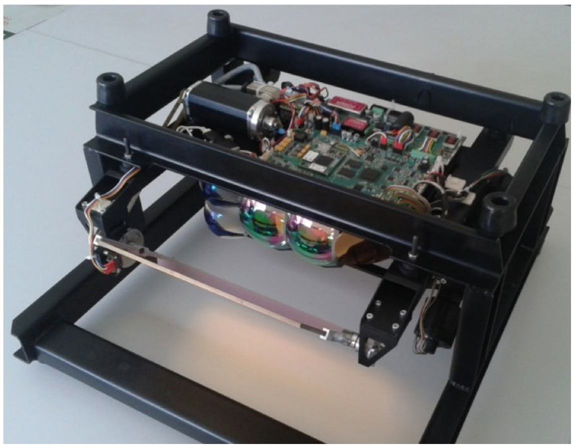

**Fig. 2.** Picture of analyzed terrain

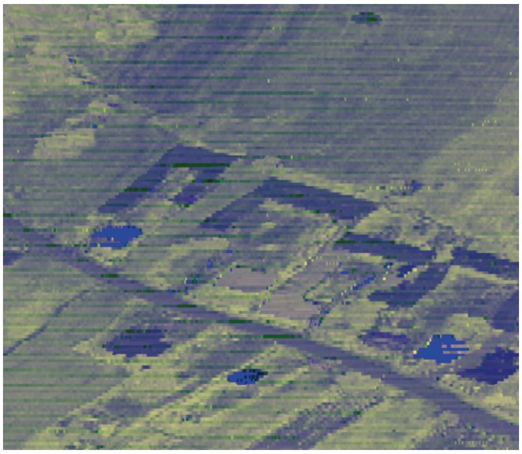

**Fig. 3.** Digital surface model

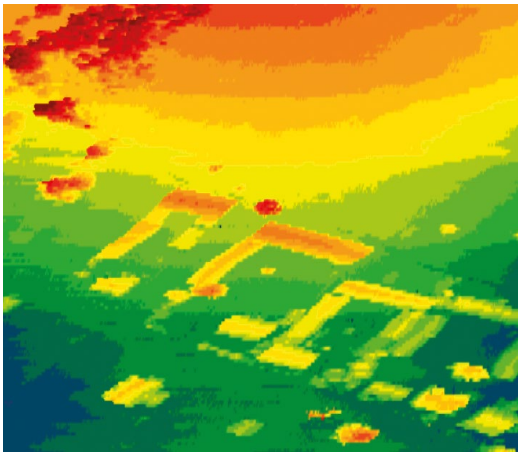

**Fig. 4.** Digital elevation model

# 5.3. BIO-LIDAR TESTS IN USA

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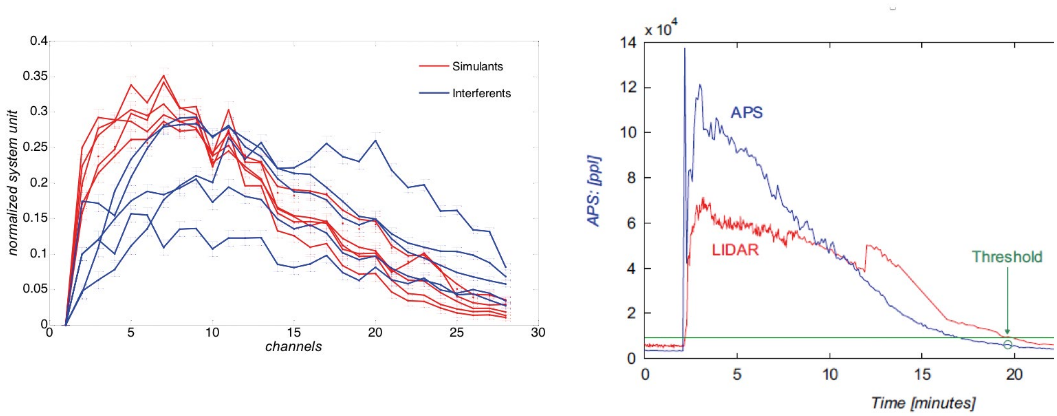
LIDAR (Light Detection and Ranging) system for medium-range stand-off detection of biological hazards underwent a 2-week test in military technology training facility DPG (Dugway Proving Ground) located in the US (UT).

During the first week, a verification of the overall sensitivity was performed and a database of fluorescence and depolarization signatures was built. LIDAR was located approx. 1 km from specialized bio- chamber, where a variety of biological aerosols were released in a controlled manner. The chamber looked like a cylinder, opened at both sides, with a base diameter of 3.5 m and a length approx. 40 m, additionally equipped at both ends with air curtains to prevent the escape of particles sprayed inside to the outside. Inside the chamber, a number of devices designed to maintain spatial uniformity of aerosol throughout its volume was installed. The concentration was monitored in real time by three independent APC sensors (Aerosol Particle Counter) located in the chamber, which allowed the assessment of LIDAR sensitivity. In many cases, our system showed a sensitivity for detection of biological particles at a concentration of several hundred ppl which is comparable to the concentration level of natural biological background constantly present in Earth atmosphere.

Experiments carried out during the second week, were aimed at spraying biological aerosols in the open space, at different (unknown) points within the monitored area. Evolution of the clouds in terms of their size and movement was dependent on weather conditions and especially wind. LIDAR operated in automatic mode, scanning the designated space sector to detect the presence of aerosols, confirm or exclude their biological character (based on a fluorescence signal), and follow the trajectory of aerosol movement.

**Fig. 1.** Spectral signatures (left) and integrated fluorescence signal (right) measured by Bio-LIDAR during field tests



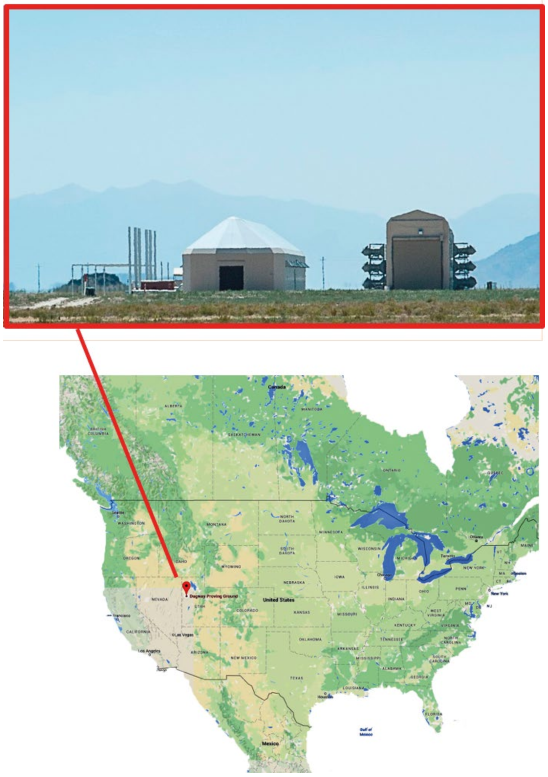


**Fig. 2.** DGP location and photo of the chambers

**Fig. 3.** Photo of the Bio-LIDAR

# 5.4. HANDHELD LASER PHOTO-SPEEDOMETER

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The project was completed and the final version of the laser speedometer integrated with video recording was obtained. This final prototype takes into account any improvements in the field of algorithms, ergonomics and mechanical design, the need for which was identified during testing of the intermediate version of the device (in 2014).

