40 years of the Institute of Electronic Materials Technology

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THE ORIGIN OF ITME

The origin of the Institute of Electronic Materials Technology (ITME) dates back to the 1970s. In 1970 the Scientific-Production Center of Semiconductors CEMI (NPCP) came into being. Comprising the TEWA Semiconductor Factory, the Institute of Electron Technology and the Industrial Institute of Electronics.

On 1 July 1970 the Scientific and Production Center of Semiconductor Materials (ONPMP) was established in Warsaw, acting as a branch of the Scientific-Production Center of Semiconductors. The person who initiated of the foundation of the center was prof. Bolesław Jakowlew, who also became its first director. Established in the NPCP by The Minister of Machine Industry the Experimental Department of Semiconductor Materials Manufacturing to prepare for the production and the experimental production of materials such as semiconductor materials, high-purity metals and chemical compounds as well as ceramics and glass. In the following year, the Experimental Department was incorporated to the Scientific and Production Center of Semiconductor Materials.

The main activity of the Scientific and Production Center of Semiconducting Materials was to solve the problems concerning materials by undertaking the tasks such as conducting both fundamental and applied research, development and implementation work as well as by carrying out the production at the Experimental Department.

The areas of the activity of the Center included the development of technology and the research concerning the following materials:

- silicon and germanium,
- semiconductor compounds of the $A^{III}B^{V}$ and $A^{II}B^{VI}$ type
- high-purity metals and special-purpose alloys,
- chemical compounds applied in the production of semiconductor devices and microelectronic systems,
- dielectrics and products made of these materials,
- openworks for integrated circuits.

Fot. Maciej Żyliński

The year 1973 marked the start of the quarterly bulletin "Electronic Materials" with prof. Bolesław Jakowlew as its first editor-in-chief. The bulletin has been issued ever since.

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In the years 1970-1975 the Scientific and Production Center of Semiconductor Materials started the production of over three hundred ranges of special purpose materials. Thanks to the very good results achieved in the field of materials, ONPMP was voted a leading role in the Government Research and Development Program PR-3 "Materials and components for electronics". The main task of the research center was to coordinate the research projects and the implementation of the new materials, in various the institutions of several departments.

In 1978 the Experimental Department of Semiconductor Materials Manufacturing was selected from ONPMP, to form a state-controlled enterprise, named the Electronic Materials Scientific and Production Centre (CNPME).

THE ESTABLISHMENT OF ITME

The Institute of the Electronic Materials Technology was established after transformation of the Scientific and Production Center of Semiconductor Materials by the Ordinance no 14 of the Prime Minister of 5 February 1979 (the Official Journal of the Republic of Poland "Monitor Polski", M.P, No. 4, Item 37). The Institute was controlled by the Minister of Machine Industry and directed by the Director of the Electronic Materials Scientific and Production Centre. The Institute carried out the research and development projects, and dealt with the implementations in the field of electronic materials. In particular, their work concetrated on the technology of obtaining, processing and the effective applications of the materials to the needs of electronization.

In the years 1982-1983 the production processes were transferred to new premises, located at Wólczyńska Street 133 in Warsaw. The first director of the Institute (until 1980) was prof. Bolesław Jakowlew. In the consecutive years Mieczysław Frącki, Ph.D. (in the years 1980-1987), followed by Wiesław Marciniak, Ph.D., D.Sc., Prof. (1987-1994). Took over the post in February 1994 as a result of public competition Zygmunt Łuczyński, Ph.D., was appointed director of the Institute through a public competition.

RESEARCH INSTITUTE AND ŁUKASIEWICZ RESEARCH NETWORK

On 1 October 2010 pursuant to the Act on Research Institutes of 30 April 2010 (Journal of Laws [Dz. U.] No. 96/2010, Item 618), the legal form of the Institute of Electronic Materials Technology was changed transforming it into a research institute under the supervision of the Minister of Economy.

