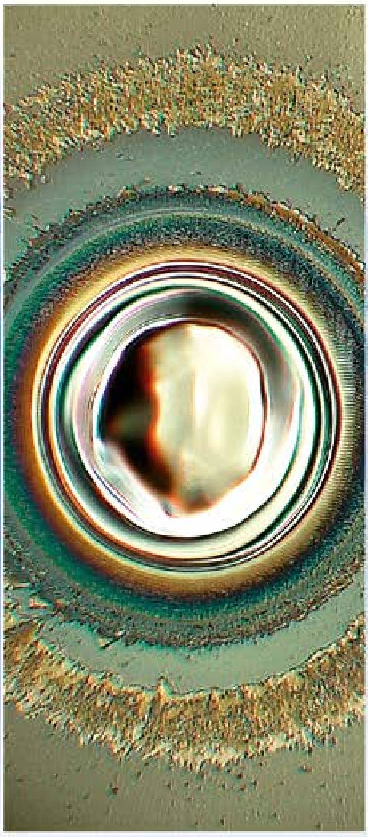


Institute of **Optoelectronics**

Annual **Report**

2013

Institute of **Optoelectronics**

Annual **Report**

2013

2013 Annual Report

Institute of Optoelectronics
Military University of Technology

Editor: prof. dr hab. inż. Jan K. Jabczyński
mgr Ewa Jankiewicz

DTP: Tomasz Wajnkaim

Photography: Magdalena Wiśniewska-Krasińska

Printing: DRUKARNIA GRAFFITI
ul. Kolejowa, 13 Łomianki
www.drukarnia-graffiti.pl

Available from the Institute of Optoelectronics
Military University of Technology, ul. gen. S. Kaliskiego 2
00-902 Warsaw, Poland
tel. +48 22 683 94 30, fax: +48 22 666 89 50
www.ioe.wat.edu.pl

table of contents

	Preface	6
1.	**General information**	10
2.	**Laser Technologies**	12
2.1.	**Research on solid state and fiber lasers**	12
2.1.1.	Mid-Infrared, all-fiber supercontinuum (SC) generator built using a Tm-doped fiber amplifier	12
2.1.2.	Mid-infrared supercontinuum (SC) generator based on fluorozirconate (ZBLAN) fiber	13
2.1.3.	Mid-infrared supercontinuum generator built using ZBLAN fiber pumped by Tm-doped fiber laser and amplifier system with mode-locked-like operation	14
2.1.4.	Active Q-switching in Ho:YAG laser “in band” pumped by Tm:fiber laser	15
2.1.5.	Passive Q-switching in side-pumped Nd:YAG laser in self-adapted closed-loop resonator	16
2.2.	**Research on laser-plasma sources of soft X-rays and extreme ultraviolet**	17
2.2.1.	Intense laser–plasma SXR/EUV source	17
2.2.2.	Generation of high-order harmonics of the femtosecond laser in EUV range	18
2.2.3.	Research on influence of partial ionization of gaseous media on absorption properties of neutral atoms	19
2.2.4.	EUV and SXR (“water-window”) microscopy	20
2.2.5.	EUV material processing for biocompatibility control of polymer surfaces	22
2.3.	**Laser modification of outer layers of metals and alloys**	23

3.	**Optoelectronic Technologies and Systems**	24
3.1.	**Optoelectronic systems for stand-off-detection and free-space communication**	24
3.1.1.	Laser rangefinder module	24
3.1.2.	Reflectance profile-meter	25
3.1.3.	Third-generation free-space optics data transmission link	26
3.1.4.	Stand-off detection of explosives using LIBS	27
3.1.5.	Measuring system for hazardous chemical detection and identification	28
3.2.	**Optoelectronic technologies for biological threat detection and recognition**	29
3.2.1.	Field range tests of LIDAR systems	29
3.2.2.	Optoelectronic methods of “in situ” bacteria detection	30
3.2.3.	Plasmonic nanostructures in biological material detection	32
3.3.	**Nanotechnology**	34
3.3.1.	Multilayers deposited by laser ablation technique for the membrane-electrode assemblies	34
3.3.2.	Technology development for surface coating with polymer-like carbon-type layers	36
3.3.3.	Fabrication of plasmonic nanostructures by PVD	37
4.	**Optoelectronic Systems for defense and security**	38
4.1.	**Testing and Training Systems for MANPADS Missiles**	38
4.1.1.	Dynamic simulator and tester of MANPADS GROM	39
4.1.2.	Training System for MANPADS missile operators	40
4.2.	**Multispectral systems for threat detection and recognition**	41
4.2.1.	Development and testing of terahertz sensor for explosives detection	41
4.2.2.	Development and testing of fiber-optic sensor system with distributed field detection	42
4.2.3.	Development and testing of a ship protection system	43
4.3.	**Optoelectronic technologies for trace gas detection**	44
4.3.1.	Optoelectronic sensor for nitrogen dioxide detection	45
4.3.2.	Optoelectronic system for explosives detection	46
4.3.3.	CO_2 detection module	47
4.3.4.	Laboratory intrapulse system for laser absorption spectroscopy	48
4.3.5.	Explosives vapor concentrators for optoelectronic NOX sensors	49

5.	**Infrared Technologies and thermal imaging**	50
5.1.	**Biomedical applications of thermal imaging**	50
5.1.1.	Assessment of metabolic activity and brain functions	50
5.1.2.	Application of thermal imaging in biopsy and brain tumor resection	51
5.2.	**Optical technology for infrared systems**	52
5.2.1.	Technology development for manufacturing spherical and aspherical lenses for infrared spectral range	53
5.2.2.	Technology development for applying diamond-like carbon (DLC) layers for infrared spectral range	54
5.3.	**Metrology equipment for infrared devices**	55
5.3.1.	Development of procedures for measurement of parameters	55
	of thermal cameras, LLLTV cameras, and night vision devices	55
5.3.2.	Development of measurement procedure and test stand for non-uniformity correction of infrared microbolometer focal plane arrays	56
5.4.	**Implementation of thermal weapon sight SCT "RUBIN"**	57
6.	**Accredited Testing Laboratory**	58

PREFACE

The Institute of Optoelectronics (IOE) is the research institute with faculty status within the Military University of Technology. Its work is focused on scientific research and education in the fields of optoelectronics and photonic technologies. The principal mission of the IOE is research and development related to defense and security needs defined by the Ministry of National Defense (MoD). IOE activities include a wide range of undertakings, ranging from basic scientific investigations, development of laboratory models and technology demonstrators, to testing prototypes.

The remarkable professional competence and experience of the staff at the IOE enables an interdisciplinary approach towards research tasks and development projects. The IOE conducts scientific research in the following areas:

- Solid-state lasers
- High-power laser systems
- Laser optics and electronics
- Laser-driven X-ray and EUV sources
- Laser-matter interaction and laser-assisted material processing
- LIDAR systems
- Optical and optoelectronic technologies
- Optical spectroscopy
- Optical and optoelectronic metrology
- Nanotechnologies and plasmonics
- Infrared technology and thermal imaging
- THz physics and technology
- Fiber-optic techniques
- Optoelectronic systems for defense and security
- Biotechnology, biochemistry and biomedical engineering

For many reasons, 2013 was an important year for the IOE. The Ministry of Science and Higher Education completed an evaluation and categorization of academic and R+D institutions, which included assessment of research and development achievements for last 4 years. The IOE remained in the A category, (6th place among 44 scientific institutions in the discipline of electronics in Poland). There has also been an addition to the structure of IOE, with the founding of the Biomedical Engineering Center, which serves to accomplish its own objectives and tasks as well as to support the Polish nation-wide Claster CIBio.

The year 2013 has also seen the launching of the 10-year Program of Technical Modernization of Armed Forces of Poland. To date, the IOE has made substantial contributions to the modernization programs established by MoD. Several defense programs currently operate with substantive participation of the IOE, including the National Air Defense System (including the anti-aircraft MANPADS missiles GROM and PIORUN, and the middle-range missile system WISŁA) and the advanced future soldier ordnance program TYTAN. IOE participation in defense programs has significantly widened and tightened our collaboration with Polish research centers and the defense industry.

Another very important part of IOE activity is international collaboration. Over recent years, we have acquired considerable financial support from the EU for laboratory modernization. We have also participated in numerous scientific collaboration programs managed by the EU, EDA, and NATO. For many years, we have had close relations with several scientific groups worldwide, in the framework of bilateral collaboration agreements.

The research work of the IOE has been always accompanied by the activities in the field of education. For several years, IOE employees have taught on the various faculties of the Military University of Technology. Since 2010, we have run the 2nd stage studies in optoelectronic systems and lasers. We consider the training, education, and scientific promotion of young employees to be of great importance. During 2013, 34 employees of IOE were engaged in Ph.D. studies. Other employees have also participated as lecturers, tutors, and supervisors of Ph.D. studies conducted at MUT faculties. Furthermore, for last two years, we have educated several foreign Ph.D. students within the framework of international program ERASMUS-MUNDUS.

Over recent years, the laboratory infrastructure of the IOE has seen considerable development as a result of successive investments and realizations of several projects and programs including the largest program: “Optolab - base expansion laboratory of the Institute of Optoelectronics, Military University of Technology”. As a result, OPTOLAB - laboratory complex which consists of 6 fully equipped optoelectronic laboratories has been organized and run in 2013. The main objectives of OPTOLAB are as follows:

- development of knowledge in the areas of photonic technologies including generation, detection and application of optical radiation,
- building research capacity, which will allow conducting high-quality research in the field of modern optoelectronic technology based on knowledge,
- extension of national and international scientific collaboration.

Col. Krzysztof Kopczyński, PhD. Eng.

Director of Institute of Optoelectronics

1.
GENERAL INFORMATION

Table 1.1. Organizational structure of the Institute of Optoelectronics

The organizational structure of the Institute of Optoelectronics comprises 15 research groups located in four divisions, the Accredited Testing Laboratory, and the recently founded Biomedical Engineering Center (Table 1.1).

Division	Group	Group leader
Laser Technology Division	Fiber Lasers Group	dr inż. J. Świderski,
	Laser Optics Group	prof. dr hab. inż. J. Jabczyński,
	Laser Mater Interaction Group	prof. dr hab. inż. H. Fiedorowicz
	Laser Applications Group	dr hab. inż. J. Marczak,
Optoelectronic Technologies Division	Laser Teledetection Group	prof. dr hab. inż. Z. Mierczyk,
	Optical Technologies Group	dr inż. K. Kopczyński,
	Laser Nanotechnology Group	dr hab. E. Michalski
	Optical Spectroscopy Group	dr hab. inż. M. Kwaśny
	Biochemistry Group	dr hab. A. Padzik-Graczyk,
Optoelectronic Systems Division	Quantum Electronics Group	prof. dr inż. Z. Puzewicz
	Security Systems Group	prof. dr hab. inż. M. Szustakowski,
	Optical Signal Detection Group	prof. dr hab. inż. Z. Bielecki,
Infrared Technology and Thermovision Division	Thermal detection and Thermovison Group	dr hab. inż. H. Madura,
Accredited Testing Laboratory	Laser Metrology Group	dr hab. inż. J. Owsik †,
Biomedical Engineering Center		dr hab. n. med. M. Łapiński,

At the end of 2013, the staff of the IOE consisted of 144 employees (19 females and 125 males) working in research and development (see Table 1.2). 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 Ph.D. degree in electronics. In 2013, one scientific employee of the IOE achieved a D.Sc. degree in physics, and three Ph.D. procedures have been open.

Table 1.2. Distribution of the research and development employees of the Institute of Optoelectronics in 2013.

Domain	prof.	D.Sc.	Ph.D.	M.Sc.	together
Technical Sciences	9	8	50	50	117
Chemistry	0	1	7	5	13
Physics	1	1	6	6	12
Medicine	1	1	0	0	2
together	11	11	63	59	144

Chapters 2–5 of the annual report present the main results of the research + development projects conducted in the IOE in 2013.
IRP: research projects ordered by industry; Teaching - teaching subvention; Statute: statute subvention;
R+D projects financed by the Ministry of Science; EU: projects financed by the EU.

Those works, conducted in the framework of 92 projects, were financed from several sources (Figure 1.1). The research results have been presented in 254 scientific publications and reports, http://www.ioe.wat.edu.pl/badania-naukowe/publikacje2/publikacje-2013/ including 60 articles published in the journals included in the JCR list (Figure 1.2.).