The field tests were also conducted - the results of velocity measurements obtained remotely using the laser speedometer were confronted with the results recorded on the so called calibration gate. The measurements were performed repeatedly, at different times, under different atmospheric conditions, with respect to different vehicles and for different measuring distances. Statistical analysis of the results confirms the speed measurement accuracy below 1 km / s. The device is safe for eyes (Class 1) and has a maximum operational range of 1 km. In addition to the participants of road incident, the system records how the measurement was conducted by the operator. The speedometer has two displays - the main (touch-screen) and near-eye (of strong sunlight conditions), as well as a number of useful features and functions. It received particularly positive comments from police representatives and the commercialization is expected in nearest future.


**Fig. 1.** Photos of hand held photo-speedometer

# 5.5. OPTOELECTRONIC DETECTOR OF SURFACE CONTAMINATION

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In this work we developed an optoelectronic device for quick audit of hospital equipment surface cleanliness. Application of UV radiation can quickly estimate the potentially contaminated areas and pinpoint the places where samples should be collected for further analysis, and decontamination should be carried out. The use of systems based on laser induced fluorescence for the constant monitoring of microbiological purity of operating rooms, sanitary items and medical equipment, can significantly reduce the risk of spread of pathogenic microorganisms and affect the security of the citizens.

**Photos 1.2.** Contamination on the sanitary equipment in visible and UV light

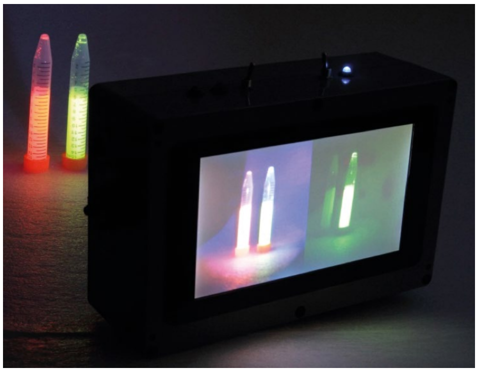

**Photo 3.** Application of an optical filter, so that only the fluorescence of fluorophores present in microorganisms is visible

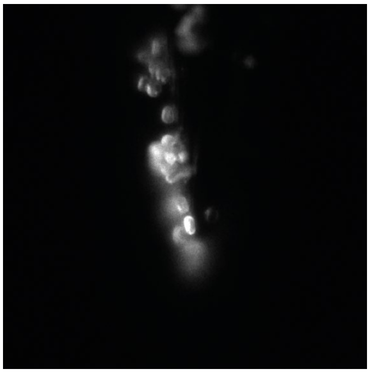

**Photo 4.** Autofluorescence of pollen on the tip of the needle

# 5.6. BIOMETRMOBILE SYSTEM

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Experimental mobile system for services performing the biometric control was worked out. The design is based on the vest with freely configurable components. The developed system allows checks of second-generation biometric documents.


**Fig. 1.** Biometric vest

**Fig. 2.** Reading data from the passport

Safety data verification is done through communication with the server certificates. The system is equipped with an experimental ultrasonic fingerprint reader. Work is underway on the possibility of using Augmented Reality technology for data acquisition and visualization of information (HMD module).

**Fig. 3.** Acquisition of fingerprints

**Rys. 4.** Concept of data visualization

Additional components of the system are PKI card reader, a heart rate monitor. Communication with the individual elements of the system is realized by wireless communication. The vest has its own energy center.

# 5.7. A COMPOSITE SYSTEM OF PASSIVE AND ACTIVE PROTECTION OF CRITICAL INFRASTRUCTURE

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The Operational Programme Innovative Economy, Institute of Optoelectronics as Applicant (leader) and the company Intermet with Człuchów (as a Consortium Member Business) realized the project no. POIG.0I.03.01-14-033/12, financed by The National Centre for Research and Development entitled „A composite system of passive and active protection Critical Infrastructure".

The aim of the project was the implementation of an innovative technology to Business Consortium Member, active composite mechanical security system through the integration of mechanical elements of the composite fences, fiber optic and electromagnetic sensors and system integrator. The result of the project is:

1. The development of experimental technological line for the manufacture of composite mechanical components of Critical Infrastructure (CI) protection by extrusion.
2. Installing experimental line for the production of composite components in Business Consortium Member Intermet in Człuchów (fig. 1) and realization the elements for the construction the experimental composite mechanical systems security CI objects (fig. 2).
3. The development of fiber optic cable sensor for use in composite mechanical security systems CI.
4. The development of electromagnetic cable sensor for use in composite mechanical security systems CI.
5. The development of an integrator of electronic sensor systems for use in composite mechanical security systems CI.
6. Development and implementation of an active integrated research system for mechanical safety of composite components made on a pilot a technological line.

Active composite mechanical security systems are made through the integration of mechanical elements composites, sensors and integrator. They have been tested in operational conditions:

- razor mesh fence (fence 30 m long and 2.7 m height with installed sensors, built in MUT).
- razor barbed wire - coiled wire roller with composite blade with electromagnetic sensor (manufactured and examined by a Business Consortium Member).
- mesh floating security fence for submarines and surface ships protection (tested in the dock in Gdynia).
- portable stretched barbed wire to protect the sides of ships from pirates (difficult boarding) - tested in Gdynia on the ship Amaranth

**Fig.1.** Technological line for extrusion installed at a Consortium Member Business in Człuchów

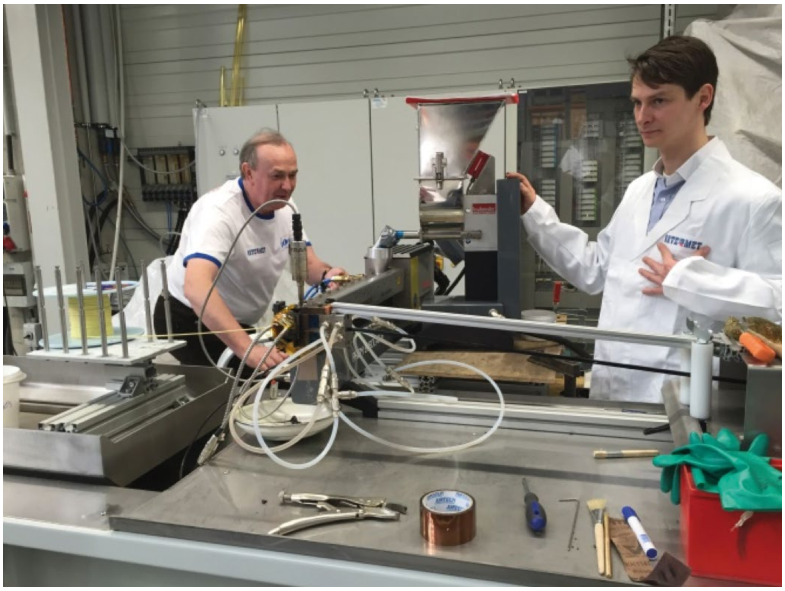

**Fig.2.** Composite structures made of razor mesh done at Consortium Member Business in Człuchów

# 5.8. "LOCK-IN" SIGNAL PROCESSING SYSTEMS FOR PHOTORECEIVERS

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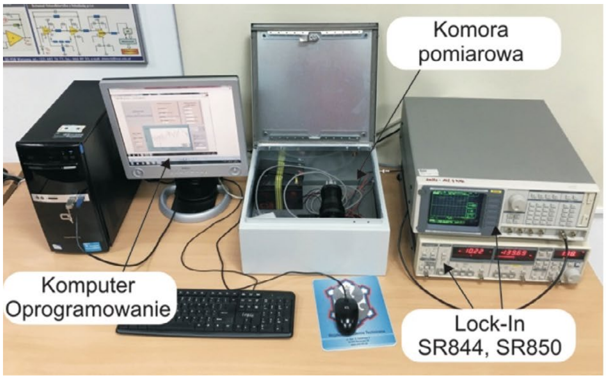
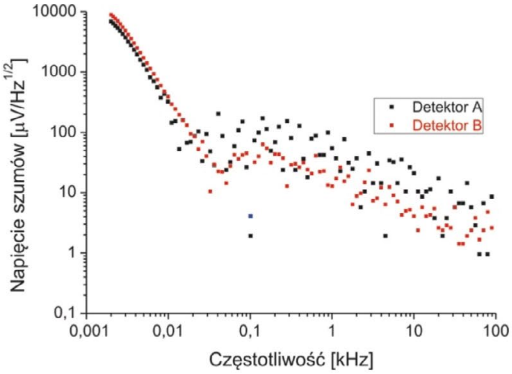
The main objective of this work was to develop laboratory setups employing the advanced optical signal detection methods. This is important issue for identify opportunities for improvement of optoelectronic technologies. It involves closely with military applications related to sensors and surveillance. A measurable effect of this work was to design and develop:

- automated laboratory setup for noise parameters testing of components and systems for both electronic and optoelectronic devices,



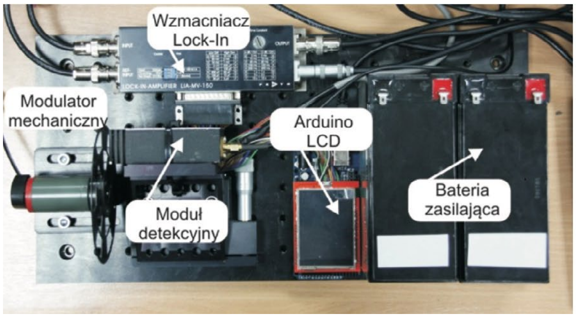

a)



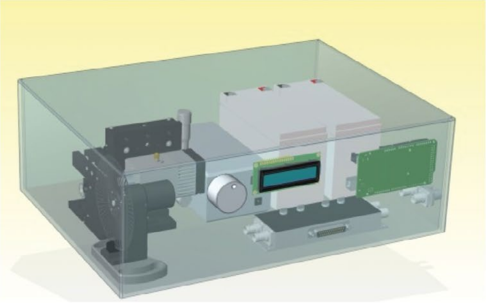

b)

**Fig. 1.** Photography of the laboratory setup (a) and example of measured characteristics of noise voltage spectral density for selected photoreceivers (b)

- "Lock-in" type platform for optical radiation detectors and photoreceivers,




a)

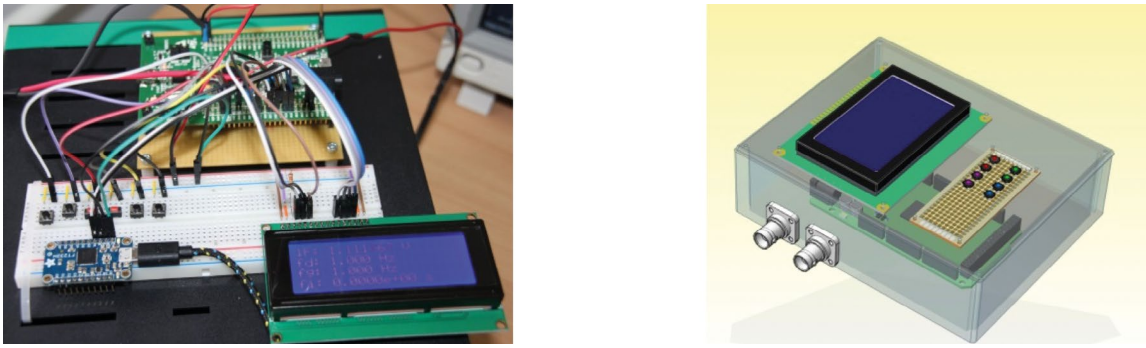


b)

**Fig. 2.** Lab model platform of Lock-in technique (a) and its 3D visualization (b)

- compact Lock-in amplifier module.

The developed instruments can provide valuable information, which will be applied to construct new detectors and photoreceivers, as well as their practical application.



a) b)

**Fig. 3.** Photo of Lock- in lab module (a) and its 3D visualization (b)

# 5.9. THERMAL WEAPON SIGHT COMPATIBLE WITH TYTAN INDIVIDUAL WARFARE SYSTEM

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Nowadays all armed forces utilize a wide variety of advanced optoelectronic observation devices. Institute of Optoelectronics, in co-operation with PCO S.A. and WB Electronics S.A., developed a high-resolution thermal weapon sight for small-arms weapons. The sight is compatible with TYTAN individual warfare system and can be paired up with a helmet-mounted display and laser IFF module. Furthermore the sight is equipped with interfaces allowing for a remote control of its main functions.

Thermal weapon sight is used for precise firing, observation, target detection and identification during day and night, regardless of natural lightning. It is also effective in the presence of light fog or smoke. The sight is fitted with a state-of- the-art uncooled microbolometer focal plane array detector made of amorphous silicon, with a 640x480 resolution and 17 μm pixel pitch. As a result it provides sufficiently long detection ranges for a variety of potential targets. Electronic circuits, optics and mechanical construction of the sight were designed with the application of cutting-edge technology, which resulted in feature-rich, yet lightweight and energy-efficient solution.

**Fig. 1.** Thermal weapon sight compatible with TYTAN individual warfare system mounted on 5,56 mm Beryl assault rifle

a)

b)


**Fig. 2.** Prototype thermal weapon sight compatible with TYTAN individual warfare system with attached laser IFF module

# 5.10. OBSERVATION AND RECONNAISSANCE LLL/CCD TV CAMERAS WITH HIGH DYNAMIC RANGE

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Institute of Optoelectronics, in co-operation with PCO S.A. and WB Electronics S.A., developed a high dynamic range (HDR) camera with a video link to TYTAN individual warfare system. One of the key features of this camera is its ability to produce visual image in low ambient light environment (e.g. at night) resulting from the application of highly sensitive image sensor with an extended spectral response. This HDR camera was developed using monochrome image sensor Lynx (by PHOTONIS), featuring SVGA 1280 x 1024 resolution and spectral range 350 nm - 1100 nm.

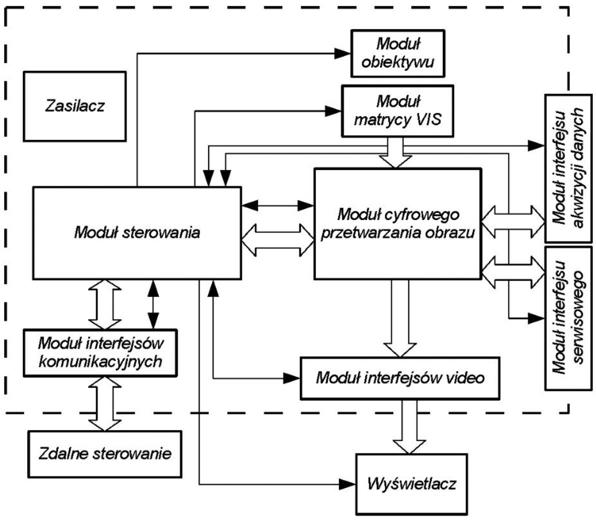


**Fig. 1.** Simplified block diagram of HDR camera

**Fig. 2.** Photos of the developed HDR camera: without casing (left), in a weather-sealed enclosure (center) and helmet-mounted (right)

# 5.11. OBSERVATION AND RECONNAISSANCE CAMERA WITH DIGITAL ZOOM, COMPATIBLE WITH TYTAN INDIVIDUAL WARFARE SYSTEM

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Institute of Optoelectronics, in co-operation with PCO S.A. and WB Electronics S.A., developed a camera with digital zoom and advances image processing capabilities. It also features a video interface to TYTAN individual warfare system, which makes it possible to display its video feed on a personal computer and/or helmet-mounted display. The camera enhances the visual observation capabilities of a soldier, being able to adapt itself to a changing scene illumination. Camera features a digital zoom and image processing system, which provide sharp, enlarged view of objects in the center (adjustable x2/x4 zoom) yet retaining the overview of a wider scene.

