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## Report

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# The report of joint research over 20 years of the Bulgarian Academy of Sciences and Hiroshima Institute of Technology

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### Abstract

The Department of Electronics and Computer Engineering, Hiroshima Institute of Technology (EC-HIT) started the international joint research with the Laboratory “Physical Problems of Electron Beam technologies” of the Institute of Electronics, Bulgarian Academy of Sciences (IE-BAS) from 1994. 20 papers, included a book chapter, were published by implementing the international joint research under 5 Agreements for Academic Cooperation and Exchange between HIT and IE-BAS. Our international joint research is getting the important position in joint research between Japan and Bulgaria.

(The first Agreement for Academic Cooperation and Exchange between the Hiroshima Institute of Technology and the Institute of Electronics of the Bulgarian Academy of Science was signed in 1998. The President of HIT and the President of the BAS and the Director of IE-BAS signed the 4<sup>th</sup> Agreement in May 2009 and the 5<sup>th</sup> Agreement was signed in 2012.)

The semiconductor fabrication process such as thin film deposition, Electron and Ion Lithography, Etching, Ion implantation, Plasma treatment, etc., evaluation technique such as X-ray photoelectron spectroscopy, optical spectroscopy, X-ray diffraction, etc., and their simulation technology were used for application in industry, medical service, medicine manufacture, biotechnology, dental, etc.

In the future, this bilateral research partnership between EC-HIT and IE-BAS becomes more stable and further develops the bilateral relation between HIT and BAS.

**Key Words:** joint research, Institute of electronics at the Bulgarian Academy of Sciences, Hiroshima Institute of Technology

## 1. Introduction

The Department of Electronics and Computer Engineering, Hiroshima Institute of Technology (EC-HIT) started the international joint research with the Laboratory “Physical Problems of Electron Beam technologies” of the Institute of Electronics, Bulgarian Academy of Sciences (IE-BAS) from 1994. 20 papers, included a book chapter, were published by implementing the international joint research under 5

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#### *Mission of the Bulgarian Academy of Sciences1)*

The Bulgarian Academy of Sciences is dedicated to the development of science in conformity with the universal human values and with the country's national interests and promotes the enhancement of the intellectual and material wealth of the Bulgarian people.

#### *50th ANNIVERSARY OF ACADEMICIAN EMIL DJAKOV INSTITUTE OF ELECTRONICS2)*

In 2013, the Academician Emil Djakov Institute of Electronics of the Bulgarian Academy of Sciences turns 50. It was established on September 27, 1962, by a Resolution of Bulgaria's National Assembly and began its independent existence in 1963 based on the Physical and Applied Electronics Section formed in 1948 at the Institute of Physics of the BAS by the Institute of Electronics' founder, first Director and builder, Academician Emil Djakov. Initially, the Institute had 30 employees and comprised two sections and two laboratories located on the fourth floor of the Institute of Physics' new building. According to the Resolution of September 27, 1962, the Institute of Electronics' scope of activities was academic research in the fields of cathode electronics, electro-vacuum microwave devices, quantum electronics and applied electronics. At the time, the term Electronics included the set of fundamental knowledge, technologies and algorithms for the development and manufacture of the electronic components necessary for creating modern communications, computing

equipment and information technologies. The Institute was relied on to become the academic motor in the drive of laying the scientific foundations and forming the research cadres necessary for the nascent electronic stage of Bulgaria's development.

In its quality of a part of the Bulgarian Academy of Sciences, the Institute's mission is to acquire, accumulate and disseminate scientific knowledge and technologies in its research field, thus contributing to Bulgarian people's intellectual and material enrichment and to widening humankind's scientific horizons.



Fig. 1 50 years Institute of Electronics "Acad. Emil Djakov" – June 2013.

Through the years, the Institute's research field and structure have developed dynamically in response to the changes taking place in the main trends in applied physics and technologies: materials science and technologies, physics of nano-sized objects and nanotechnologies, nanoelectronics, photonics, opto-electronics, quantum optics, environmental physics and monitoring, biomedical photonics and biomedical applications.