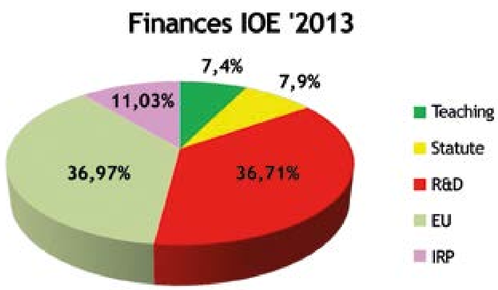


Figure 1.1. Distribution of financial sources of the IOE in 2013.

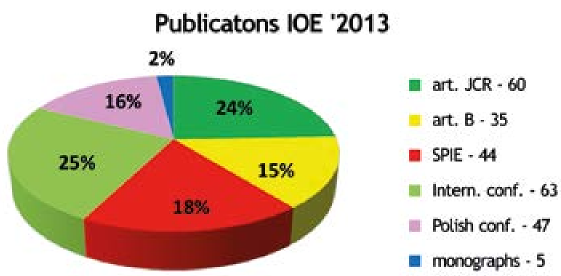


Figure 1.2. Distribution of publications of the IOE in 2013 (total number, 254).

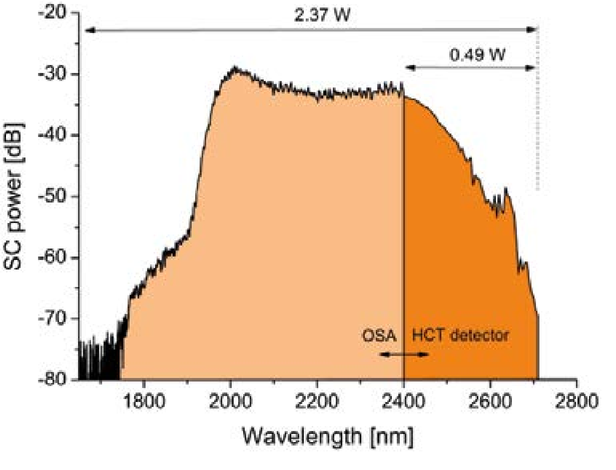
2.
LASER TECHNOLOGIES

2.1. RESEARCH ON SOLID STATE AND FIBER LASERS

jswiderski@wat.edu.pl

2.1.1. MID-INFRARED, ALL-FIBER SUPERCONTINUUM (SC) GENERATOR BUILT USING A Tm-DOPED FIBER AMPLIFIER

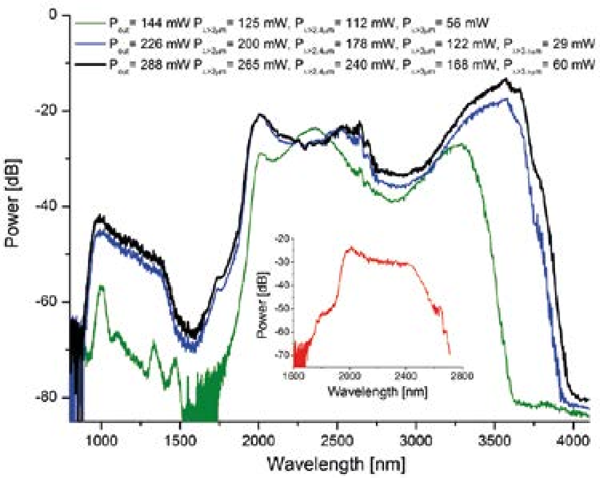
The SC generator comprises a pulsed DFB laser, a chain of three Er-doped and Er/Yb-doped fiber amplifiers, and a chain of two Tm-doped fiber amplifiers. The system delivers 2.37 W of average power (24% slope efficiency) with a spectrum (measured at the −10 dB level below the maximum peak) extending from around 1.95–2.52 μm. The power beyond 2.4 μm was measured to be 0.49 W, constituting 21% of total SC output power. The long-wavelength edge of the spectrum was 2.7 μm. These achieved results are the best obtained regarding SC generation in single-mode Tm-doped fibers.

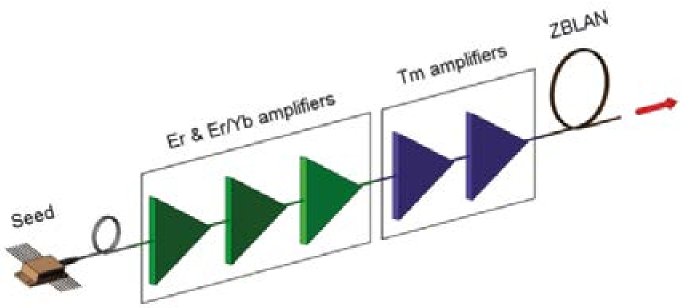


2.1.2. MID-INFRARED SUPERCONTINUUM (SC) GENERATOR BASED ON FLUOROZIRCONATE (ZBLAN) FIBER

jswiderski@wat.edu.pl

The SC generator consists of a pulsed DFB laser, a chain of three Er-doped and Er/Yb-doped fiber amplifiers, a chain of two Tm-doped fiber amplifiers, and a piece of ZBLAN fiber. SC generation is reported to have 288 mW of output power and a spectrum extending from around 0.9–4 µm. The powers for wavelengths longer than 2 µm, 2.4 µm, 3 µm, and 3.6 µm were measured to be 265 mW (92%), 240 mW (82%), 168 mW (58%), and 60 mW (21%), respectively. These results show the best power conversion efficiency ever achieved in the mid-infrared using soft glass fibers.

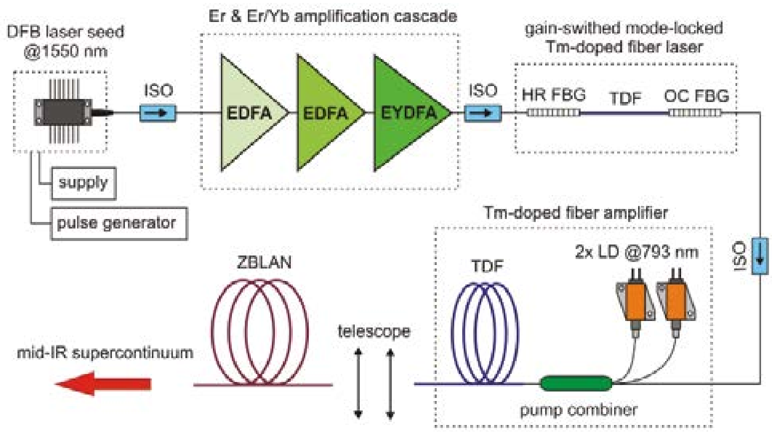


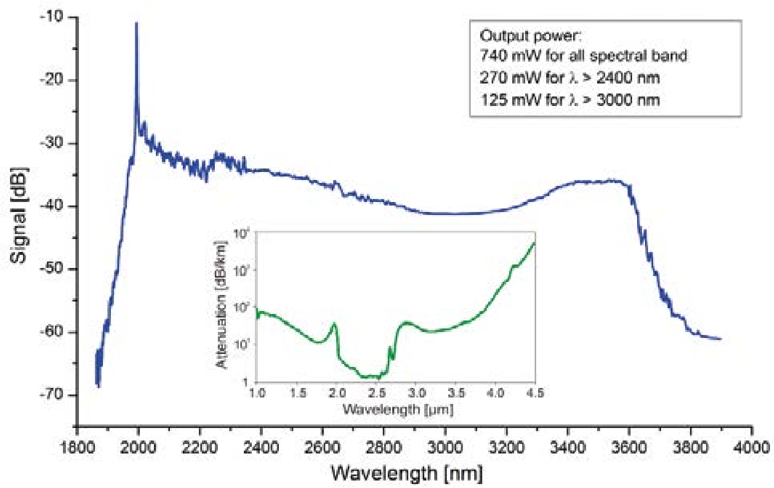


jswiderski@wat.edu.pl

2.1.3. MID-INFRARED SUPERCONTINUUM GENERATOR BUILT USING ZBLAN FIBER PUMPED BY Tm-DOPED FIBER LASER AND AMPLIFIER SYSTEM WITH MODE-LOCKED-LIKE OPERATION

The Tm-doped fiber laser with mode-locked-like operation was extended by adding an additional amplification section, allowing achievement of over 2.3 W of average power at a repetition rate of 26 kHz. Peak power was over 25 kW for the most intensive mode-locked-like subpulses (recorded within the gain-switched pulse envelope). When this pulse train was launched into a ZBLAN fiber, we achieved 0.74 W of average supercontinuum power at its output. The continuum extended from approximately 1.9–3.8 µm. This is the first report of this original high-power mid-infrared supercontinuum system.

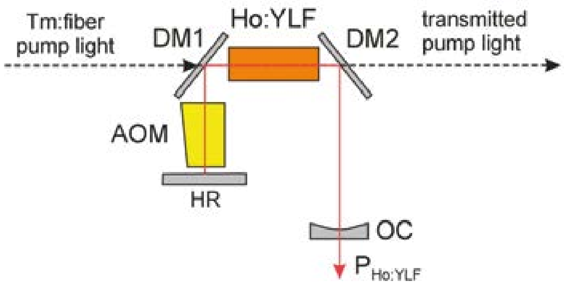


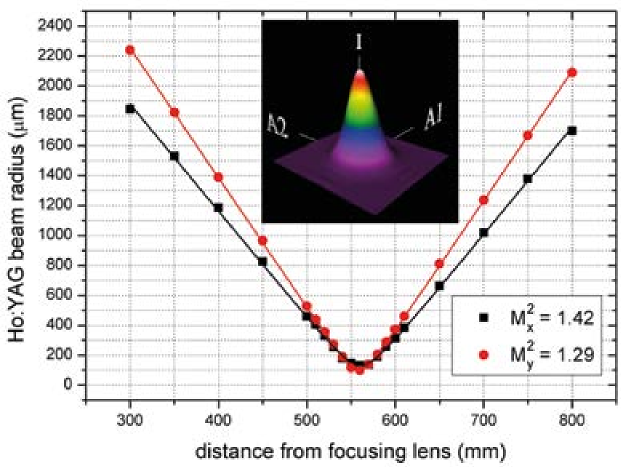


2.1.4. ACTIVE Q-SWITCHING IN Ho:YAG LASER "IN BAND" PUMPED BY Tm:FIBER LASER

jswiderski@wat.edu.pl

The compact set-up of a Ho:YAG laser "in band" pumped by a 20-W Tm:fiber laser was developed and examined in both free-running and Q-switching operations. In free-running operation, up to 13.3 W power was demonstrated at 2090 nm. With active Q-switching by means of acousto-optic cell, an average power of 12.3 W was found with a 15-KHz repetition rate. Both operation modes showed a near-diffraction-limited beam with M^2 = 1.42. For a low repetition rate of 4 kHz, pulses were achieved with 2.18-mJ energy and 8.8-ns duration, corresponding to 250 kW peak power.

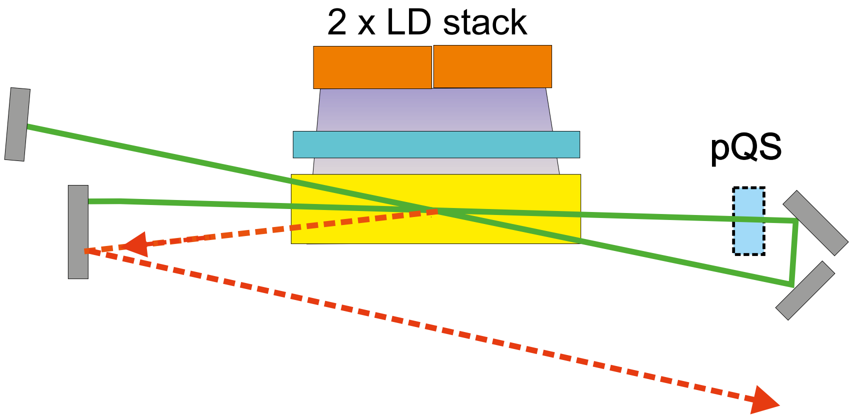




wzendzian@wat.edu.pl

2.1.5. PASSIVE Q-SWITCHING IN SIDE-PUMPED ND:YAG LASER IN SELF-ADAPTED CLOSED-LOOP RESONATOR

Free-running and passive Q-switching operations were examined in a novel design of a Nd:YAG slab laser in a self-adaptive closed-loop cavity. Up to 250 mJ was achieved in free-running for 0.9 J pump energy with $M^2 < 1.3$. In passive Q-switching by means of Cr:YAG, energy of 120 mJ was achieved in a 5-pulse series, with 14% efficiency compared with pump energy. A near-diffraction-limited beam ($M^2 < 1.8$) with 1-MW peak power was demonstrated.