The camera design was based on color CMOS image sensor AR0132AT6C00XPEA0 ( by APTINA) with 1280 x 960 resolution.

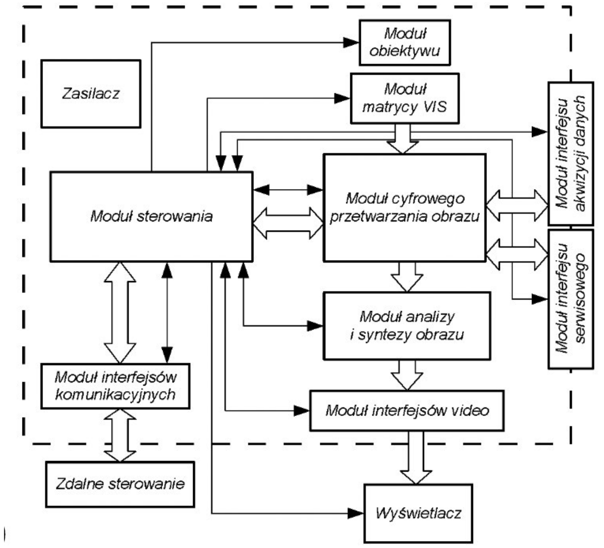
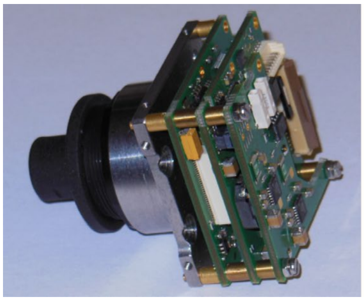



**Fig. 1.** Block diagram of the developed camera (a) and the operation of digital zoom and image processing system (b)



a)

b)

**Fig. 2.** Inside view of the developed camera module (a) and the camera case which can be mounted on a helmet (b)

# 5.12. CAMERA SET FOR OPTOELECTRONIC, MULTISPECTRAL SYSTEM AIDING AIRPLANE LANDING OPERATION

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Institute of Optoelectronics, in co-operation with PIT-RADWAR S.A. and PCO S.A., developed the camera set to be used in optoelectronic, multispectral airfield system intended to assist aircraft landings. The main purpose of this system is to provide detailed information on approaching aircraft (in day/night, fog conditions), such as: position with respect to runway axis, altitude, distance to touchdown point and visual image of landing gear (or other aircraft components). The camera set consists of three camera units: two newly developed, high-resolution thermal cameras with cooled focal plane array detectors (640x512 pixels, pixel pitch15 μm) and a video camera module. Thermal cameras operate in MWIR (35 μm) and LWIR (8-12 μm) bands of infrared spectrum whereas the video camera covers visible spectrum (0,38 - 0,78 μm). MWIR thermal camera is fitted with InSb infrared array detector Pelican D manufactured by SCD (Israel) and LWIR camera uses MCT infrared array detector supplied by AIM (Germany).
Real test conducted on an airfield confirmed the performance and proper operation of the camera set. Thermal cameras were capable of aircraft detection and tracking from the distance exceeding 10 kilometers, both at night and light fog conditions (visibility 1 kilometer).

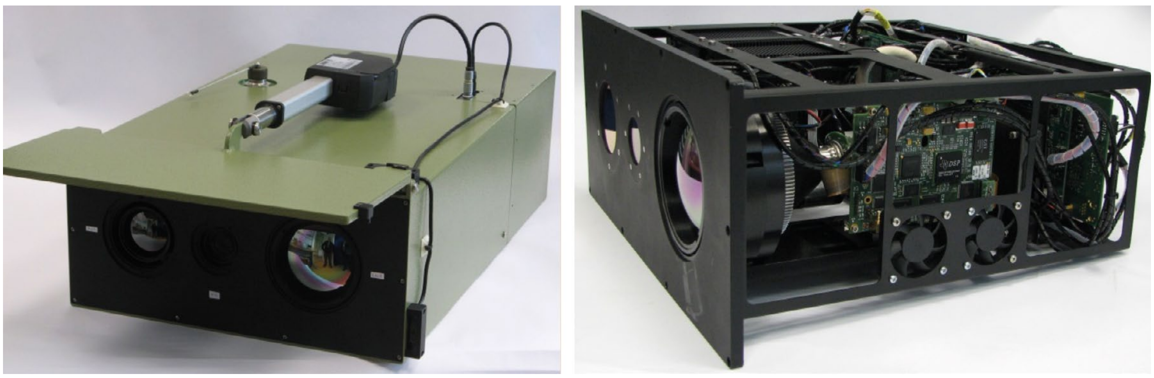

**Fig. 1.** Photo of the set from the camera lens side ( from left to right: MWIR, VIS, LWIR) and an inside view with casing removed

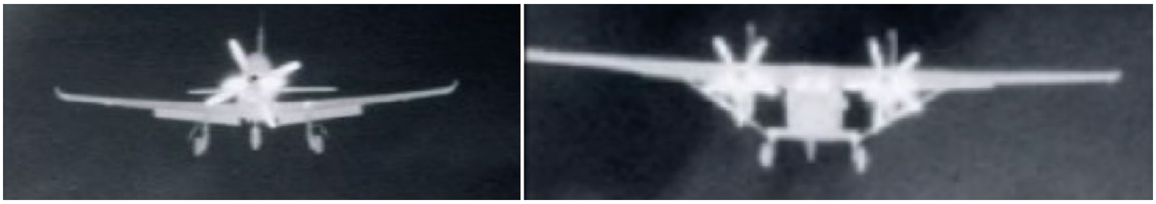

**Fig. 2.** Sample aircraft images recorded from 2 kilometer distance: PZL-130 Orlik, MWIR camera (left), PZL M28B Bryza, LWIR camera (right). Visibility 1 kilometer (light fog)

# 6.
# APENDICES

## D.1.1. INTERNATIONAL PROJECTS FINANCED BY UE AND OTHER INTERNATIONAL ORGANIZATIONS

M1. PUM/09-041/2013/WAT, „Terahercowe platformy obrazujące do zdalnej detekcji IED (improwizowanych ładunków wybuchowych) (TIPPSI) „EUROPEJSKA AGENCJA OBRONY EDA, Kierownik: PAŁKA Norbert

M2. PUM/09-058/2013/WAT, RAMBO „EUROPEJSKA AGENCJA OBRONY EDA, Kierownik: JANKIEWICZ Bartłomiej

M3. PUM/09-153/2014/WAT, „AMURFOCAL -Active Multispectral Reflection Fingerprinting of Persistent Chemical Agents" „EUROPEJSKA AGENCJA OBRONY EDA, Kierownik: KASTEK Mariusz

M4. PMW/35-002/2013/WAT, „Wytwarzanie laserem promieniowania rentgenowskiego i skrajnego nadfioletu (EUV) do zastosowań w inżynierii materiałowej i biomedycynie. LASERLAB-EUROPE „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: FIEDOROWICZ Henryk

M5. PRUE/31-089/212/WAT, Laserlab Europe III „KOMISJA WSPÓLNOT EUROPEJSKICH, Kierownik: FIEDOROWICZ Henryk