The Institute's main areas of scientific development have been preserved, while the specific research today takes into account the contemporary problems and requirements, the world-wide tendencies and Bulgaria's specificity and traditions.

The research efforts in physical electronics are concentrated on studying and solving the problems of generating and controlling electron and ion beams and their interaction with materials. This includes theoretical modeling, modern techniques, research and industrial equipment for micro- and nano-struc-

turing, thin films deposition and study, modification of surfaces, vacuum melting and welding of metals by intense electron beams. The physical basis is being formed of creating nanostructures, nanomaterials and nanoelements by using electron and ion beams. Furthermore, fundamental properties are being investigated of gasses and gas plasma, plasma arcs and plasma torches in view of developing diagnostic techniques and applications in thin films deposition and plasma chemistry.

The research in photonics and quantum electronics comprises theoretical and experimental studies on the interaction of short and ultrashort lasers pulses with matter; development of novel nanostructuring technologies; laser thin-films deposition and treatment; light-induced absorption and transmission in alkaline vapors; development of complex laser systems for analysis and modification of semiconducting and superconducting materials; theoretical and experimental investigation of non-linear optical phenomena; biomedical photonics.

The research efforts in radiophysics are directed to clarifying the processes of interaction of optical and microwave electromagnetic radiation with the atmosphere and the Earth's surface; developing experimental systems for laser remote sensing and monitoring of the atmosphere; microwave remote radiometric measurement of soil moisture content; developing algorithms and techniques for signals and information processing; constructing microwave units and systems for radar and communication applications; studying non-linear processes in optical communication media. New ferrite devices with micrometric dimensions were developed with possibility for higher degree of integration. Active research on gyro-magnetic materials is underway, in view of reaching higher frequency ranges, especially mm-waves for wireless communications and protection from powerful microwave radiation.

In all three fields of research, the Institute's scientists have achieved internationally-recognized priority by discovering new physical phenomena and relations, among which are particularities in the interaction of electron and ion beams with materials; ion channeling in the semi-channels of a crystal surface and hyper channeling at grazing angles; ion-

stimulated sorption; plasma electrodes for gas lasers; electromagnetically induced absorption in Hanle configuration.

During the 50 years of the Institute's existence, its scientists have published over 7000 scientific papers that have been cited more than 4500 times. The Institute has taken an active part in the international scientific cooperation by establishing partnerships with scientific research institutions of the USA, Russia, France, Germany, Japan, India, Italy, Poland, the Czech Republic, Slovak Republic, Sweden, Ukraine, Canada, Finland, and Vietnam. In recent years, in its collaboration with the European scientific research institutions, the Institute has placed the accent on joint work within the framework of the European priority research programs.

The Institute has represented Bulgaria in international scientific organization, such as the International Institute for Weights and Measures, the International Laboratory of Low Temperatures and High Magnetic Fields in Wroclaw, Poland, the European Physical Union, the International Union for Pure and Applied Physics, the International Union on Vacuum Physics and Applications, the International Radiosciences Union, the NATO Advanced Study Institute, as well as in the editorial boards of reputable international scientific journals.

The following important innovative technologies and devices have been developed for the first time in Bulgaria in laboratory conditions, mastered technologically and made available to the Bulgarian industry and economy: lasers, lidars, electron lithography systems and installations and technologies for electron beam melting, welding and refining of metals; plasma torches, electro-optical converters with a micro-channel plate; technology for optical fibers production; electron and ion projectors; ion technologies and systems for deposition of thin wear-resistant coatings; low-noise parametric solid-state microwave amplifiers; line- and strip line circulators; converters; microwave absorbers; microwave amplifiers, SQUID devices; portable microwave moisture meters for bulk materials; microwave radiometers and systems for remote soil moisture sensing; a mobile laboratory for remote microwave sensing of sea and land surfaces; magnetometers based on various