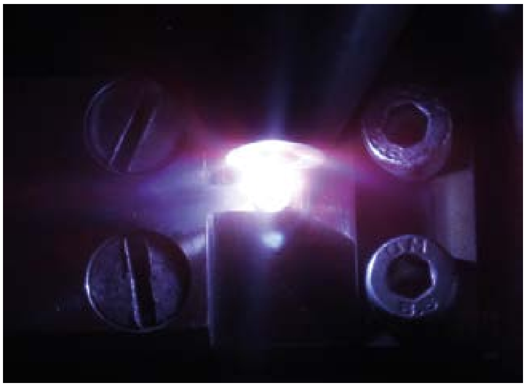


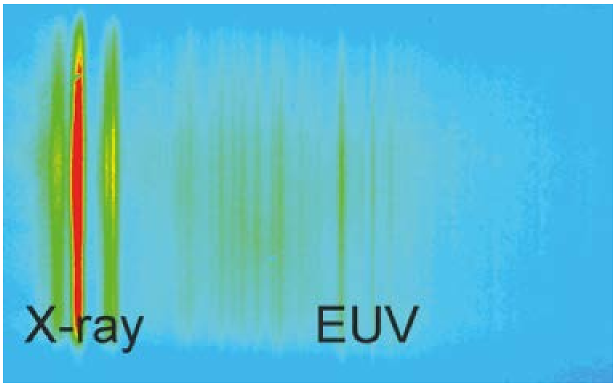
2.2. RESEARCH ON LASER-PLASMA SOURCES OF SOFT X-RAYS AND EXTREME ULTRAVIOLET

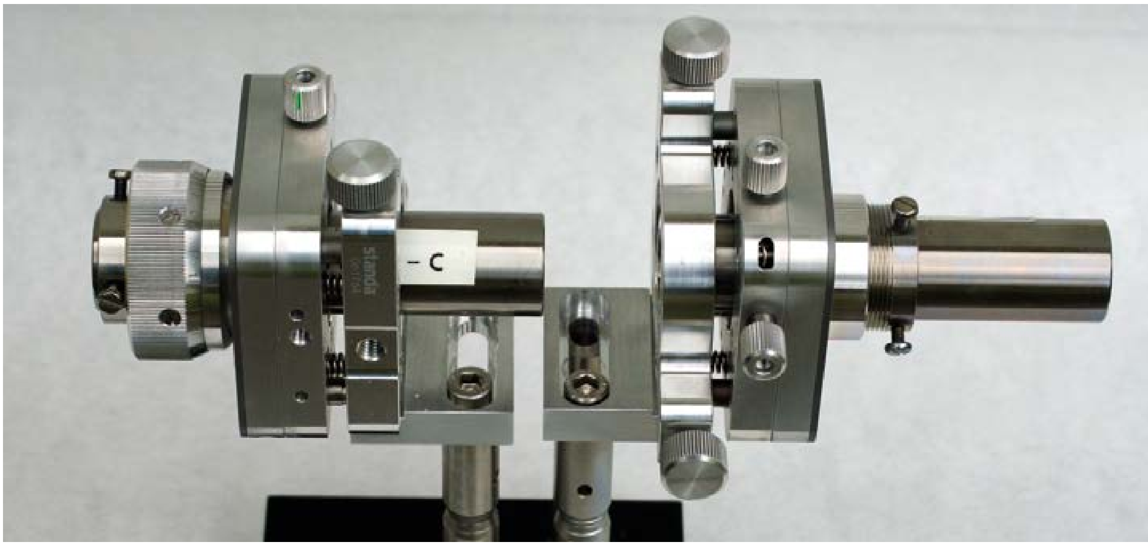
2.2.1. INTENSE LASER–PLASMA SXR/EUV SOURCE

abartnik@wat.edu.pl

A new laser-plasma source of soft X-ray (SXR) and extreme ultraviolet (EUV) was developed. The source is based on a gas puff target irradiated with 2-10 ns laser pulses of energy up to 10 J produced with a Nd:YAG laser system operating at 10 Hz repetition rate. The spectral distribution of emitted radiation spans a wavelength range of 1–70 nm, with maximum emission at approximately λ = 1.4 nm. For point to point focusing of the SXR/EUV radiation in the full wavelength range, we employed a dedicated collector that consists of two axis-symmetrical, grazing incidence, parabolic mirrors. The maximum fluence of the SXR/EUV radiation in a single pulse reaches 250 mJ/cm^2 in the center of the focal spot. The source is an unique in Europe laboratory system dedicated to research on interaction of the SXR/EUV pulses with matter.



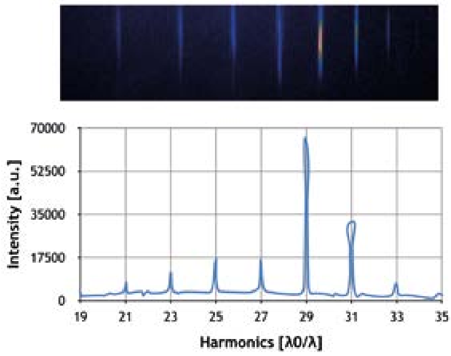


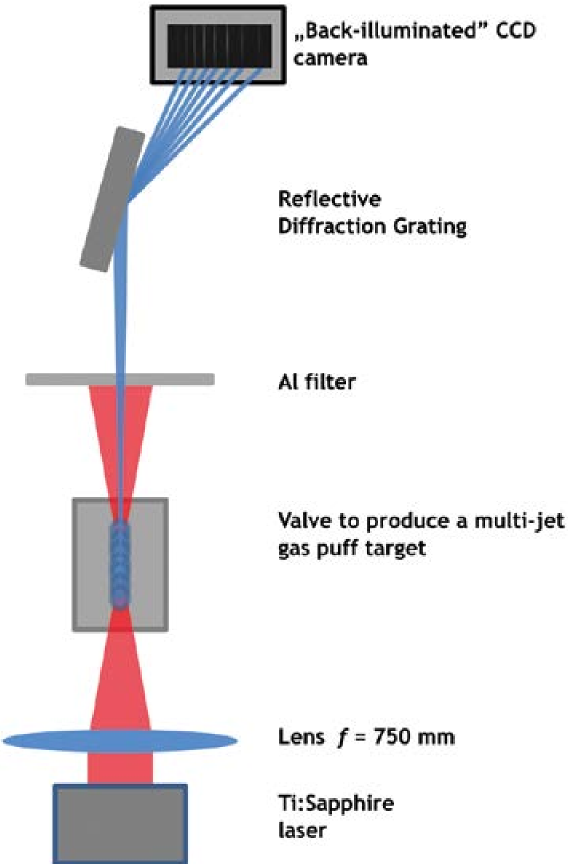


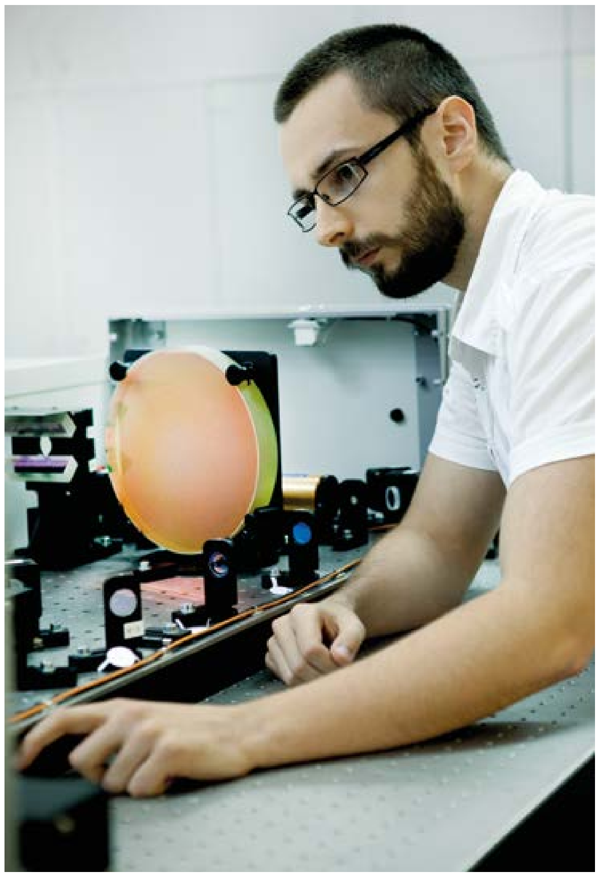
abartnik@wat.edu.pl

2.2.2. GENERATION OF HIGH-ORDER HARMONICS OF THE FEMTOSECOND LASER IN EUV RANGE

High-order harmonics (HH) were produced through the interaction of high-power fs Ti:S laser pulses with a multi-jet gas puff target, with periodic density distribution along the laser beam. This method makes possible to increase of HH intensity, compared to a gaseous target with a uniform density profile. In case of the argon target the highest intensities were detected for three harmonics: 27 (λ_{H27} = 30 nm), 29 (λ_{H29} = 27.9 nm), and 31 (λ_{H31} = 26.1 nm). Proper adjustment of the target and the pumping laser beam parameters enables control of the spectral distribution of HH. Significant increase of an individual harmonic in relation to other harmonics was obtained.



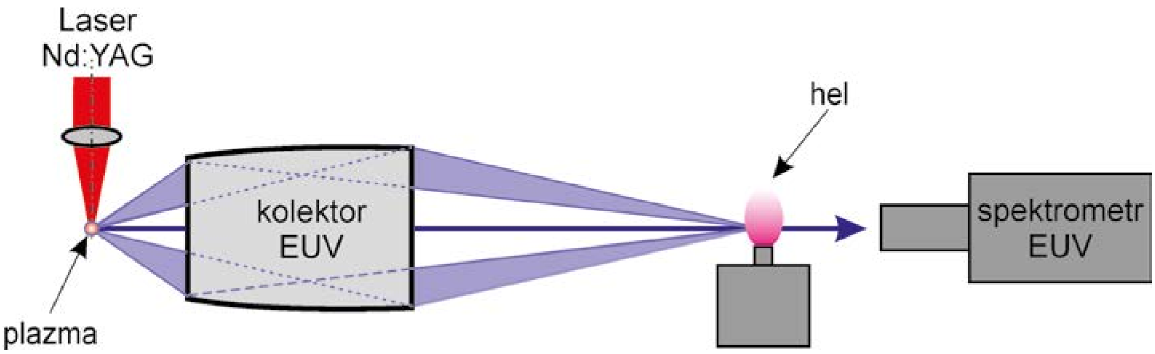


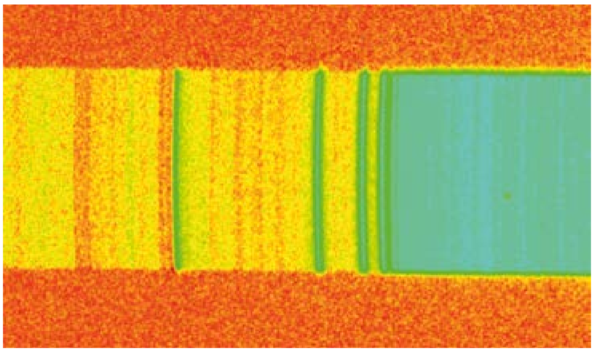


2.2.3. RESEARCH ON INFLUENCE OF PARTIAL IONIZATION OF GASEOUS MEDIA ON ABSORPTION PROPERTIES OF NEUTRAL ATOMS

abartnik@wat.edu.pl

Low-temperature photo-ionized plasmas were produced for the first time by interaction of intense SXR/EUV radiation beam with gases, using a laboratory-scale, laser-plasma source. Emission and absorption spectra of the photo-ionized plasmas in a vacuum and extreme ultraviolet (VUV/EUV) wavelength range were investigated. The plasmas produced in this manner exhibited a relatively low electron temperature of 0.3 – 1×10^4 K, which denotes only partial ionization. In this case, the absorption properties of neutral atoms are significantly affected by the plasma. A strong increase of absorption line intensities, together with a pronounced shift of the absorption edge of helium and neon has been demonstrated with respect to neutral gas.