M6. NCN/36-433/2013/WAT, Impulsowe lasery na ośrodkach quasi-III-poziomowych pompowanie poprzeczna 2D stosami diod laserowych dużej mocy „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: JABCZYŃSKI Jan

M7. PMN/36-236/2015/WAT, Badania generacji supercontinuum w światłowodach fluoroindowych pompowanych impulsami optycznymi o czasie trwania z zakresu femtosekund, pikosekund oraz nanosekund. „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: ŚWIDERSKI Jacek

M8. FS/32-015/2013/WAT, Rozwój Klastra Centrum Inżynierii Biomedycznej „POLSKA AGENCJA ROZWOJU, Kierownik: ŁAPIŃSKI Mariusz

KL1. FS/32-309/2015/WAT, Rozbudowa Laboratoriów Centrum Inżynierii Biomedycznej Wojskowej Akademii Technicznej „Zarząd Województwa Mazowieckiego Mazowiecka Jednostka Wdrażania Programów Unijnych., Kierownik: ŁAPIŃSKI Mariusz

M9. FS/32-480/2013/WAT, Kompozytowy system pasywnej i aktywnej ochrony obiektów infrastruktury krytycznej „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: SZUSTAKOWSKI Mieczysław

M10. PPFM/37-363/2015/WAT, OPTOLAB- Rozbudowa bazy laboratoryjnej Instytutu Optoelektroniki Wojskowej Akademii Technicznej „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: SZCZUREK Mirosław

# D.1.2. STRATEGIC PROGRAMS FINANCED BY NATIONAL CENTRE FOR RESEARCH & DEVELOPMENT

PST1. PSOB/16-062/2014/WAT, Metody i Sposoby Ochrony i Obrony przed impulsami HPM „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: KOPCZYŃSKI Krzysztof

PST2. PSOB/16-064/2014/WAT, Laserowe systemy Broni Skierowanej Energii, Laserowe Systemy Broni Nieśmiercionośnej „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: KOPCZYŃSKI Krzysztof

# D.1.3. BASIC RESEARCH PROGRAMS FINANCED BY NATIONAL SCIENCE CENTRE

BP1. NCN/07-145/2012/WAT, Badanie procesu zatężania I dekompozycji w optoelektronicznym sensorze par materiałów wybuchowych „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: RUTECKA Beata

BP2. NCN/07-148/2012/WAT, Mikroskopia w zakresie skrajnego nadfioletu oraz miękkiego promieniowania rentgenowskiego „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: WACHULAK Przemysław

BP3. NCN/07-150/2012/WAT, Wpływ budowy plazmonowych monostruktur core-shell na bazie tlenku tytanu i metali szlachetnych na ich właściwości optyczne i fotoelektryczne „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: JANKIEWICZ Bartłomiej

BP4. NCN/07-381/2013/WAT, Nowe lasery ciała stałego z samo-adaptującymi rezonatorami wykorzystujące efekt cztero-falowego mieszania w ośrodku czynnym. „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: ŻENDZIAN Waldemar

BP5. NCN/07-124/2014/WAT, Analiza teoretyczna oraz badania właściwości generacyjnych pompowanego koherentnie, impulsowego lasera Cr:ZnSe, przestrajalnego w paśmie widmowym około 2400 nm. „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: GORAJEK Łukasz

BP6. NCN/07-125/2014/WAT, Fotojonizacja ośrodków gazowych impulsami promieniowania plazmy laserowej „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: BARTNIK Andrzej

BP7. NCN/07- 094/2015/WAT, Badanie generacji supercontinuum w paśmie widmowym średniej podczerwieni z użyciem wybranych światłowodów nieliniowych oraz nowoczesnych laserowych układów światłowodowych generujących pikosekundowe impulsy promieniowania o długości fali 2000 nm „NARODOWE CENTRUM NAUKI KRAKÓW, Kierownik: ŚWIDERSKI Jacek

# D.1.4. RESEARCH & DEVELOPMENT PROJECTS FINANCED BY NATIONAL CENTRE FOR RESEARCH & DEVELOPMENT

BR1. PBR/15-291/2012/WAT, Celownik termowizyjny kompatybilny z systemem C4ISR ISW TYTAN, zintegrowany z wyświetlaczem nahełmowym, modułem laserowego systemu identyfikacji „swój-obcy" (IFF) z możliwością zdalnego sterowania głównymi funkcjami celownika. „NARODOWE CENTRUM BADAŃ I ROZWOJU , Kierownik: SOSNOWSKI Tomasz

BR2. PBR/15-305/2012/WAT, Kamery obserwacyjno-rozpoznawcze o szerokim zakresie natężenia światła LLL/CCD TV kompatybilne z systemem C4ISR ISW TYTAN „NARODOWE CENTRUM BADAŃ I ROZWOJU ( BUMAR ŻOŁNIERZ S.A.), Kierownik: MADURA Henryk

BR3. PBR/15-301/2012/WAT, System monitorowania integralności łącza światłowodowego w celu ochrony przed nieautoryzowanym dostępem do informacji niejawnych. „NARODOWE CENTRUM BADAŃ I ROZWOJU , Kierownik: ŻYCZKOWSKI Marek

BR4. PBR/15-314/2012/WAT, Uprawnienie procesu odprawy granicznej osób przy wykorzystaniu biometrycznych urządzeń do samokontroli środków transportu przekraczających granicę zewnętrzną UE. „NARODOWE CENTRUM BADAŃ I ROZWOJU , Kierownik: SZUSTAKOWSKI Mieczysław

BR5. PBR/15-316/2013/WAT, Środki ochrony wzroku i sprzętu przed wysokoenergetycznym promieniowaniem elektromagnetycznym, w tym laserowym, w szerokim zakresie widma zgodnie z ISW TYTAN. „NARODOWE CENTRUM BADAŃ I ROZWOJU ( WYDZIAŁ NOWYCH TECHNOLOGII I CHEMII), Kierownik: ZYGMUNT Marek

BR6. PBR/15-098/2013/WAT, Mobilna kontrola graniczna z wykorzystaniem technik biometrycznych dostosowana do wymogów i zaleceń UE. „NARODOWE CENTRUM BADAŃ I ROZWOJU , Kierownik: SZUSTAKOWSKI Mieczysław

BR7. PBR/15-097/2013/WAT, Inteligentny antypocisk do zwalczania pocisków przeciwpancernych „NARODOWE CENTRUM BADAŃ I ROZWOJU WYDZIAŁ MECHANICZNY, Kierownik: ZYGMUNT Marek

BR8. PBR/15-114/2014/WAT, Narzędzie wspomagające prowadzenie postępowania przygotowawczego i wykonywanie czynność w procesie wykrywczym poprzez odtwarzanie wyglądu miejsca zdarzenia i okoliczności zdarzenia. „NARODOWE CENTRUM BADAŃ I ROZWOJU CGS , Kierownik: KASTEK Mariusz

BR9. PBR/15-067/2014/WAT, Innowacyjny hełm strażacki zintegrowany z obserwacyjnym systemem termowizyjnym i systemem umożliwiającym monitorowanie funkcji życiowych strażaka ratownika oraz wyjściem do transmisji obrazów i danych do urzdzeń zewnętrznych. „NARODOWE CENTRUM BADAŃ I ROZWOJU CENTRALNA SZKOŁA PAŃSTWOWEJ STRAŻY POŻARNEJ CZĘSTOCHOWA. PRZEDSIĘBIORSTWO SPRZĘTU OCHRONNEGO ‚ASKPOL S.A., Kierownik: MADURA Henryk