principles; ultra-high vacuum pumps and installations; devices and installations for studying the surfaces and properties of semiconducting materials; optical gas sensors; technologies and systems for nanoparticles and nanostructures formation; a technology and installation for nano powders production; industrial and medical laser and plasma technologies and installations; optical and microwave communication systems. Proofs of the above achievements have been participation in and awards from numerous industrial exhibitions and fairs and a large number of practical developments and industrial implementations resulting in revenues for the Bulgarian economy measured in millions of BGN or foreign currency. Gradually, the Institute acquired the role of a secondary center for education of scientists and dissemination of knowledge and methodologies in Bulgaria and abroad. Under the conditions of a free and fierce competition, the Institute won the status of a center for and a coordinator of the research on lasers and lidars, remote microwave sensing of sea and land surfaces, remote radiometric microwave sensing of soil moisture, electron beam and plasma technologies, microwave solid-state electronics.

Through the years, the Institute has provided the scientific ambiance and opportunities that allowed the formation and successful scientific carriers of one academician and three corresponding members of the Bulgarian Academy of Sciences, 18 professors, 21 doctors of sciences and 111 PhDs; 37 former members of the Institute's research staff are now working on leading positions at research institutions in the USA, Sweden, Canada, France, Great Britain, Switzerland, Germany, Vietnam.

The Institute's staff has been instrumental in the development and advancement of highly efficient techniques for and approaches to implementing scientific products in the industry, agriculture, public health and defense by way of joint development programs, inter-branch and joint laboratories, experimental installations and workshops for pilot production; research and development of technologies, measuring and technological equipment, single devices and technologies; training of specialists.

During the Institute's existence, its work and

staff have been evaluated several times by the Bulgarian Academy of Science and other national institutions having the relevant authority, as well as twice by prestigious international commissions. With no exceptions, the marks have been high, accompanied by recommendations for further development and expansion.



Fig. 2 Academician Emil Djakov – founder of the Institute of Electronics.

The IE-BAS and the laboratory “Physical Problems of Electron Beam Technologies” is a leading research and development unit of BAS that is doing theoretical and experimental research connected with the application of electron beam technologies in science, industry and other areas. The laboratory research and development and innovation activities include: physics and characterization of intense electron beams, theoretical and experimental study of electron and ion penetration in materials, mathematical models and computer simulation of processes at sub-micron and nano-dimensional electron and ion lithography, electron beam welding, surface modification by thermal treatment, electron beam melting and refining of metals and alloys, new materials, thin films, modeling and computer simulation and improvement of processes, computer simulation of signals at investigation of surfaces and thin films by electron spectroscopy, development and application of statistical methods for control and optimization of electron beam technologies. The first Bulgarian installations for electron beam melting and refining of metals, for electron lithography, and electron beam welding have been set up in the IE-BAS.

The gained knowledge and experience of the

group in the Laboratory “Physical problems of electron beam technologies”, the obtained scientific results and the established international connections are contributions that gave a lot to physical electronics, vacuum and micro- and nano-technologies, and new materials and have great potential for future development. They rise the level of the Bulgarian science and find new applications in the industry.



Fig. 3 Poster of the Laboratory “Physical Problems of Electron Beam Technologies” for the 50<sup>th</sup> anniversary of the Institute of Electronics “Acad. Emil Djakov”.



Fig. 4 Researchers from Lab. “Physical Problems of Electron Beam Technologies”, IE-BAS, May 2013.

The IE-BAS and particularly the Laboratory “Physical problems of electron beam technologies” is a creator and organizer of the International Conference on Electron Beam Technologies (EBT). This conference takes place in Bulgaria every three years, starting in 1985. The fact that the conference takes place in Bulgaria is a sign of recognition from the in-

ternational community of scientists and industrial experts for the contribution of the Bulgarian scientists in the development of those technologies and technique and for their efforts for the effective conduction of the forum. During the EBT conferences physicists, chemists, and engineers from research and academic organizations and from the industry meet. The full text of the presented papers and lectures during the EBT’2000, EBT’2003 and EBT’2006 after the reviewing were published in the journals Vacuum v. 62, (2001); Vacuum v. 77 (4), (2005); “Elektrotehnika & Elektronika”, v. 5–6, (2006), (2009).