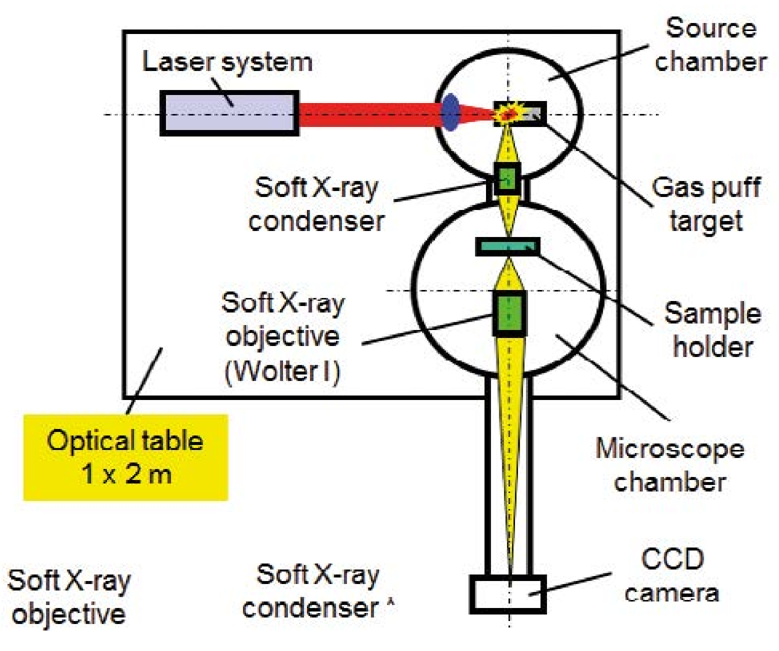


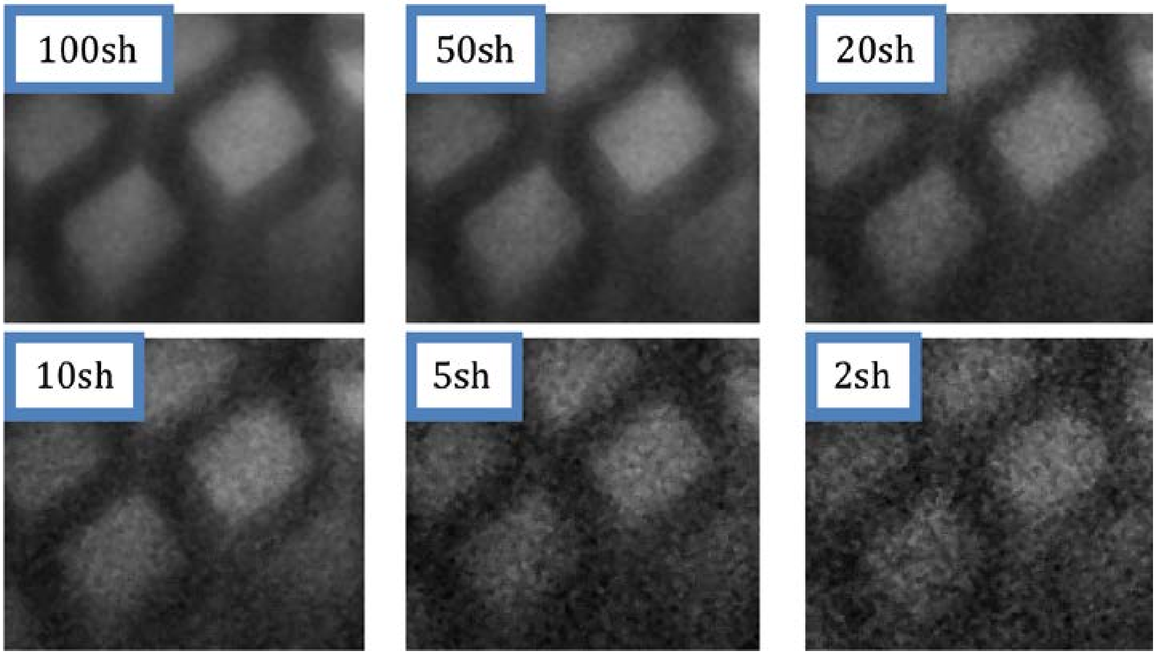


pwachulak@wat.edu.pl

2.2.4. EUV AND SXR ("WATER-WINDOW") MICROSCOPY

A laser-plasma source was used to conduct research related to imaging in the extreme ultraviolet (EUV) and soft X-ray (SXR) region. An EUV microscope based on a Fresnel optic was used to image microcracks in a thin silicon membrane and zinc oxide nanofibers, reaching spatial resolution better than 100 nm, with the aim of obtaining additional information about the object. A SXR microscope equipped with a Wolter type mirror and ellipsoidal condenser was developed. Working in the "water-window", this system allowed test sample imaging with a spatial resolution of approximately 900 nm. The first experiments on imaging of biological samples with relatively large thicknesses of up to 40 μm have been performed.

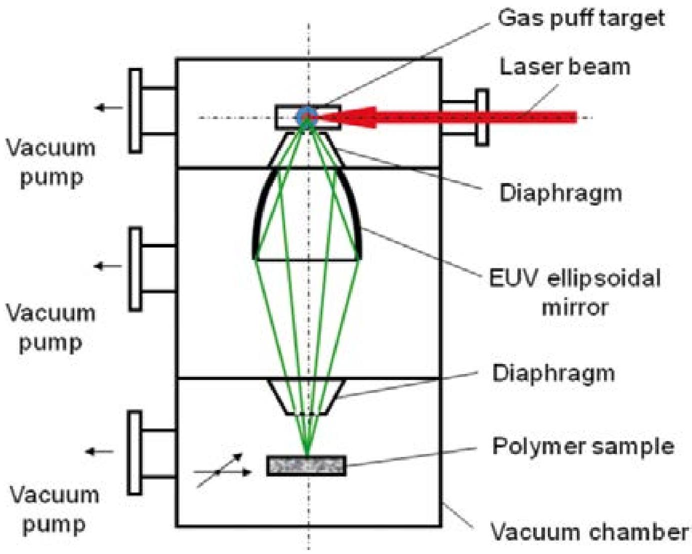


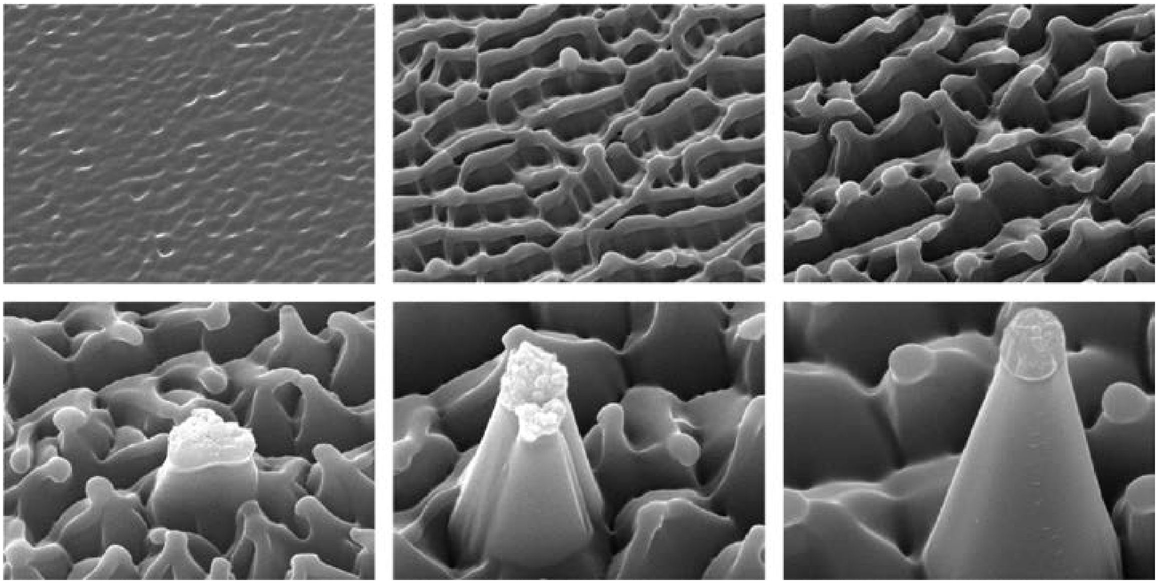

100sh
50sh
20sh
10sh
5sh
2sh

abartnik@wat.edu.pl

2.2.5. EUV MATERIAL PROCESSING FOR BIOCOMPATIBILITY CONTROL OF POLYMER SURFACES

The unique laser plasma EUV source developed in the IOE for nano- and microprocesing of materials was used in research on biocompatibility control of polymer surfaces. Strong improvement of PTFE and PVF biocompatibility after irradiation with EUV pulses has been demonstrated for the first time. The biocomapatibility studies were supported with investigation on physical and chemical modification of polymer surfaces as well as changes of their wettability.



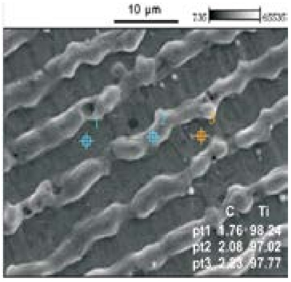


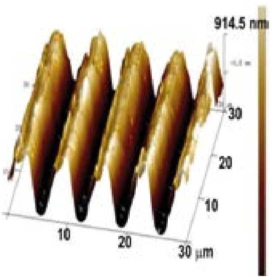
2.3. LASER MODIFICATION OF OUTER LAYERS OF METALS AND ALLOYS

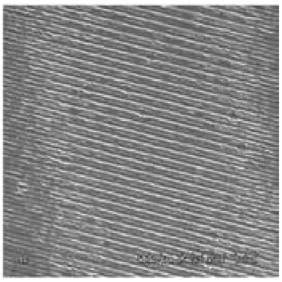
jmarczak@wat.edu.pl

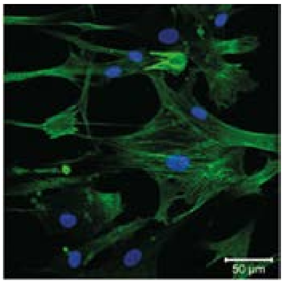
The two-channel pulsed Nd:YAG laser system consisted of a “p-branch” type unstable oscillator with an electro-optic Q-switch and two parallel rod amplifiers. Exploiting the Mach-Zehnder scheme, the laser beams create the interference field in the working area, with spatial frequency controlled via intersection angle changes. Total energy delivered to the 12-mm-diameter operation area is up to 3 J, with a 7-ns pulse duration. Set-up’s were also developed for conversion to the 2nd, 3rd, and 4th harmonics. The 2D interference structure was developed by means of sample rotation (30°, 45°, 60°, or 90°) and XY scanning.

A series of experiments were conducted, applying the two-channel Nd:YAG laser system to fabricate several microstructures on the surfaces of different alloys, such as Au-Cr, Cr-Cu-Cl, and Ti_6Al_4V. The close agreement between the numerical model and the experimental results was confirmed. The elaborated microstructures were thoroughly examined by means of 3D optical microscope, SEM, AFM microscopes, etc. The results were used to determine the optimal conditions for micro-structuring of biocompatible surfaces of implants made of Ti_6Al_4V alloys.









3. OPTOELECTRONIC TECHNOLOGIES AND SYSTEMS

3.1. OPTOELECTRONIC SYSTEMS FOR STAND-OFF-DETECTION AND FREE-SPACE COMMUNICATION

mzygmunt@wat.edu.pl

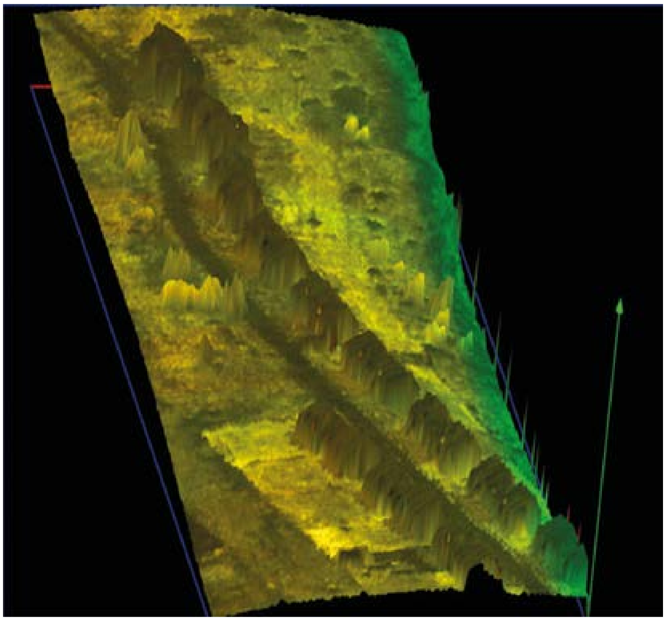
3.1.1. LASER RANGEFINDER MODULE

The miniature rangefinder module is characterized by high-speed action, a range of about 3000 m, and accuracy of 1 m. Thanks to the use of innovative optical, mechanical, and electronic solutions, it presents a new quality of distance measurements. Its small size and weight enable the device to very easily integrate with other systems. This developed solution will be practical for use in specific applications in security systems and automated measuring systems, and in the fields of automation and robotics.