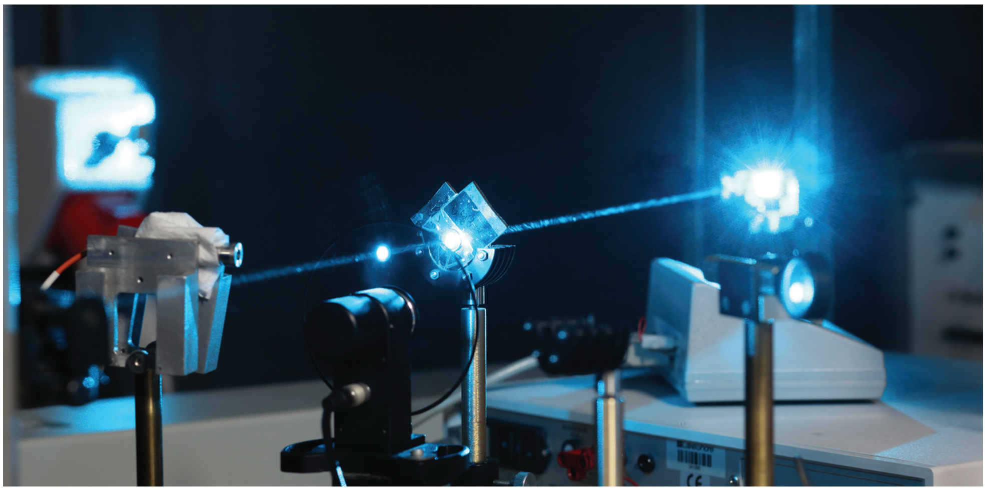
In 2015 Ireneusz Marciniak, Ph.D., won the competition for the post of the director of the Institute. In 2016 the following divisions were included in the organizational structure of the scientific departments compromised the following divisions: Department of High Purity Materials Characterization, Department of Microstructural Research, Department of Ceramic-Metal Composites and Joints, Department of Ceramics, Department of Silicon Technology, Department of Optoelectronics, Department of Chemical Technologies, Laboratory of Mössbauer Spectroscopy, Department of Glass, Department of Epitaxy, Department of Epitaxy and Characterization, Department of Thick-Film Materials, Department of Functional Materials, Department for Applications of $A^{III}B^{V}$ Materials and Department of Piezoelectronics.

In 2017 Zbigniew Matyjas, Ph.D., D.Sc., was appointed the new director of the Institute. The restructuring that was then initiated has brought many changes and has been continued until prezent day.

On 1 April 2019, ITME became one of 38 institutes of the Łukasiewicz Research Network, and its name was changed to the Łukasiewicz Research Network - Institute of Electronic Materials Technology. The Łukasiewicz Research Network, established under the Act of 21 February 2019, is providing complete business solutions within 6 research groups: automation, chemistry, biomedicine, teleinformatics, materials and production. The Institute belongs to the group named "materials".

RESEARCH DEPARTMENTS OF ŁUKASIEWICZ - ITME

There are several scientific-research departments operating in ŁUKASIEWICZ - ITME, together with the separate Laboratory of Structural Research and Materials Characterization and the Electron-beam and nanoimprint laboratory.



The activity of the Department of Graphene and Materials for Electronics is focused on the investigations of the epitaxial structures of the compounds of III-V and I-IV semiconductors for electronic applications as well as on the manufacture of high-quality graphene on SiC, Ge and metallic substrates. The technologies of semiconductor devices on the single-crystal matrices and epitaxial layers are also developed. Our professional technological equipment enables the structures based on GaAs, InP, GaN, GaSb and SiC to be produced with the highest quality, using the chemical vapor deposition method (CVD and MOCVD).

The Department of Chemical Synthesis and Graphene Flakes specializes in the chemical synthesis of advanced materials, designed to be utilized in materials science and engineering, electronics, optoelectronics and in the energy production and storage industry. The team that works in that department has extensive experience in the manufacture of nanomaterials, including graphene flakes. The most intensive studies concern the applications of the chemical methods to obtain graphene flakes and their derivatives, as well as the composite materials containing graphene structures. Simultaneously, the research is carried out on the chemical synthesis of the nanocrystalline materials and nanostructures, performed with various techniques, namely: sol-gel process, co-precipitation, hydrothermal synthesis, combustion synthesis, reversed microemulsion synthesis, electrochemical method and the solid phase methods, including microwave synthesis and mechanosynthesis. The third area of the scientific interests of the Department concerns the synthesis of electrode materials for lithium-ion cells and supercapacitors.