The latest 10<sup>th</sup> meeting (EBT’2012), as all nine previous ones, provided an excellent forum for exchange of results, experience, knowledge and ideas in the development of EB technologies. As usual, it was also a place for establishing personal and business contacts and funding partners for joint work programs and networks. The anniversary 10<sup>th</sup> EBT Conference owes its success to all participants, to the International Organizing Committee and to the Local Committee.

The Conference proceedings was printed and



distributed as a regular issue of the most respected Bulgarian scientific and technical journal in our field Elektrotehnika & Elektronika (-<http://www.ceec.fnts.bg/sp-E+E.htm>), v.5-6, 2012.

The number of published papers is 62,

representing the research results of 176 scientists from academic institutions or industry of many countries: Germany, Russian Federation, Ukraine, Czech Republic, Slovak Republic, UK, Japan, Romania, France, Algeria, China, India, etc. Leading companies, such as ALD Vacuum Technologies GmbH, Hanau, Germany; VON ARDENNE, Dresden, Germany; JSC “NVO “Chervona Hvilya”, Kiev, Ukraine; TWI, Cambridge, UK; TARGETS LTD, Plovdiv, Bulgaria had the opportunity to present their latest e-beam equipments and products.

The following main activities concerning the successful collaboration between the Hiroshima Institute of Technology (HIT) and the Institute of Electronics of the Bulgarian Academy of Science (IE-BAS) during the last 20 years can be mentioned:

1. During the last 20 years under 5 Agreements for Academic Cooperation and Exchange between HIT and IE-BAS joined results in the field of modification and computer simulation of the processes of electron, ion and x-ray radiation of electronic materials have been obtained. The results were published in more than 20 common publications in one Chapter in book, in journals and conference proceedings and these common papers are cited more than 25 (see the list of common papers below).

Our results concerning the computer simulation of signals at investigation of surfaces and thin films by electron spectroscopy are summarized and published in a Chapter in a special review book "Practical Aspects and Applications of Electron Beam Irradiation" [5]. The angle-resolved XPS is a promising surface-sensitive electron spectroscopy method for non-destructive depth-profile analysis in a few nanometers in depth. The developed and presented model for computer simulation of the XPS angular intensity distributions and the obtained results can be used to describe investigations at real surface structures (for analysis of electron spectra generated from textured surfaces, including also the shadowing effect). Surface roughnesses, which are important phenomena at real samples, were modelled by different 3D geometrical shapes of variable size. This computer simulation helps to understand the behaviour of measured angular XPS signal distributions, provided that the approximation of the textured surface resembles the analyzed sample surface. The height of the investigated surface roughnesses is similar to the ones studying using microscopy, based on the atomic forces and potential, as well as scanning electron-microscopy methods. This approach allows developing XPS profilography using the integral evaluation of the surface roughnesses (instead of obtaining many profiles and subsequent mathematical processing).

2. Prof. Katia Vutova was invited as a guest re-

searcher in HIT (February 1998), invitation from T.Kawasaki, M.D., Ph.D - President of the Hiroshima Institute of Technology, Hiroshima, Japan, Lectures on "Mathematical modeling and computer simulation of the processes in electron and ion



Fig. 5 Noboru Tsuru, founder of the Hiroshima Institute of Technology (left) and Prof. K.Vutova (right)



Fig. 6 Takashi Kawasaki, President of the Hiroshima Institute of Technology was presented.



Fig. 7 Prof. K.Vutova's lecture in the Hiroshima Institute of Technology.



Fig. 8 Prof. K.Vutova was presented in the Hiroshima Institute of Technology.



Fig. 9 After Prof. Vutova' lecture, commemoration photography with students from the Hiroshima Institute of Technology.