3.1.2. REFLECTANCE PROFILE-METER

mzygmunt@wat.edu.pl

The reflectance profile-meter is an optoelectronic device based on laser remote sensing techniques. Its basic to define the shape of terrain, as well as to identify and analyze elements of the terrain coverage, characterized by high spatial resolution. The developed laser head uses three selected wavelengths of laser radiation (850 nm, 905 nm, and 1550 nm), enabling measurement of the distance from the object, as well as a comparative analysis of the optical echo signal intensity for different wavelengths and estimation of their relationships. The developed head is designed for use on unmanned aerial vehicles (UAV).



zbielecki@wat.edu.pl

3.1.3. THIRD-GENERATION FREE-SPACE OPTICS DATA TRANSMISSION LINK

The currently available free-space optics (FSO) systems offer data transmission links operating in the spectral ranges of 0.8 microns and 1.5 microns, corresponding to the atmosphere transmission windows. The development of a third generation of FSO links was driven by dynamic progress in constructing both quantum cascade lasers and MCT detectors (e.g., those produced by the Polish company Vigo SYSTEM). These elements can work in the range of about 10 microns. Operation at longer wavelengths makes it possible to maintain the data transmission parameters in worsening weather conditions, especially in the case of fog.

3.1.4. STAND-OFF DETECTION OF EXPLOSIVES USING LIBS

jjanucki@wat.edu.pl

This project aimed to develop a technology demonstrator—specifically, a sensor for stand-off explosive detection—and to investigate the possibility of using the laser-induced breakdown spectroscopy (LIBS) method to detect explosives and dangerous substances in trace amounts on various object surfaces. The system has been tested in the field to evaluate the effectiveness of the technology. A working range of 41 m has been confirmed for the system. For metallic substances, a minimal detectable amount of 700 ng/cm^2 has been achieved for explosives. As a result of this project, a database of spectral signatures of explosives has been established, and unique algorithms have been created for explosive hazard recognition with LIBS.

mmiczuga@wat.edu.pl

3.1.5. MEASURING SYSTEM FOR HAZARDOUS CHEMICAL DETECTION AND IDENTIFICATION

This project aimed to develop and built a technology demonstrator—specifically, a measuring system dedicated to hazardous chemical substance detection and identification, in which a semiconductor cascade laser is implemented for generating IR radiation. The main part of the measuring system is the optical detection unit that comprises a laser head with a cascade laser, an optical setup, an AMAC-76L multipass cell, and a PVMI-4TE IR detector. The system also includes the analysis and control unit and the Server of the Chemical Reconnaissance. These components make it possible to reveal and identify explosives, industrial toxic gases, chemical weapons, drugs, and many other hazardous chemicals. The system has been tested in the field to evaluate the effectiveness of the technology. Its high sensitivity enables the system to determine the hazardous chemical concentrations in the air at the level of a single ppb.

3.2. OPTOELECTRONIC TECHNOLOGIES FOR BIOLOGICAL THREAT DETECTION AND RECOGNITION

kkopczynski@wat.edu.pl

3.2.1. FIELD RANGE TESTS OF LIDAR SYSTEMS

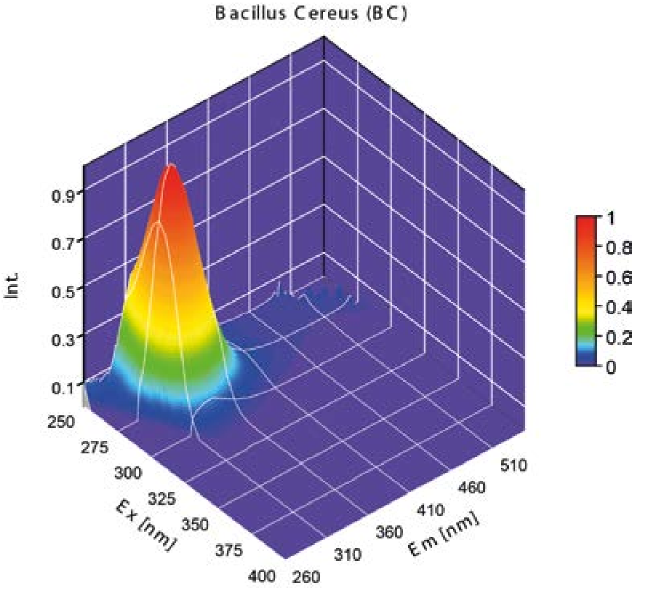
jwojtanowski@wat.edu.pl

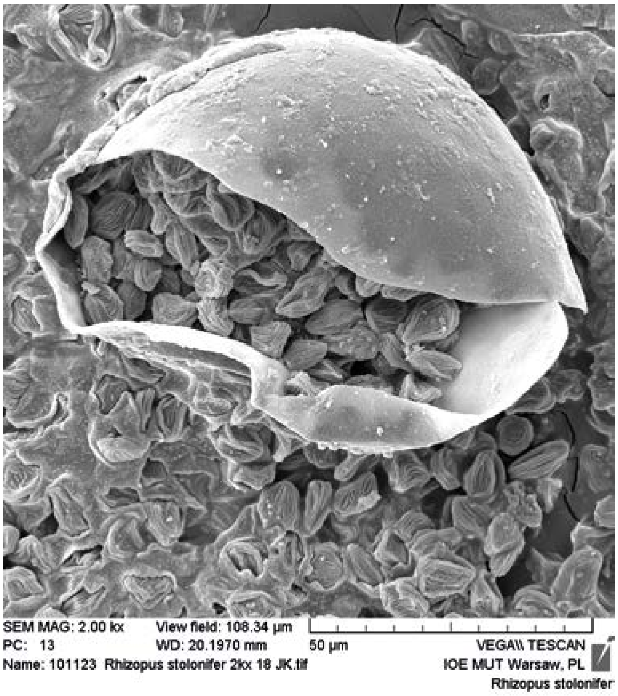
A two-week biological LIDAR measurement campaign was organized using the facilities of Dugway Proving Ground (DPG) in the U.S. (July 22nd to August 2nd of 2013). During the first week, the system was located at a constant distance of about 700 m from a specialized chamber, from which known quantities of the tested biological particles were released to form a cloud of aerosol in the interior. This configuration allowed evaluation of the system's fluorescence sensitivity for a variety of biological species, creation of a library of fluorescence spectral signatures, and calibration of the system.
In the second week, the LIDAR system was challenged by biological particles releases in open terrain, including unknown species and unknown locations. The obtained results can be regarded as satisfactory. The system showed high sensitivity at the level of several hundred ppl detected at a 1-km-range distance. Additionally, the recorded fluorescence signatures demonstrate a certain level of distinguishability, which is promising in terms of stand-off classification capabilities.

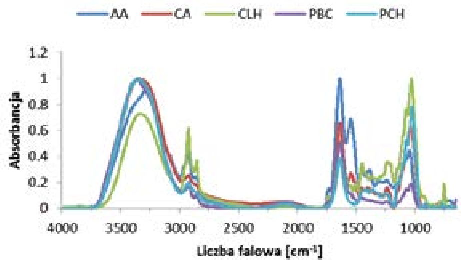
abombalska@wat.edu.pl

3.2.2. OPTOELECTRONIC METHODS OF "IN SITU" BACTERIA DETECTION

Laser-induced fluorescence (LIF) is a promising method for real-time detection of biological warfare agents (BWA). The possibility to build devices that could detect pathogens without pre-analytical preparation, prompted the undertaking of further research into the emission characteristics of a large group of biological compounds. The main research is focused on the excitation-emission characteristics of BWA in the UV-Vis. This method is ideal for distinguishing a substance's emission properties, and allows tracking processes, such as bacteria sporulation, aging, and death. Other analytical techniques used include infrared spectroscopy (FTIR), and Raman spectroscopy. This study led to the establishment of an extensive database of biological compounds.



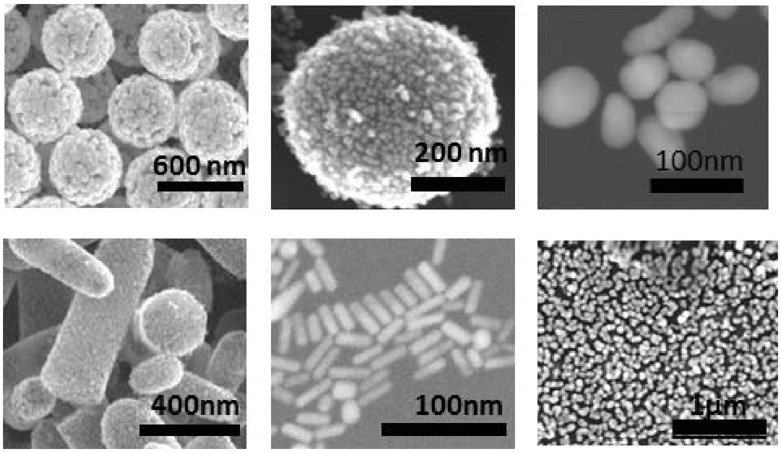

SEM MAG: 2.00 kx
View field: 108.34 µm
PC: 13
WD: 20.1970 mm
50 µm
VEGA\\ TESCAN
Name: 101123 Rhizopus stolonifer 2kx 18 JK.tif
IOE MUT Warsaw, PL
Rhizopus stolonifer

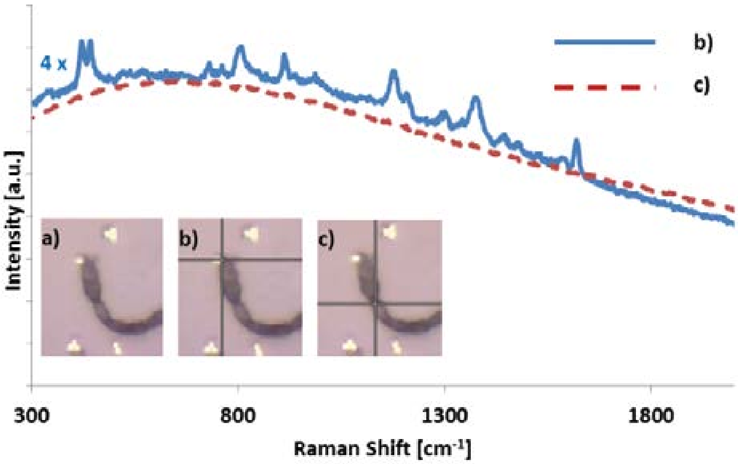

AA
CA
CLH
PBC
PCH
Absorbancja
1.2
1
0.8
0.6
0.4
0.2
0
4000
3500
3000
2500
2000
1500
1000
Liczba falowa [cm⁻¹]

bjankiewicz@wat.edu.pl

3.2.3. PLASMONIC NANOSTRUCTURES IN BIOLOGICAL MATERIAL DETECTION

These research studies included the fabrication and characterization of various types of plasmonic nanostructures, created using chemical methods and physical vapor deposition (PVD) methods. These chemical methods were used to synthesize gold and silver colloids of various shapes and sizes, as well as core-shell nanostructures with a silica core and metallic shell. Gold and silver nanolayers of various morphologies were fabricated employing both chemical and physical methods. Fabricated plasmonic nanostructures were used to study the surface enhancement of Raman scattering and fluorescence signals of biological materials. We were able to the obtain SERS spectrum of a single bacteria cell by using single core-shell nanostructure of $Ag@SiO_2$.