BR10. PBR/15-072/2014/WAT, Opracowanie środowiska do wdrożeń koncepcji SmartBorders. „NARODOWE CENTRUM BADAŃ I ROZWOJU JAS TECHNOLOGIE GEMALTO SP Z O.O. , Kierownik: SZUSTAKOWSKI Mieczysław

BR11. PBR/15-361/2015/WAT, System przeciwdziałania i zwalczania zagrożeń powstałych w wyniku bezprawnego i celowego użycia platform mobilnych (latających, pływających). „NARODOWE CENTRUM BADAŃ I ROZWOJU JAS TECHNOLOGIE GEMALTO SP Z O.O. , Kierownik: KASTEK Mariusz

BR12. PBR/15-364/2015/WAT, Symulatory szkoleniowe w zakresie zwalczania pożarów wewnętrznych. „NARODOWE CENTRUM BADAŃ I ROZWOJU JAS TECHNOLOGIE GEMALTO SP Z O.O. , Kierownik: FIRMANTY Krzysztof

BR13. PBST/27-054/2013/WAT, Opracowanie energooszczędnego zestawu biometrycznego do mobilnej kontroli dokumentów i osób z użyciem systemów akustycznych i zobrazowania twarzy „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: SZUSTAKOWSKI Mieczysław

BR14. PBST/27-086/2012/WAT, Emitery i detektory podczerwieni nowej generacji do zastosowań w urządzeniach do detekcji śladowych ilości zanieczyszczeń gazowych „NARODOWE CENTRUM BADAŃ I ROZWOJU ( Instytut Technologii Elektronowej), Kierownik: BIELECKI Zbigniew

BR15. PBST/27-219/2015/WAT, Aktywny sub-THz skaner 3D do zastosowań antyterrorystycznych. „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: SZUSTAKOWSKI Mieczysław

BR16. PBST/27-220/2015/WAT, Pompowany diodowo, modułowy zestaw laserowy do zastosowań specjalnych. „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: JABCZYŃSKI Jan

BR17. PBST/27-225/2012/WAT, Wielopikselowy detektor promieniowania THz zrealizowany z wykorzystaniem selektywnych tranzystorów MOS i jego zastosowanie w biologii, medycynie i systemach bezpieczeństwa. „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: ZAGRAJEK Przemysław

BR18. PBST/27-238/2012/WAT, Opracowanie głowicy skanującej z układami nadawczo-odbiorczymi nowej generacji do wielospektralnego laserowego profilometru reflektancyjnego umożliwiającego określanie rzeźby i charakterystyk fizykochemicznych pokrycia terenu do zastosowania na platformie powietrznej. „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: PIOTROWASKI Wiesław

BR19. PBST/27-239/2012/WAT, Optoelektroniczny system sensorów markerów chorobowych. „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: BIELECKI Zbigniew

BR20. PBST/27-281/2012/WAT, Opracowanie warunków wytwarzania spinela magnezowego MgA1204,skandowo-magnezowego ScMgA104,oraz szkła Er, Yb, do zastosowania w mikrolaserach dalmierczych „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: MŁYŃCZAK Jarosław

BR21. PBST/27-345/2012/WAT, Ręczny fotoradar laserowy. „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: WOJTANOWSKI Jacek

BR24. INT/19-045/2014/WAT, Lasery chirurgiczne wysokiej mocy pracujące na długości fali 1470nm i 1940 nm do zastosowań w małoinwazyjnej chirurgii endoskopowej i robotycznej. „NARODOWE CENTRUM BADAŃ I ROZWOJU (METRUM CRYOFLEX S z o.o., sp.k.), Kierownik: ŚWIDERSKI Jacek

BR25. INT/19-190/2015/WAT, Opracowanie nowatorskiego czujnika detekcji upadku osób wraz z systemem sterowania inteligentnym budynkiem. „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: ŻYCZKOWSKI Marek

BR26. INT/19-335/2015/WAT, Spektrometr ramanowski z heterodyną optyczną „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: KOPCZYŃSKI Krzysztof

BR25. PPFN/34-198/2012/WAT, Nanostruktury plazmonowe do zastosowań w fotowoltaice i optoelektronice „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: NYGA Piotr

BR26. PPFN/34-038/2013/WAT, Metoda i system do wykrywania obiektów z użyciem polarymetrii obrazowej w zakresie dalekiej podczerwieni „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: BIESZCZAD Grzegorz

BR27. PPFN/34-049/2013/WAT, Mikroskop EUV z nanometrową rozdzielczością przestrzenną do zastosowań we współczesnej nauce i technologii „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: WACHULAK Przemysław

BR28. PPFN/34-068/2014/WAT, Detektory promieniowania THz wytworzone z wykorzystaniem tranzystorów polowych do zastosowania w komunikacji bezprzewodowej „NARODOWE CENTRUM BADAŃ I ROZWOJU, Kierownik: ZAGRAJEK Przemysław

# D.1.5. SCIENTIFIC SCHOLARSHIPS FOR OUTSTANDING YOUNG SCIENTISTS

SN2. PPFN/34-001/2012/WAT, Finansowanie stypendium naukowego decyzją Ministra z dnia 31.10.2012 dla wybitnego młodego naukowca „MINISTERSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: NYGA Piotr

SN3. PPFN/34-004/2014/WAT, Finansowanie stypendium naukowego decyzją Ministra z dnia 31.10.2012 dla wybitnego młodego naukowca „MINISTERSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: JANKIEWICZ Bartłomiej

# D.1.6.

## STATUTE RESEARCH PROJECTS FINANCED BY MINISTRY OF SCIENCE AND HIGHER EDUCATION

ST1. PBS/23-902/2014/WAT, Optoelektroniczne rozpoznanie pola walki. „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: ZYGMUNT Marek

ST2. PBS/23-903/2014/WAT, Optoelektroniczne metody wytwarzania i charakteryzacji nanostruktur dla potrzeb techniki wojskowej. „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: GIETKA Andrzej

ST3. PBS/23-904/2014/WAT, Zabezpieczenie metrologiczne optoelektroniki. „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik:

ST4. PBS/23-905/2014/WAT, Analiza porównawcza symulatorów lotów przenośnych rakiet przeciwlotniczych krótkiego zasięgu. „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: PUZEWICZ Zbigniew

ST5. PBS/23-906/2014/WAT, Multispektralne urządzenia optoelektroniczne w systemach bezpieczeństwa „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: SZUSTAKOWSKI Mieczysław

ST6. PBS/23-907/2014/WAT, Militarne zastosowania laserów pompowanych wiązkami światła „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: ŻENDZIAN Waldemar

ST7. PBS/23-908/2014/WAT, Laserowe i plazmowe technologie mikro-i nano - obróbki warstwy wierzchniej materiałów „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: BARTNIK Andrzej

ST8. PBS/23-920/2015/WAT, Układy przetwarzania sygnałów do detektorów promieniowania optycznego. „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: BIELECKI Zbigniew

ST9. PBS/23-921/2015/WAT, Obserwacyjne kamery termowizyjne dla autonomicznych platform bojowych z niechłodzonymi matrycami detektorów podczerwieni o dużej rozdzielczości . „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: SOSNOWSKI Tomasz

MRN1. PRM 08-754/2015/ WAT, Wytwarzanie ultrakrótkich impulsów spójnego promieniowania w zakresie widmowym skrajnego nadfioletu (EUV) w wyniku oddziaływania femtosekundowych impulsów laserowych z tarczami gazowymi o zmiennym rozkładzie gęstości. „MINISTESSTWO NAUKI I SZKOLNICTWA WYŻSZEGO, Kierownik: FOK Tomasz

D.1.7.