Fig. 10 Commemoration photography with the Hiroshima Institute of Technology's students.

lithography". (see Figs.5-12).

3. In December 2003 Prof. K.Vutova was invited from Dr. of Eng. Kazu-hiro MORI - President of the HIT, Hiroshima, Japan. She also visited the company "Soken Kogyo CO.", LTD. Kawagoe-shi. Presented lectures:

- "Bulgarian Academy of Sciences – history and present"
- "Institute of electronics – laboratories, activities and collaborations"
- "Electron and Ion Beam Lithography – physical processes, computer simulation and experimental data"
- "Ion Scattering Modeling in Amorphous Targets"



Fig. 11 Hiroshima Institute of Technology's students present experiments to Prof. K.Vutova.



Fig. 12 Meeting of the audience of Prof. Vutova' lecture in front of the gate of the Hiroshima Institute of Technology.

- "Introduction in mathematical analysis"

4. In 2004 The Executive Council of the BAS conferred the Decoration of Honour "FOR SPECIAL MERIT TO THE BULGARIAN ACADEMY OF SCIENCES" on Prof.K.Kawabata and Prof. T.Tanaka for their merit to IE-BAS and their contribution to promoting the cooperation between HIT, Hiroshima and IE-BAS, Sofia in the field of the interaction between electrons and ions with different materials. (see Fig.13). [3]



Fig. 13 Prof. Kawabata and Prof. Tanaka were awarded the Medal of Honor for “Special achievement to Bulgarian Academy of Sciences” on December 1, 2004. The certificates and badges were presented to both of them by the Bulgarian Academy of Sciences. [3]

5. Prof.K.Kawabata (since 2000) and Prof.T.Tanaka (since 2006) were members of the International Organizing Committee and attended many times the International Conference on Electron Beam Technologies, organized by IE-BAS every 3 years in Varna, Bulgaria.



Fig. 15 Academician Sendov (right) – Ambassador of the Bulgarian Embassy in Japan, Tsuru (left) - Chairmen of the board of directors and the presidents of a university during exchange of opinions in the Tsuru school and Hiroshima Institute of Technology, May 8, 2008.



Fig. 16 Prof. Tanaka explains the Automatic control model to Ambassador Sendov and accommodation persons.



Fig. 14 Prof. Mladenov and Prof.Vutova exchange experience with Prof. Takeshi Tanaka in IE-BAS, June 18, 2008.

6. Since October 2009 Prof.T.Tanaka is a member of the International Editorial Board of the scientific journal “Elektrotechnica & Elektronika”, published by the Union of Electronics, Electrical Engineering and Telecommunications (CEEC), Bulgaria. [4]

7. Since December 2009 Joint Electronics Research Center in HIT and in IE-BAS is established. Coordinators: Prof. Takeshi Tanaka from HIT and Prof. Katia Vutova from IE-BAS.



Fig. 17 Academician N.Sabotinov (President of BAS, front row center) shaking hands with Dr. TANAKA (HIT, front row left). Prof. Vutova (IE-BAS, front row right), Mr. Imamura (President, Bulgaria Association of Hiroshima, back row left), Mr. Yamamoto (Director, Bulgaria Association of Hiroshima, back row right).





Fig. 18 Surround the Japanese wrapping cloth of the peace of Hiroshima Institute of Technology.



Fig. 19 Ambassador Sendov's farewell party on September 12, 2009 in Republic of Bulgaria ambassador's official residence in Japan.



Fig. 20 The 48th time and a regular meeting (an executive director and executive board ) 17:00 on Sat., March 9, 2013 in the Hiroshima foreign student hall adviser's Foreign Minister, Fumio Kishida, participates and encourages.

### List of the common papers:

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6. K.Vutova, G.Mladenov, T.Tanaka, K.Kawabata, "Simulation of the energy absorption and the resist development at sub-150 nm ion lithography", *Microelectronic Engineering*, 78-79 (2005), 533-539.
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- [3] <http://www.ie-bas.dir.bg/Awards.htm#award1>
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