The Department of Composite and Ceramic Materials specializes in the manufacture of ceramic-metal composite materials, graded materials and welding advanced materials. In particular, the physical and chemical phenomena, accompanying the aforementioned processes, are also considered. The following examples of composite materials are obtained: materials with high thermal conductivity, contact materials and construction materials. The scientists work on the preparation and characterization of the thermoelectric materials designed for energy conversion. The investigations are focused on two groups of materials - skutterudites and tellurides (of antimony and bismuth). The composite materials are manufactured using powder metallurgy or by the infiltration of porous ceramic preforms with a liquid alloy. The Department is also responsible for developing technologies of welding composite materials with other types of materials, including combining various electrical insulators (corundum, nitride ceramics, carbide ceramics, glass) with metals (copper, molybdenum, FeNi alloys, steels) for the vacuum, electronic and nuclear applications as well as to the use in power engineering.

The research carried out at the Department of Optoelectronics covers a wide range of subjects: development of new sources of white light, laser diodes, solid-state lasers, heat removal techniques, assembly and integration of optoelectronic devices, as well as optical and thermal characterization of various materials and devices. Thanks to their long-term experience, the scientists working in that department have managed to develop a numerous innovative devices, such as: low-beam divergence high-power laser diodes characterized, with optical fiber lead or devices integrated with diffractive optical components, installed on microchannel coolers. The scientists offer new solutions in the dedicated laser sources, the integration and assembly of the electronic devices. We provide services in the design of the prototypes of optoelectronic devices, as well as in testing of the materials for photonics.

The team of the Department of Glass has extensive experience in manufacturing optical-fiber components, image guides and classic optical waveguides (including active fibers) and photonic crystal fibers (passive and active), as well as nano-optic components. By combining the technological capacities with the fiber design and computer modelling abilities, our scientists can match the customer's requirements in the production of micro- and nanostructured optical fibers and fiber optic components for the range of the visible, near infrared and middle infrared radiation. The application areas concern nonlinear optics (supercontinuum generation), polarization wavefront shaping and the introduction of the light beam into the micro-optofluidic systems.

The Department of Experimental Production consists of two laboratories. The Laboratory of Silicon Technology is involved in the manufacture of silicon wafers of the diameters ranging from 1 to 4 inches and the thicknesses from 50 micrometers to over 40 000 micrometers and with different crystallographic orientations, after having them cut, etched and polished (one-side or double-side). In the Laboratory of Epitaxy, silicon epitaxial wafers and multilayer epitaxial structures, such as p/n/n+, n/p/p+, etc. are fabricated using the CVD method. These structures are characterized by the epitaxial layers of a thickness in the range of 2-150 micrometers and resistivity in the range 0.003-1000 Ω cm. The research activity of the Department is also focused on the examination of defects in wide band-gap semiconductors.

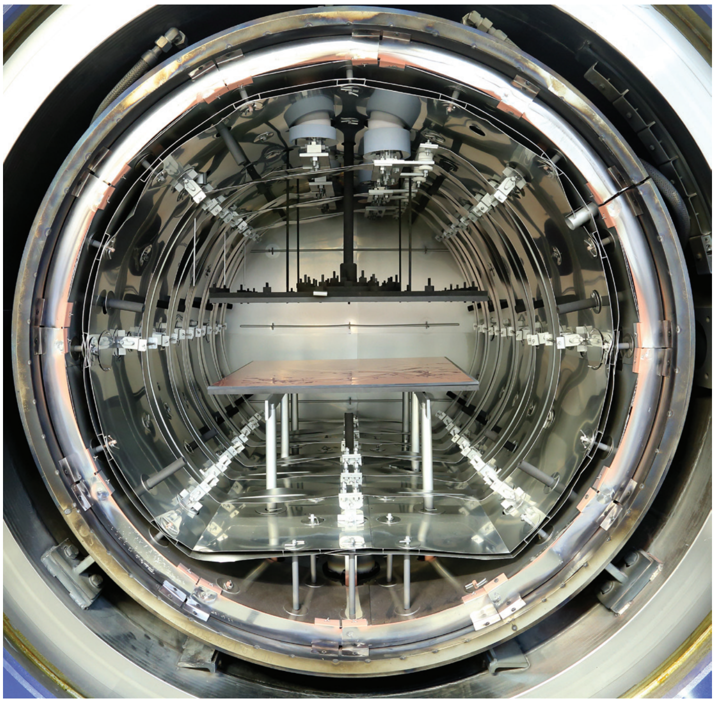
The Department of Functional Materials is involved in the fundamental and applied research in the field of crystal growth, new composite materials and the methods of their characterization. The technologies concerning the growth of oxide single crystals, $A^{III}B^{V}$ compounds, as well as 4H- and 6H-SiC are being developed. The scientists in the Department also utilize the micro-pulling-down to examine the growth of metamaterials, plasmonic materials and eutectic systems. The services offered here include the development of crystal growth technologies and the processes of mechanical processing (the manufacture and a proper surface treatment of the obtained materials).