# RESEARCH PROJECTS FINANCED BY OTHER SOURCES

PBU1. PBU/01 /598 2011/WAT, Modernizacja przenośnego przeciwlotniczego zestawu rakietowego „GROM" „BUMAR AMUNICJA S.A., Kierownik: PUZEWICZ Zbigniew

PBU2. PBU/01-122/2012/WAT, Wykonanie 19 szt. Układów detekcyjnych FAD Mod.1 do głowicy samonaprowadzającej na promieniowanie podczerwone rakiety morskiej P-22, zwanej dalej „towarem". „CENZIN SP. Z O.O. , Kierownik: NOGA JANUSZ

PBU3. PBU/01-195/2012/WAT, System amunicji precyzyjnego rażenia do 120 mm moździerza kryptonim RAK i System amunicji precyzyjnego rażenia dla samobieżnych haubic kal.155 mm kryptonim KRAB,KRYL. „BUMAR AMUNICJA S.A., Kierownik: PUZEWICZ Zbigniew

PBU4. PBU/01-356/2012/WAT, Cytadela Bezpieczeństwa Statków - system ochrony jednostek pływających przed atakami pirackimi. „Przedsiębiorstwo Produkcyjno - Usługowe INTERMET Sp. z o.o., Kierownik: SZUSTAKOWSKI Mieczysław

PBU8. PBU/01-172/2014/WAT, Zadanie 1 Analiza problemu diagnostycznego dotyczącego degradacji łopatek turbin -opracowanie metody pomiarowej i wymagań dla innowacyjnego laserowego systemu wizyjnego. W ramach realizacji projektu" Innowacyjne laserowe metody diagnostyki oraz technologie naprawy łopatek turbin parowych" „Zakład Remontowy Energetyki Katowice Spółka Akcyjna, Kierownik: PISZCZEK Marek

PBU9. PBU/01-036/2014/WAT, Badania i pomiar parametrów zestawu 12 kamer termowizyjnych w zakresie określonym w zał. Nr 1. „Bracia Strzelczyk, Kierownik: KASTEK Mariusz

PBU10. PBU/01-185/2015/WAT, Opracowanie nowego wzoru / typu kamuflażu. „MASKPOL S.A., Kierownik: KASTEK Mariusz

PBU11. PBU/01-271/2015/WAT, Opracowania udoskonalonego systemu do wideoweryfikacji decyzji sędziowskich w sporcie „BIRS Sp.J., Kierownik: KOPCZYŃSKI Krzysztof

PBU12. PBU/01-282/2015/WAT, Opracowanie i wdrożenie lekkiego systemu ze sterowaną rakietą o zasięgu 2,5 km kryptonim „PIRAT". „MESKO S.A, Kierownik: PUZEWICZ Zbigniew

PBU13. PBU/01-336/2015/WAT, Wykonanie 19 sztuk układów detekcyjnych FAD Mod1 do głowicy samonaprowadzającej na promieniowanie podczerwone rakiety morskiej P-22 . „CENZIN Sp. z o.o., Kierownik: PUZEWICZ Zbigniew

PBU14. PBU/01372/2006/WAT, Przeprowadzenie przez Akademię na rzecz Zamawiającego badań na zgodność z warunkami technicznymi (WT) fotodetektorów InSb, PbS przeznaczonych do GSN GROM w roku 2006 i 2007 oraz przeprowadzenie badań kontroli wejściowej półfabrykatów owiewki dla GSN GROM na warunkach określonych w dalszej jej części. „CRW TELESYSTEM MESKO SP.z o.o., Kierownik: PUZEWICZ Zbigniew

PBU15. PBU/02-254/1999/WAT, Poufna „BUMAR AMUNICJA S.A., Kierownik: PUZEWICZ Zbigniew

PBU16. PBU/02-189/2014/WAT, Zaawansowane Indywidualne Systemy Walki(ZISW) kr. TYTAN „Skarb Państwa Inspektorat Uzbrojenia, Kierownik: ZYGMUNT Marek

PBN1. PBN/03-192/2014/WAT, Pomoc ekspercka w organizacji i przeprowadzaniu postępowania o udzielenie zam. publicznego „Kancelaria Sejmu, Kierownik: SZUSTAKOWSKI Mieczysław

PBN2. PBN/03-119/2015/WAT, Wytworzenie struktur Periodycznych przy użyciu techniki DLIL na powierzchni blachy wykonanej z tytanu Grade 2. „Politechnika Warszawska, Kierownik: MARCZAK Jan

PBN3. PBN/03-147/2015/WAT, Instrumentalna analiza defektów ,gładkości, rozkładu środków barwnych i rozdzielczości w dekoracji laserowej szkła przy naświetlaniu laserowym od strony podłoża. „Instytut Ceramiki i Materiałów Budowlanych, Kierownik: MARCZAK Jan

PBN4. PBN/03-155/2014/WAT, Doradcy w procesie wyłonienia Wykonawcy w organizowanym przez spółkę postępowaniu na zaprojektowanie i wykonanie technicznego systemu ochrony perymetrycznej Lotniska Warszawa / Modlin oraz uczestnictwo w ocenie należytego wykonania umowy w wyniku postępowania wykonawcą.. „Spółka Mazowiecki Port Lotniczy Warszawa –Modlin Sp. z o.o., Kierownik: SZUSTAKOWSKI Mieczysław

PBN5. PBN/03-257/2015/WAT, Badania porównawcze efektów ciśnieniowych w odczycie bezpośrednim i interferometrycznym w materiałach pod wpływem silnych impulsów laserowych. „Instytut Podstawowych problemów Technik PAN, Kierownik: MARCZAK Jan

PBN6. PBN/03-273/2015/WAT, Lokalizacji zawodników w czasie poszczególnych akcji w piłce siatkowej. „BIRS Sp.J., Kierownik: KOPCZYŃSKI Krzysztof

PBN7. PBN/03-289/2015/WAT, Laserowa modyfikacja powierzchni tytanu. „Politechnika Warszawska, Kierownik: MARCZAK Jan

PBN8. PBN/03-232/2015/WAT, Usługi wsparcia w charakterze konsultanta w zakresie rozwiązań technicznych dla etapu II i III. „Państwowe Muzeum Auschwitz-Birkenau, Kierownik: ŻYCZKOWSKI Marek

PBN9. PBN/03-025/2014/WAT, Opracowanie urządzenia do wytwarzania dwustrumieniowej tarczy gazowej przeznaczonej do badań w zakresie oddziaływania impulsów laserowych z gazem pod wysokim ciśnieniem oraz wytwarzania promieniowania w zakresie widmowym skrajnego nadfioletu (EUV). „Inframet Krzysztof Chrzanowski, Kierownik: FIEDOROWICZ Henryk

PBN10. PBN/03-048/2014/WAT, Wykonanie badań laboratoryjnych kamery termowizyjnej i kamery dziennej TV wyrobu ZMO-1, zastosowanego w ZSMU, w zakresie określenia zasięgu wykrycia, rozpoznania i identyfikacji celu dla wąskiego i szerokiego pola widzenia. „Wojskowy Instytut Techniki Pancernej i Samochodowej, Kierownik: KASTEK Mariusz

# D.2. PATENT APPLICATIONS IN 2015

ZP1. No. 415256, T: Sposób określania względnej transmisji promieniowania i urządzenie do wykorzystania tego sposobu

ZP2. No. 415227, T: Sposób korekcji wpływu temperatury na wartość czułości napięciowej detektorów w matrycy mikrobolometrycznej

ZP3. No. 415226, T: Urządzenie z ruchomą przesłoną do zdalnego wykrywania par alkoholu w poruszających się pojazdach