600 nm
200 nm
100nm
400nm
100nm
1µm

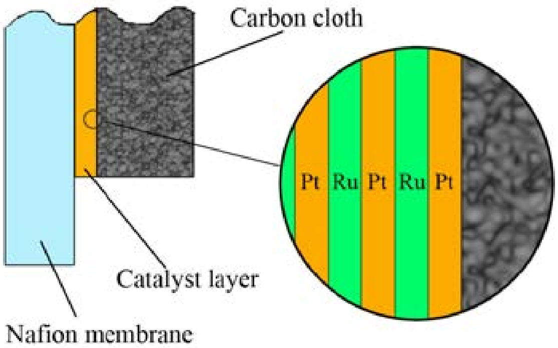

4 x
b)
c)
Intensity [a.u.]
a)
b)
c)
300
800
1300
1800
Raman Shift [cm-1]

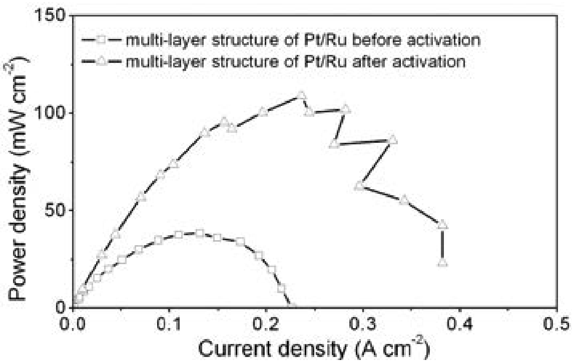
3.3. NANOTECHNOLOGY

wmroz@wat.edu.pl

3.3.1. MULTILAYERS DEPOSITED BY LASER ABLATION TECHNIQUE FOR THE MEMBRANE-ELECTRODE ASSEMBLIES

These studies focus on membrane-electrode assemblies (MEA) that are coated with nanometer-thin multilayers of Pt deposited on the surface of the ion-conductive Nafion membrane, and on the carbon surface diffusion layer of electrodes. The deposition of Pt using the laser ablation technique is three times more efficient compared to the traditional ink technique with Pt black. The efficiency of the measured MEA is strongly dependent on the type and morphology of the surface base upon which the catalyst is deposited. The MEA with Pt layers deposited on the carbon diffusion layer was twice as efficient as those with the same amount of Pt layers deposited on the Nafion membrane. Further studies examined catalytic layers in the form of a multilayer structure consisting of alternating layers of Pt and Ru. MEA were made with catalytic layers having various Pt/Ru weight ratios. The multilayer structures were made from 15 Pt layers and 15 Ru layers, with the total layer thickness being up to several nanometers. A method of catalyst layer activation was developed, which increased the efficiency of the prepared MEA. A strong dependence was observed between the efficiency of activated MEA and the weight ratio of the noble metals deposited on the carbon diffusion layer surface of the electrodes. In the best case, the activated MEA efficiency was increased up to two-fold.

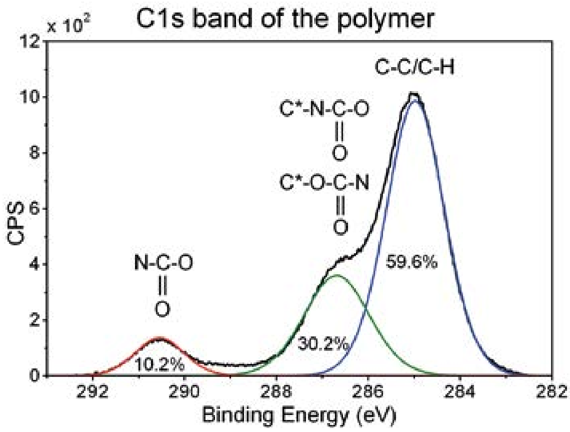

Carbon cloth
Pt
Ru
Pt
Ru
Pt
Catalyst layer
Nafion membrane

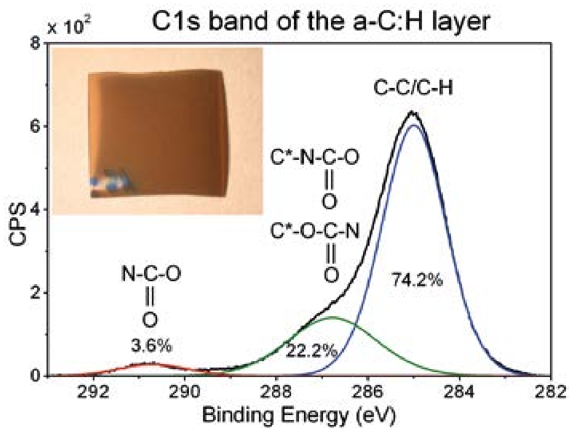

multi-layer structure of Pt/Ru before activation
multi-layer structure of Pt/Ru after activation
Power density (mW cm^{-2})
Current density (A cm^{-2})
0
50
100
150
0.0
0.1
0.2
0.3
0.4
0.5

wmroz@wat.edu.pl

3.3.2. TECHNOLOGY DEVELOPMENT FOR SURFACE COATING WITH POLYMER-LIKE CARBON-TYPE LAYERS

Amorphous hydrogenated carbon layers of the a-C:H and a-C:N:H types were prepared on a polymer surface using the plasma-enhanced chemical vapor deposition technique (PE-CVD with RF 13.56-MHz generator discharge). The chemical structures and mechanical properties of the obtained layers were similar to the characteristics of the coated polymer. The layers were prepared under reduced pressure in a gas mixture of CH_4, O_2, N_2, and Ar, and with various proportions of these components. The deposited layers were very well connected with the polymer substrate (chemical type), with a strong similarity between their chemical structure and that of the polymer substrate. The collected X-ray photoelectron spectra demonstrated the existence of the same functional groups in the deposited layer and in the polymer substrate, but with different proportions. Measurement of the dynamic friction coefficient in the sample/anti-sample configuration showed an almost four-fold decrease of the friction coefficient of deposited layers compared to the substrate polymer.

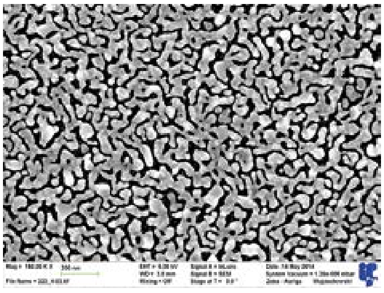


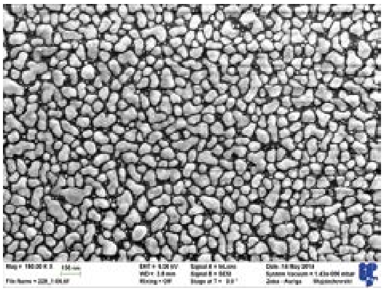


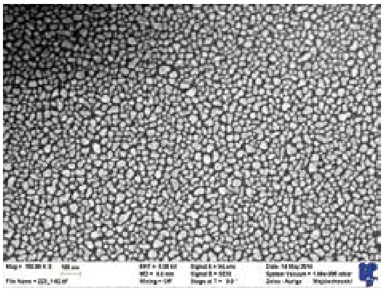
3.3.3. FABRICATION OF PLASMONIC NANOSTRUCTURES BY PVD

pnyga@wat.edu.pl

Using the physical vapor deposition (PVD) technique, we have mastered the fabrication of several types of plasmonic nanostructures on various dielectric substrates. Our main target was to optimize the deposition of metal island films (MIFs) made of silver. By controlling the layer thickness, deposition temperature, and other process parameters, we can fabricate layers of narrow- and broad-band absorption, based on specific distributions of silver nanoisland sizes and shapes. MIFs have been used to modify the absorption and fluorescence of various photosynthetic complexes, and as SERS substrates.







4. OPTOELECTRONIC SYSTEMS FOR DEFENSE AND SECURITY

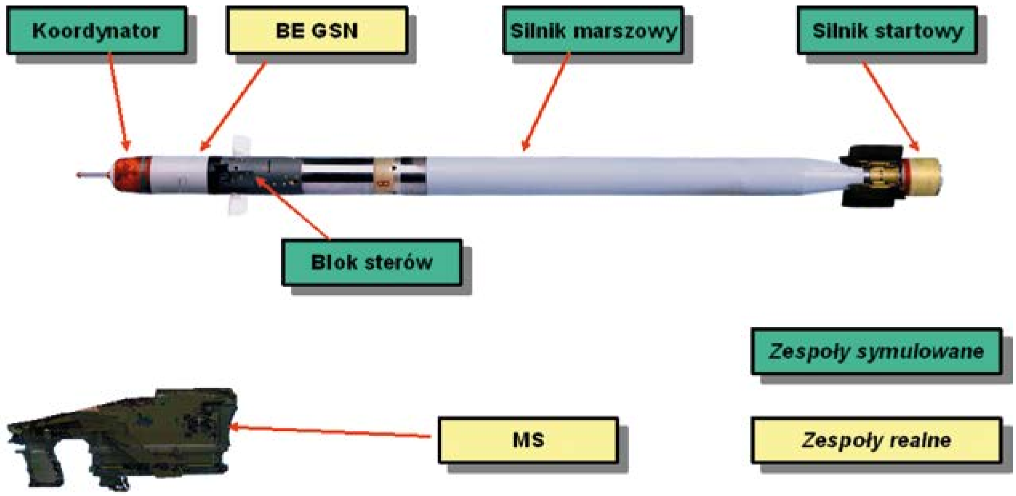
4.1. TESTING AND TRAINING SYSTEMS FOR MANPADS MISSILES

4.1.1. DYNAMIC SIMULATOR AND TESTER OF MANPADS GROM

zblaim@wat.edu.pl

MANPADS development and modernization require specialized simulators and testers to avoid the costs of frequent fire field tests. The IOE has developed two such advanced systems, which have been used to test and evaluate the GROM missile and its subsystems:

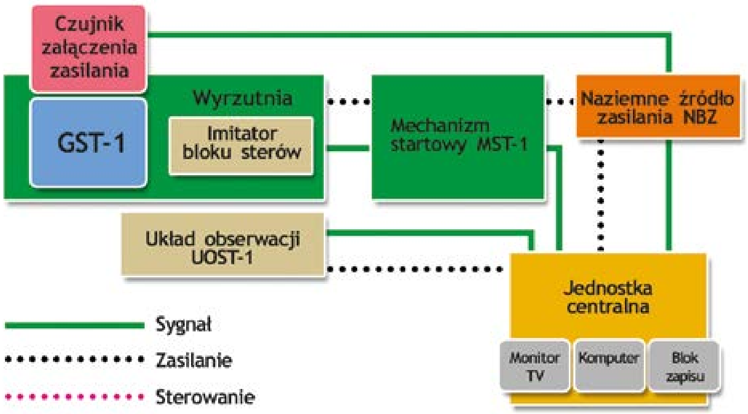
- Laboratory system HWIL (Hardware-in-the-Loop) for testing the effectiveness/efficiency of various missile subsystems as well as for adjusting the specific parameters of the sub-systems. The tester is also used for preliminary validation of missile modifications
- Mobile system for assisting with missile field tests, used for multi-aspect assessment of manufactured batches of pro-duct.



zblaim@wat.edu.pl

4.1.2. TRAINING SYSTEM FOR MANPADS MISSILE OPERATORS

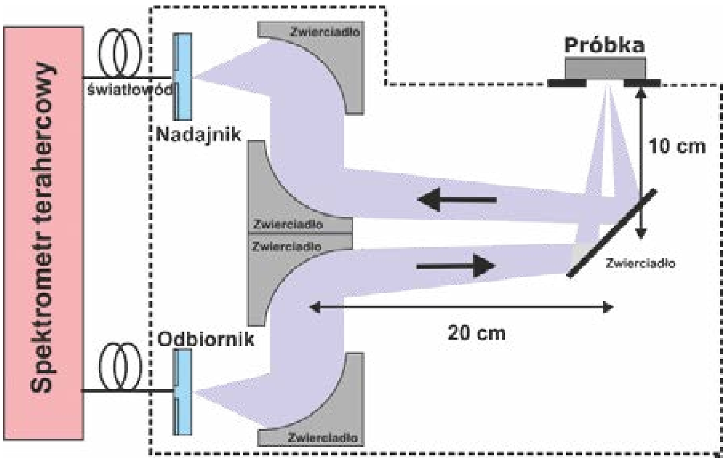
The Training System developed in the IOE is used to train operators in engagement of various aerial targets and in the presence of thermal jamming if required. The operators can be trained in the engagement of various types of real targets and imitators on the missile ranges. Training with use of simulated aerial targets is also possible. Operators are trained in acquisition of targets, in both lock-on and tail-chase modes. The system provides a complete launching analysis and estimation of training results. Another advantage of the system is its ability to determine launch zones in the real field or in PC simulation (optional).