The Laboratory of Structural Research and Materials Characterization carries out fundamental and applied research on the physical properties of materials. These investigations are devoted to the development and improvement of new methods of material analysis and their modification with the use of ion beams. The goal is to improve the structural and functional properties of new materials.

The Laboratory specializes in:

- surface analysis of the materials using scanning electron microscopy (SEM) and other techniques, such as: EDS, EBSD, CL, FIB, which are coupled with a scanning electron microscope,
- structural testing with the use of advanced X-ray diffraction methods (XRD) and high-resolution secondary ion mass spectrometry (SIMS),
- development of the numerical methods for the analysis of data obtained by X-ray diffraction and high-resolution secondary ion mass spectrometry (SIMS),
- development of the methods of material modification using ion beams,
- analysis of the radiation defects in the materials applied in nuclear engineering,
- testing the functional properties of the irradiated polymers,
- examination of the tribological properties (the processes of wear and friction) of various materials.

The Electron-beam and nanoimprint laboratory deals with the manufacture of micro- and nanostructures in the processes of electron-beam lithography (the generation of structure patterns) and nanoimprint (replicas of 3D structures). Thanks to the Micro and Nanotechnology Center MINOS project it has been possible to equip the Laboratory with a Vistec SB251 electron beam lithography system, which is a fully autonomous, professional apparatus, allowing high-resolution patterns (less than 50 nm) to be written over a large area (175 mm × 175 mm) with the address grid of 1 nm. In the laboratory the standard masks are fabricated to be used in other lithographic techniques, i.e. UV lithography (contact photolithography), DUV lithography (optical projection type lithography) and nanoimprint. The electron-beam lithography is also used for a direct generation of the patterns on a variety of semiconducting substrates and optical substrates, which makes it possible to produce electronic and photonic micro- and nanostructures as well as complex diffractive optical elements with the features as small as 50 nm.



RESEARCH WORKS IN LABORATORIES OF ŁUKASIEWICZ - ITME

The researchers in ŁUKASIEWICZ - ITME are currently involved in tens of scientific projects, i.e. Polish and European projects as well as those carried out under the Horizon 2020 Framework Program for

Research and Innovation. The examples of the undertakings being prepared at the Institute are presented below.

The researchers perform the tasks within the framework of 10-year Graphene Flagship Programme funded by the European Commission. An international scientific-industrial consortium, consisting of nearly 150 partners from 21 countries, carry out a wide range of objectives, from the production of materials and sub-assemblies to the construction of integrated systems. The goal of the project is the development of scientific research devoted to the utilization of graphene and other two-dimensional (2D) materials in various areas of life and economy. Graphene Flagship Programme belongs to one of two projects that won the contest of the Future and Emerging Technologies (FET) Programme. The European Commission has allocated a sum of almost 1 000 000 000 EUR to the implementation of both of these projects.

The team at the Department of Functional Materials is involved in a project carried out by an international consortium (whose member is ŁUKASIEWICZ - ITME), under the name ENSEMBLE3 (Center of ExcelleNce for nanophotonicS, advancEd Materials and novel crystal growth-Based technoLogiEs) within a framework of the program Horizon 2020 - Teaming for Excellence. The purpose of the first phase of this undertaking is the preparation for setting up the Center of Excellence, where new, advanced materials will be developed on the basis of crystal growth technologies, including the materials to be applied in the sectors of nanophotonics, optoelectronics, telecommunications, medicine and photovoltaics. In principle, The Center of Excellence should compete with the leading global scientific institutions, both in terms of innovativeness and mastery in research and development. The ENSEMBLE3 project is carried out by a consortium consisting of: the University of Warsaw, Łukasiewicz Research Network - Institute of Electronic Materials Technology, the National Center for Research and Development, Karlsruhe Institute of Technology (Germany), the nanoGUNE Cooperative Research Center (Spain) and the Sapienza University of Rome (Italy).