ZP4. No. 414689, T: Impulsowy detektor zaburzeń mechanicznych światłowodowej linii transmisyjnej i sposób detekcji zaburzeń mechanicznych światłowodowej linii transmisyjnej

ZP5. No. 414705, T: Kwantowy detektor zaburzeń mechanicznych światłowodowej linii transmisyjnej i sposób detekcji zaburzeń mechanicznych światłowodowej linii transmisyjnej

ZP6. No. 414425, T: Sposób optycznego szyfrowania informacji i układ do optycznego szyfrowania informacji

ZP7. No. 15166490.1-1655, T: An active protection system

ZP8. No. 412840, T: Urządzenie do wykrywania par alkoholu w poruszających się pojazdach z wykorzystaniem międzypasmowych laserów kaskadowych

# D.3. SCIENTIFIC MEETINGS ORGANIZED BY INSTITUTE OF OPTOELECTRONICS

| Title | National/International | Date | Numbers of particpants |
|---|---|---|---|
| Application of Laser Plasma Sources of X-rays and Extreme Ultraviolet (EUV) in Technology and Science – meeting organized in the framework ofLASERLAB-EUROPE | International | July 6-9, 2015. | 43 participants from Poland – 26, Germany – 5, Sweden – 2, Japan – 2, Ireland– 2, Italy –1 UK – 1, Czech Rep – 1 France– 1, Portugal – 1, South Korea– 1. |
| XXIX Konferencja Naukowo-Techniczna EKOMILITARIS pt. „Inżynieria bezpieczeństwa – ochrona przed skutkami nadzwyczajnych zagrożeń” | national | Sept. 15-18, 2015 | ~150 participants |
| „Innowacyjne technologie w Centrum Inżynierii Biomedycznej” | national | Nov. 25 2015 . | ~ 70 participants |

# D.4. SCIENTIFIC ARTICLES IN JCR - LIST A OF MINISTRY OF SCIENCE AND HIGHER EDUCATION

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A3. E. Mavrona, U. Chodorow, E.M Barnes, J. Parka, S. Saitzek, J. F. Blach, V. Apostolopoulos, M Kaczmarek, N. Pałka, Refractive indices and birefringence of hybrid liquid crystal - nanoparticles composite materials in the terahertz region „AIP Advances, 2015, 5,7, 77143-77143

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A7. P. Kwasniak, J. Pura, M. Zwolinska, P. Wiecinski, H. Skarzynski, L. Olszewski, J. Marczak, H. Garbacz, J.K. Kurzydlowski, Laser and chemical surface modifications of titanium grade 2 for medical application', Applied Surface Science, 2015, 336, pp: 267-273

A8. J. Marczak, Micromachining and patterning in micro/nano scale on macroscopic areas', Archives of Metallurgy and Materials, 2015, 63 (2), 2221-2234

A9. Z. Bielecki, T. Stacewicz, J. Wojtas, J. Mikołajczyk, Application of quantum cascade lasers for trace gas detection', Bulletin of the Polish Academy of Sciences - Technical Sciences, 2015, Vol. 63, No. 2, 2015, 515-525

A10. M.Traczyk, J. Wojtanowski, Z.Mierczyk, M. Zygmunt, P.KNYSAK, T. Drozd, M. Muzal, Theoretical analysis and optimization of 3D laser beam shaping', Bulletin of the Polish Academy of Sciences - Technical Sciences, 2015, 63(2),str 555-560

A11. Długaszek Maria, Kurpiewska Żaneta, Mierczyk Jadwiga, Lithium content in the tea and herbal infusions', European Food Research and Technology, 2015, 241: 289-293

A12. M. Włodarski, M. Kaliszewski, E. A. Trafny, M. Szpakowska, R. Lewandowski, A. Bombalska, M. Kwaśny, K. Kopczyński, M. Mularczyk-Oliwa., Fast, reagentless and reliable screening of "white powders" during the bioterrorism hoaxes.', Forensic Science International, 2015, 248, 71-77

A13. M. Kaliszewski, M. Włodarski, E. A. Trafny, M. Szpakowska, R. Lewandowski, A. Bombalska, M. Kwaśny, K. Kopczyński, M. Mularczyk-Oliwa., Fast, Reagentless and reliable screening of „white powders" during the bioterrorism hoaxes „Forensic Science International, 2015, 248, 71-77

A14. J. Suszek, A. Siemion, M. S. Bieda, N. Blocki, D. Coquillat, G. Cywinski, E. Czerwińska, M. Doch, A. Kowalczyk, N. Palka, A. Sobczyk, P. Zagrajek, M. Zaremba, A. Kolodziejczyk, W. Knap, M. Sypek, 3-D-Printed Flat Optics for THz Linear Scanners „IEEE Transactions on Terahertz Science and Technology, 2015, 5, 2, 314-316

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A20. N. Palka, R. Panowicz, F. Ospald, R. Beigang, 3D Non-destructive Imaging of Punctures in Polyethylene Composite Armor by THz Time Domain Spectroscopy „Journal of Infrared Millimeter and Terahertz Waves, 2015, 36, 8, 770-788

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A27. J. Mlynczak, N. Belghachem, Laser generation in newly developed PAL77 and PAL80 glasses doped with Er3+ and Yb3+ ions', Laser Physics, 2015, 25,5, 1-5

A28. N. Belghachem, J. Mlynczak, Numerical simulation and optimization of passively q-switched erbium microchip lasers', Laser Physics, 2015, 25,8, 1-7

A29. J. Mlynczak, N. Belghachem, ' High peak power generation in thermally bonded Er3+,Yb3+:glass/Co2+: MgAl2O3 microchip laser for telemetry application', Laser Physics Letters, 2015, 12,4, 45803-45807

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A33. B. Zakrzewska, Very sensitive optical system with the concentration and decomposition unit for explsive trace detection', Metrology and Measurement Systems, 2015, XXII (2015), No. 1, pp. 101–110

A34. J. Ćwirko, R. Ćwirko, J. Mikołajczyk, Comparative tests of temperature effects on the performance of GaN and SiC photodiodes', Metrology and Measurement Systems, 2015, XXII (2015), No. 1, pp. 119–126

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A37. I. Ahad, B. Butruk, M. Ayele, B. Budner. A. Bartnik, H. Fiedorowicz, T. Ciach, D. Brabazon, Extreme ultraviolet (EUV) surface modification of polytetrafluoroethylene (PTFE) for control of biocompatibility', Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 2015, 364, 98-107

A38. D. Adjei, M. Ayele, P. Wachulak, A. Bartnik, Ł. Wegrzynski, H. Fiedorowicz, L. Vyšín, A. Wiecheć, J. Lekki, W. Kwiatek, L. Pina, M. Davídková, L. Juha, Development of a compact laser-produced plasma soft X-ray source for radiobiology experiments', Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 2015, 364, 27-32

A39. E. Dynowska, J. Pelka, D. Klinger, R. Minikayev, A. Bartnik, P. Dłuzewski, M. Jakubowski, M. Klepka, A. Petruczik, O. Seeck, R. Sobierajski, I. Sveklo, A. Wawro, A. Maziewski, Structural investigation of ultrathin Pt/Co/Pt trilayer films under EUV irradiation', Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 2015, 364, 33-39

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A41. P. Wachulak, A. Bartnik, Ł. Węgrzyński, T. Fok, J. Kostecki, M. Szczurek, R. Jarocki, H. Fiedorowicz, Characterization of pulsed capillary channel gas puff target using EUV shadowgraphy', Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 2015, 345, 15-21

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# D.4.1. SCIENTIFIC ARTICLES IN LIST B OF MINISTRY OF SCIENCE AND HIGHER EDUCATION

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