4.2. MULTISPECTRAL SYSTEMS FOR THREAT DETECTION AND RECOGNITION

4.2.1. DEVELOPMENT AND TESTING OF TERAHERTZ SENSOR FOR EXPLOSIVES DETECTION

napalka@wat.edu.pl

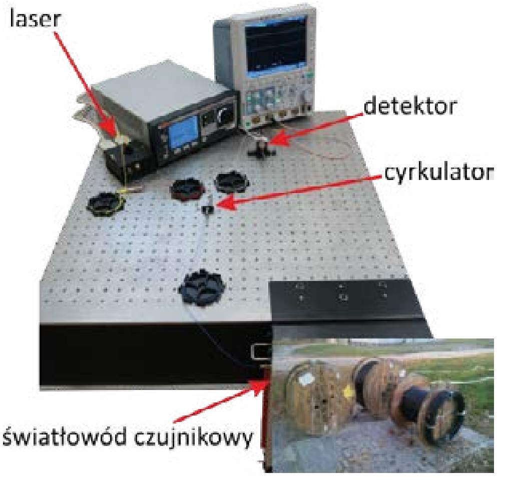


We developed an innovative terahertz sensor for detecting covered explosive materials. Terahertz radiation easily penetrates the typical packing materials (foil, paper, and clothes), is reflected from the explosive surface, and returns to the detector. The reflected signal contains spectral information about the tested material. The system can detect hexogen and its derivatives (C-4, composition B, etc.). Signal analysis is based on windowing, filtering, and Fourier transformation.

mzyczkowski@wat.edu.pl

4.2.2. DEVELOPMENT AND TESTING OF FIBER-OPTIC SENSOR SYSTEM WITH DISTRIBUTED FIELD DETECTION

Research was conducted to develop an innovative modalmetric sensor system for detecting physical disorders. The sensor system is limited to the minimum necessary elements required for its construction, thus achieving a system that has a simple structure and is cheap to produce. The system is designed to detect physical disturbances of the fiber or material to which the optical fiber is



fixed. The sensitive element of the system is a single multimode fiber. This system is used in applications in the field of security systems, such as monitoring telecommunication lines to detect physical interference in the transmission channel, perimeter security of critical infrastructure (e.g., airports, ports, etc.), and the protection of museum collections and cultural heritage objects.

4.2.3. DEVELOPMENT AND TESTING OF A SHIP PROTECTION SYSTEM

mzyczkowski@wat.edu.pl

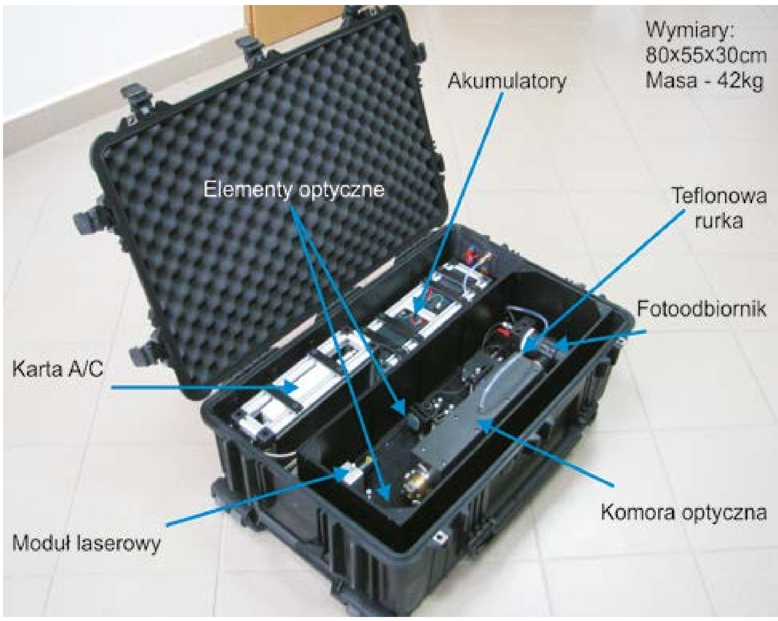
The effectiveness of a multispectral detection system for ships was tested. This system combines long- and medium-range cameras with ship radar and millimeter-wave radar. This allows imaging, detection, and identification of approaching objects. The multispectral detection system is connected via integrator with a set of removable fluted-side razor tape modules that are designed to prevent pirates from boarding the ship. Tests carried out on a PŻM "Warmia" unit confirmed the system assumptions, allowing the detection and recognition of objects near the ship and showing the effectiveness of passive barriers system.

4.3. OPTOELECTRONIC TECHNOLOGIES FOR TRACE GAS DETECTION

4.3.1. OPTOELECTRONIC SENSOR FOR NITROGEN DIOXIDE DETECTION

zbielecki@wat.edu.pl

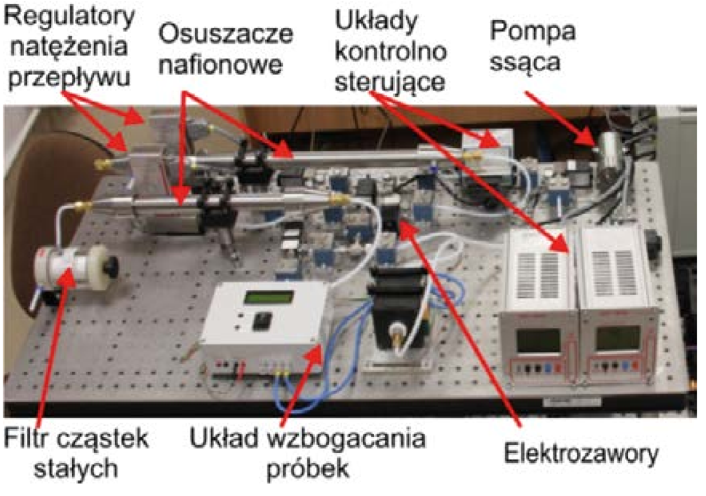
Trace detection of gases is possible by means of the cavity ring-down spectroscopy (CRDS) technique, which uses the storage effect of optical radiation in a special constructed cavity. Based on this idea, a portable optoelectronic sensor to detect nitrogen dioxide was developed. It is characterized by a sensitivity of about 10 ppb, measurement uncertainty of 5%, and a measurement time of about 10 s.



zbielecki@wat.edu.pl

4.3.2. OPTOELECTRONIC SYSTEM FOR EXPLOSIVES DETECTION

This system applies NO_x sensors employing cavity ring-down spectroscopy. The detection method is based either on the reaction of the sensors to the nitrogen oxides directly emitted by the explosives, or on the reaction to the nitrogen oxides produced during thermal decomposition of explosive vapors. Applied optoelectronic sensors can detect three gases: NO, N_2O, and NO_2. They operate at different wavelength ranges using blue-violet laser diodes (410 nm) and quantum cascade lasers (5.27 μm and 4.53 μm). The system uses Polish laser diodes from TopGaN, and Polish detection modules with HgCdTe photodiodes manufactured in the VIGO System. The system is also equipped with an air sampling system and an explosive vapor concentrator. Detection limits of better than 1 ng have been achieved for TNT, PETN, RDX, and HMX.



4.3.3. CO_2 DETECTION MODULE

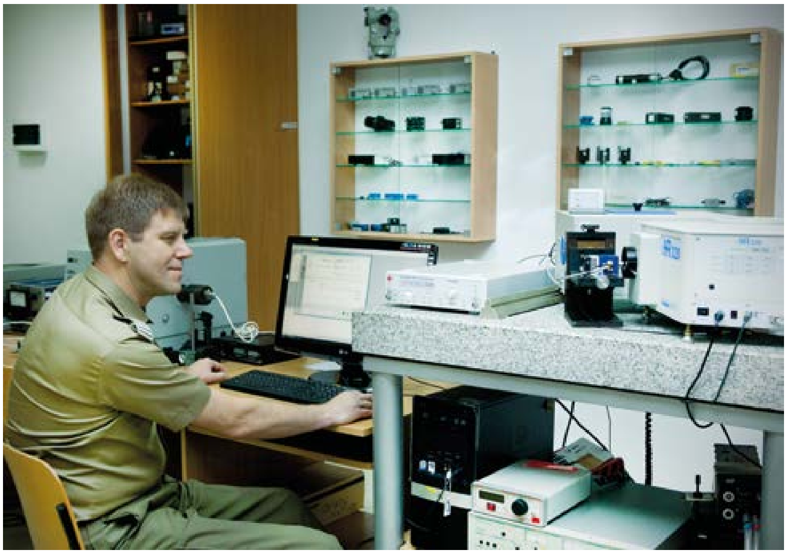
zbielecki@wat.edu.pl

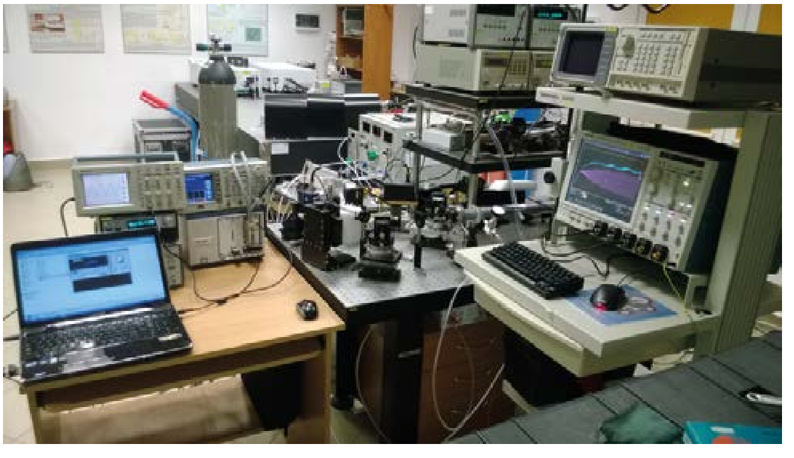
The designed module can measure the CO_2 concentration in exhaled air. The main component of the instrument is an NDIR sensor operating at a wavelength of 4.26 µm. This module can perform 20 measurements per second with an accuracy of up to 70 ppm. The obtained results are displayed on an LCD screen and sent to the computer.

zbielecki@wat.edu.pl

4.3.4. LABORATORY INTRAPULSE SYSTEM FOR LASER ABSORPTION SPECTROSCOPY

A technology demonstrator of the wavelength-tuning system for quantum cascade lasers (QCLs) was developed. An applied tuning technique provides laser excitation with rectangular pulses of a duration ranging from 100 ns to 1 µs. Long pulses result in laser heating and a sweeping change in wavelength. Therefore, this QCL tuning technique is called intrapulse. The system is designed for laser absorption spectroscopy, where the central wavelength of the laser radiation matches the absorption spectrum of the measured gas.

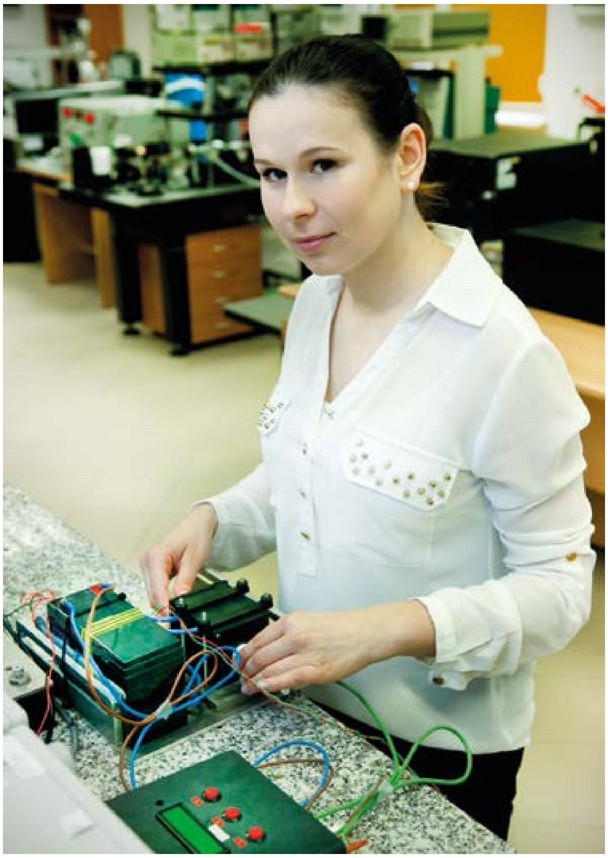




4.3.5. EXPLOSIVES VAPOR CONCENTRATORS FOR OPTOELECTRONIC NO_x SENSORS

zbielecki@wat.edu.pl

Prototype concentrators of explosives vapors were developed, which also provide thermal decomposition of concentrated explosive vapors. Thanks to this, these concentrators can be used with NO_x optoelectronic sensors for explosive detection. Preliminary experiments show that such systems are able to detect nanograms of explosives, such as HMX, during an automatic measurement procedure of an extremely short duration.