The Department of Composite and Ceramic Materials, being a part of an international consortium is involved in a M-ERA.NET program, concerning innovative Ni-Cr-Re coatings with the increased corrosion and erosion resistance for the high-temperature applications in power industry. Within a framework of the project new coatings will be developed based on nickel and chromium metal powders with the additive of rhenium, and an optimal technique for their deposition on steel substrates will be selected.

The Institute also implements an investment program, named "the Centre of Graphene and Innovative Nanotechnology", related to the purchase of modern research equipment that will allow our scientists to carry out a variety of the innovative scientific projects associated with graphene and other nanomaterials. This undertaking is financed from Structural Funds of the European Union (RPO WM for the years 2014-2020).

SCIENCE IN PRACTICE

Fundamental and applied research is carried out in the laboratories of the Institute. The offer of the Institute includes technologies such as: graphene-based magnetic sensors for industrial applications, power devices based on SiC - i.e. high-voltage diodes, on silicon carbide, high-frequency power devices based on GaN, graphene flakes, crystals, optical waveguides, lasers, white light sources, chromium masks and diffractive elements, multijunction solar cells with enhanced efficiency. We also point out that the development work is in the field of materials engineering and our scientific community is open to solving material problems. The work carried out in the ŁUKASIEWICZ - ITME laboratories results in the technologies that can be commercially applied. Some selected examples are described below:

Graphene magnetic field sensor

At the Department of Graphene and Materials for Electronics, the scientists develop the construction of an innovative magnetic field sensor (named "hallotron") utilizing the patented technology of graphene deposition on silicon carbide (SiC). The research is carried out in two ways, so that the optimum maximum working temperature and sensitivity can be reached. The first type of a sensor maintains its electrical parameters up to +300°C with a sensitivity of 160 V/AT (volts per ampere-tesla).

The second one exhibits a lower sensitivity (80 V/AT), however, it is maintained at a higher temperature, i.e. even up to +500°C. Such a temperature range is much wider than the temperature characteristic of the conventional devices made of semiconductor materials, such as silicon, gallium arsenide, indium arsenide or indium antimonide. Potentially, this solution could be applied, for instance, in the construction of brushless DC electric motors (BLDC) with the permanent magnets powered by direct voltage or permanent magnet synchronous motors (PMSM) powered by alternating voltage. These types of motors can also be used in electric vehicles, numerically controlled machine tools and in the measuring devices of the new range of current transducers, as well as in single-phase and three-phase active power transducers. An additional advantage of the graphene sensor is the possibility of its operation at low temperatures. The experiments have confirmed that both types of sensors exhibit the sensitivity stability of -0.02%/°C in the temperature range from -200°C to +300°C. This record stability of the electrical parameters within a wide temperature range is the distinctive feature of graphene deposited on silicon carbide. The technology was awarded a silver medal at the 13th International Warsaw Invention

Show IWIS 2019. ŁUKASIEWICZ - ITME is planning to introduce their sensors into a commercial offer.

Production technology of graphene on metallic substrates

Simultaneously with the development of the technology of graphene deposition on silicon carbide, the team at the Department of Graphene and Materials for Electronics aims to establish a method of graphene deposition on a copper foil and on germanium. The graphene produced in such a way can further be transferred onto another material by applying a variety of technological processes. ŁUKASIEWICZ - ITME has gained international recognition due to the very high quality of the graphene transferred, which guarantees purity and predictable electrical parameters of the material. The offer of the Institute includes both small samples and larger graphene sheets. So far, the purchasers have most often ordered a copper foil coated with graphene, with dimensions 30 cm × 30 cm, but the foil measuring 50 cm × 50 cm is also available. As a research institute developing the electronic materials technology on the basis of its own initiatives and projects carried out in the cooperation with foreign and national centers, ŁUKASIEWICZ – ITME work on the implementations that can utilize graphene. So far, projects such as a femtosecond laser or transparent heaters have been successfully completed.

Graphene Ink

The Department of Chemical Synthesis and Graphene Flakes is involved in the manufacture of various nanomaterials and nanostructures, e.g. graphene flakes. The global research in this field has been conducted for only a few years. However, regarding the graphene applications, the Institute has already achieved first implementations.

The development of graphene ink belongs to one of the examples of an effective implementation of the research work carried out in ŁUKASIEWICZ - ITME in cooperation with the Electro-technological Society Qwerty. The obtained graphene ink enables printing on polymer matrices by a jet printing method, including also elastic and translucent materials. The printed layer is homogeneous and highly transparent. After proper treatment, graphene ink becomes electrically conductive. Therefore, the obtained printout can be applied in foil keyboards for the device drivers. Even the use of a small amount of graphene in the ink will enable the replacement of an expensive indium tin oxide (ITO), which is commonly used as a transparent electrical conductor.

Fiber microprobe for selective electroporation of the internal organs and single cells.

The fiber microprobe is a new therapeutic tool, dedicated to electrochemotherapy of internal organs by the laparoscopic techniques. This technology is currently commercialized. The method utilizes the phenomenon of electroporation, i.e. the electrically stimulated formation of short lived nanopores in a cell membrane, which can enable the drug delivery into the cells. Electrochemotherapy is one of the modern methods of cancer treatment.

The fiber microprobe is the only method that enables the electroporation of limited areas in hard-to-reach places. The form of a thin fiber allows the probe to easily reach the inaccessible locations in the body with the help of a needle or through the blood vessels. Simultaneously, the local delivery of drugs is possible, including very toxic or expensive ones. With a built-in imaging channel, this tool also enables a direct observation of the area being electroporated.

The electroporation microprobe was developed by the research team headed by Prof. D. Sc. Ryszard Buczyński. The technology was awarded a silver medal at the 9th International Warsaw Invention Show IWIS 2015. It also received the Polish InnoStars Award in 2016, in MedTech category (medical devices), which is awarded for the innovative projects in the field of health, medicine and biotechnology. The described technology also gained the distinction in the Polish Product of the Future competition (19th edition) in the category: Product of the Future of a scientific unit.

Transparent ceramics

The investigations aimed at obtaining transparent ceramics based on yttrium-aluminum garnet ($Y_3A_{15}O_{12}$) and magnesium aluminum spinel ($MgAl_2O_4$) are carried out at the Department of Composite and Ceramic Materials. These materials can be used both as transparent armor elements, domes and protective visors for the infrared detectors. Transparent ceramics can also serve as matrices for rare earth elements and transition metals, and hence, after doping, it can be used as a non-linear absorber for the laser beam modulation, an active laser medium in solid-state lasers, and as a converter in white light laser sources.

Luminescent materials for highly efficient white light sources

At the Department of Optoelectronics and Department of Composite and Ceramic Materials, white light sources are developed using ceramic luminescent materials stimulated by blue high-power laser diodes. Our ceramic phosphors are based on yttrium aluminum garnet doped with cerium (YAG: Ce; $Y_3A_{15}O_{12}$: Ce^{3+}) and are obtained in the form of a granulated product in various matrices, layered ceramics and ceramic composites. The controlled change in the microstructure of ceramics, the choice of the appropriate geometry, composition and manufacturing process parameters enable the preparation of the source characterized by the required color and high efficiency. The applications include laser headlights, which are one of the most modern solutions in the automotive industry, energy-efficient street lighting, high-power special-purpose light sources (e.g. medical lamps) and various types of light panels.

CAPACITY IN SCIENCE AND TECHNOLOGY

The Institute has a research potential and the devices. In its possesion are unique on a regional scale. The laboratories at the Centre of Graphene and Innovative Nanotechnology, with the specialized equipment, are the representative examples. High-tech research conducted and the advanced materials and structures are being developed in our numerous departments and laboratories. Our equipment and instruments allow the obtained materials and components to be thoroughly characterized.

The results of the investigations conducted at the Institute are important in both fundamental and applied aspects. For decades, our scientists have published the research articles in leading international scientific journals. For instance, in the years 2013-2017 over 460 reports, whose co-authors are ITME employees, were published in the peer reviewed journals belonging to Master Journal List. Our researchers are also the inventors of tens of patents and numerous patent applications.

Over the years, the achievements of ŁUKASIEWICZ - ITME have been appreciated. The Institute has appeared in the ranking of the most important scientific institutions in the world, i.e. SCImago Institutions Rankings. In 2019, it was placed on 7th position among the best state-owned scientific units in Poland and on 20th position in Eastern Europe.