5.

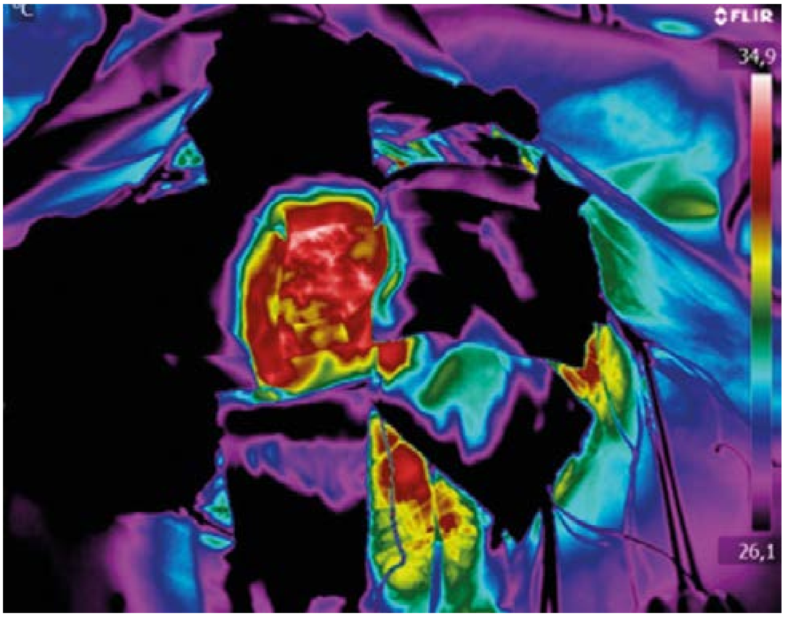
INFRARED TECHNOLOGIES AND THERMAL IMAGING

5.1. BIOMEDICAL APPLICATIONS OF THERMAL IMAGING

mkastek@wat.edu.pl

5.1.1. ASSESSMENT OF METABOLIC ACTIVITY AND BRAIN FUNCTIONS

This research aims to determine the correlation between a patient's cerebral cortex surface temperature and their clinical status. During brain surgery procedures, temperature is recorded by a thermal camera with high thermal and spatial resolution. Cerebral cortex thermal analysis is also used to verify the usefulness of thermal imaging for identifying and mapping functionally relevant areas of the cerebral cortex, and for precisely locating brain tumors that have been previously identified by other diagnostic methods, such as computed tomography or magnetic resonance. The obtained results indicated a strong correlation between cerebral cortex surface temperature and blood flow through brain tissues.



5.1.2. APPLICATION OF THERMAL IMAGING IN BIOPSY AND BRAIN TUMOR RESECTION

mkastek@wat.edu.pl

In every neurosurgical procedure, the key elements are the intraoperational identification of brain tissues affected by pathological changes, followed by their precise and complete resection. This research aimed to assess the capability of a thermal camera to identify brain tumor borders, and to develop appropriate methodology for intraoperational visualization and analysis of cerebral cortex surface temperature changes. Thermal analyses were conducted in a group of seven patients with previously identified tumors of the central nervous system. The results of intraoperational measurements proved that a thermal camera can be applied as non-invasive method for recording cerebral cortex temperature, and that this temperature was discernibly different between healthy and cancerous tissues.

5.2. OPTICAL TECHNOLOGY FOR INFRARED SYSTEMS

5.2.1. TECHNOLOGY DEVELOPMENT FOR MANUFACTURING SPHERICAL AND ASPHERICAL LENSES FOR INFRARED SPECTRAL RANGE

sgogler@wat.edu.pl

Applying aspherical elements makes it possible to produce a lightweight objective lens with fewer optical elements needed. A single aspherical surface can effectively replace several spherical ones, thus resulting in an optical construction with smaller overall dimensions, a lower price, and better transmissive properties in the infrared spectrum. Development of manufacturing technology for spherical optical elements will lead to improvements in lens evaluation parameters, such as MTF (modulation transfer function) and OPD (optical path difference). Improvements in both of these technology areas will be of primary importance for the design and manufacture of objective lenses for thermal cameras with modern array detectors of small pixel pitch.

sgogler@wat.edu.pl

5.2.2. TECHNOLOGY DEVELOPMENT FOR APPLYING DIAMOND-LIKE CARBON (DLC) LAYERS FOR INFRARED SPECTRAL RANGE

DLC technology provides coating layers that fulfill several functions simultaneously. In the infrared spectral band, a DLC layer acts as an anti-glare coating and also protects the lens against atmospheric conditions, accidental scratches, and other mechanical damages. Developing an effective technology for DLC coatings will lead to the manufacturing of more robust and weatherproof devices, especially objective lenses for military thermal imaging devices and systems.

5.3. METROLOGY EQUIPMENT FOR INFRARED DEVICES

5.3.1. DEVELOPMENT OF PROCEDURES FOR MEASUREMENT OF PARAMETERS OF THERMAL CAMERAS, LLLTV CAMERAS, AND NIGHT VISION DEVICES

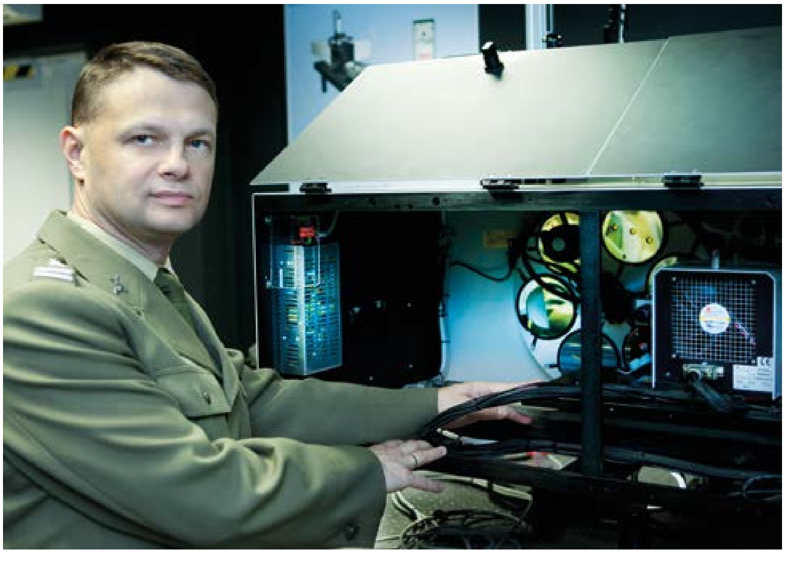
mkastek@wat.edu.pl

Appropriate procedures have been developed for testing thermal cameras, LLLTV cameras, and night vision devices. The procedures define the methodology for measuring parameters, such as signal-to-noise ratio (SNR), modulation transfer function (MTF), contrast transfer function (CTF), minimum resolvable contrast (MRC), field of view (FOV), and minimum resolvable temperature difference (MRTD). Measuring these parameters provides a reliable method for comparing the range characteristics of thermal cameras, LLLTV cameras, and night vision devices. These procedures were verified based on measurements carried out on a MST test stand for different lighting conditions. The developed measurement methods have been implemented in the measurement procedures of the Accredited Testing Laboratory of IOE WAT.

mkastek@wat.edu.pl

5.3.2. DEVELOPMENT OF MEASUREMENT PROCEDURE AND TEST STAND FOR NON-UNIFORMITY CORRECTION OF INFRARED MICROBOLOMETER FOCAL PLANE ARRAYS

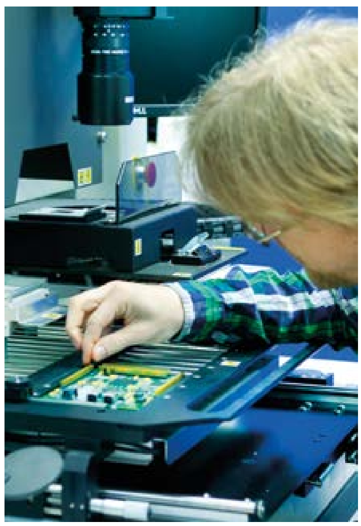
Measurement and data acquisition procedures for testing observation thermal cameras, as well as a research on test stand's, were developed for the determination of non-uniformity (NUC) correction coefficients and basic camera parameters. IR diagnostic software was updated and enhanced by introducing a measurement automation wizard, and new procedures and functions were implemented in this software for controlling a test stand. The introduction of a linear travel module with a control unit and developed software resulted in full automation of measurements. This linear travel unit assures high precision and repeatability of camera positioning, which increases measurement accuracy.



5.4. IMPLEMENTATION OF THERMAL WEAPON SIGHT SCT "RUBIN"

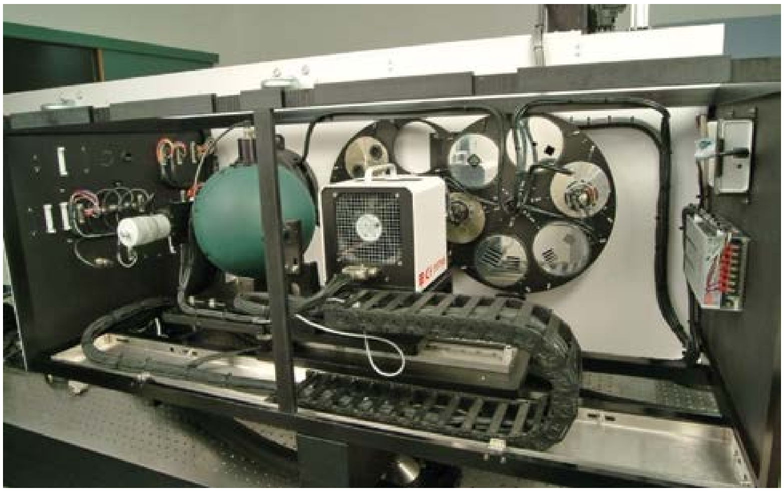
hmadura@wat.edu.pl

The thermal weapon sight SCT RUBIN was developed, together with PCO S.A., within the frame of a goal-oriented project and contracted works. The sight can be used for scouting observation, and can be mounted on a wide range of firearms (5.56 mm to 12.7 mm caliber), offering precise firing capability in both day and night and in harsh weather conditions. The thermal weapon sight uses microbolometer focal plane array with a resolution of 384×288 pixels. Mass production of the sight was initiated in 2013, which required the development of several test stands. Units randomly chosen from a production batch were tested to verify their conformity with declared specifications.



6.
ACCREDITED TESTING LABORATORY

jjanucki@wat.edu.pl



The quality management system of the Testing Laboratory meets the ISO 17025 requirements and is certified by the Polish Centre of Accreditation.

The following accredited test procedures were carried out at the laboratory:

- Measurement of laser pulse energy
- Measurement of power of continuous laser radiation
- Analysis of irradiation distribution in laser beam cross-section
- Verification of correction factor and nonlinearity of laser energy and power meters
- Measurement of absorption factor of optical materials
- Assignment of safety class for laser devices
- Measurements of parameters of thermal imaging devices: signal transfer function (STiF); components of 3D noise model; components of simplified noise model, including 1/f noise, non-uniformity, and noise equivalent power (NEP); signal-to-noise ratio (SNR); modulation transfer function (MTF) and contrast transfer function (CTF); minimum resolvable temperature difference (MRTD); and field of view (FOV)
- Measurement of parameters of TV, LLLTV cameras, and night vision devices: signal-to-noise ratio (SNR), modulation transfer function (MTF), contrast transfer function (CTF), spatial resolution, minimum resolvable contrast (MRC), and field of view (FOV).

Military University of Technology
Institute of Optoelectronics
2 gen. Sylwestra Kaliskiego Street
00-908 Warsaw, Poland

www.ioe.wat.edu.pl