INSTITUTE FOR NUCLEAR PROBLEMS OF BELARUSIAN STATE UNIVERSITY (BELARUS)

DEPARTMENT OF PHYSICS OF BELARUSIAN STATE UNIVERSITY (BELARUS)

DALIAN UNIVERSITY OF TECHNOLOGY (CHINA)

TOMSK POLYTECHNIC UNIVERSITY (RUSSIA)

REPUBLICAN CONFUCIUS INSTITUTE OF SINOLOGY AT BELARUSIAN STATE UNIVERSITY (BELARUS)

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2019

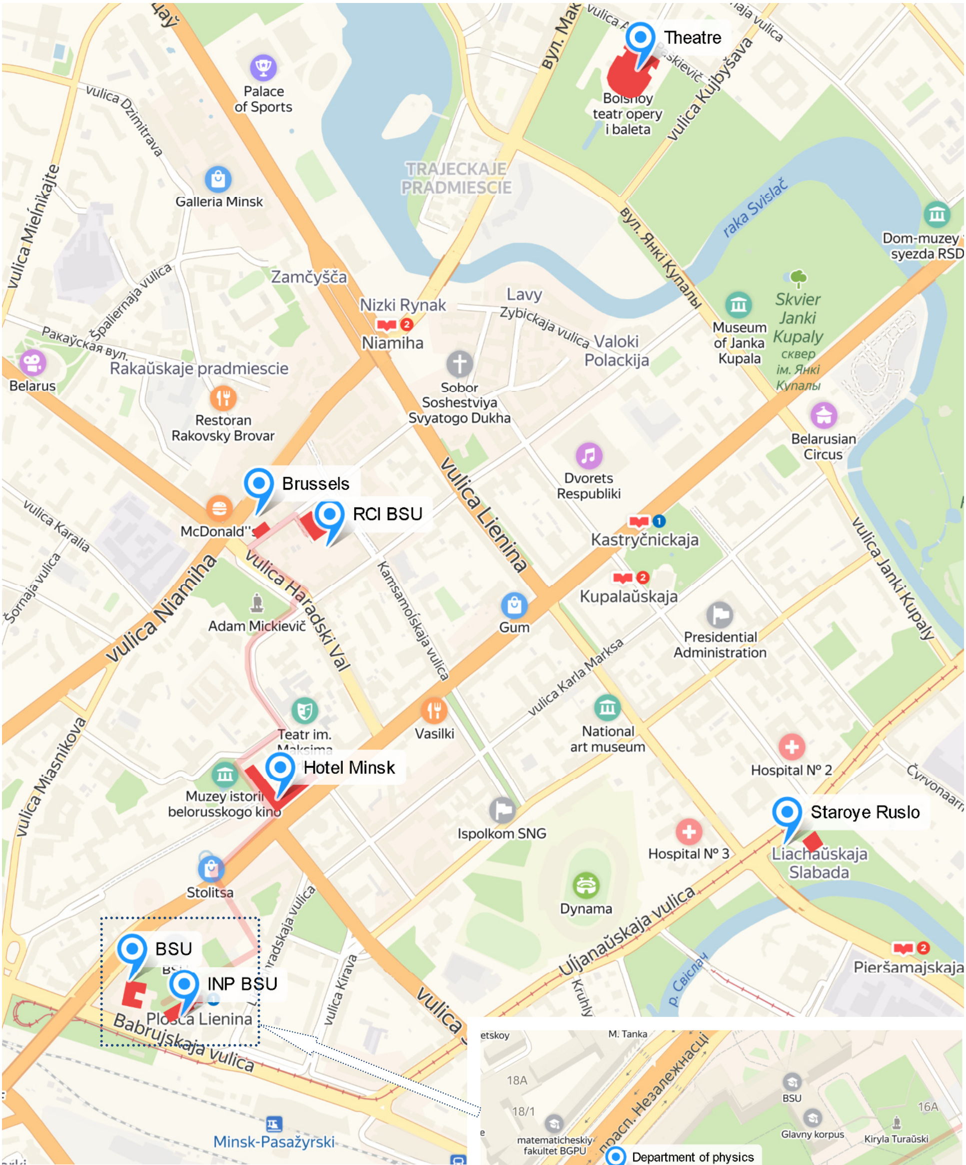
XIIth China-Russia-Belarus Workshop

PERSPECTIVE PLASMA TECHNOLOGIES 2019

Minsk, Belarus, 03–05 October, 2019

PROGRAMME
AND
BOOK OF ABSTRACTS

Minsk
2019



RCI BSU: Republican Confucius Institute of Sinology BSU,

BSU: Belarusian State University (Rectorate),

INP BSU: Institute for Nuclear Problems BSU,

Brussels, Staroye Ruslo: Restaurants

XIIth China-Russia-Belarus Workshop
PERSPECTIVE PLASMA TECHNOLOGIES 2019
Minsk, Belarus, 03–05 October, 2019

Organizers:

- Dalian University of Technology,
- Tomsk Polytechnic University,
- Institute for Nuclear Problems of Belarusian State University,
- Department of Physics of Belarusian State University,
- Republican Confucius Institute of Sinology at Belarusian State University

Co-Chairmen:

- Hongbin Ding (Dalian, China),
- Gennady Remnev (Tomsk, Russia),
- Vladimir Uglov (Minsk, Belarus),
- Sergey Maksimenko (Minsk, Belarus)

Workshop's Topics:

- New materials production (nanomaterials, materials for aerospace, biomaterials, materials for fusion and fission reactors and etc.),
- Advanced plasma sources and diagnostics,
- Plasma and surface interaction,
- Commercial plasma and pulsed beams applications.

The joint tripartite International Workshop aims to provide a forum for scientists and technologists from three participating countries specializing in the field of beam and plasma technologies and their use for fabrication of novel functional materials and coatings. Properties of materials including nanocarbon-based structures will be discussed with the focus on aeronautical applications. Assistance in training of specialists in these areas, as well as preparation of joint research projects are also in the scope of the Workshop.

PROGRAMME

Locations:

BSU: Rectorate building, *5A Babruyskaya str.*
RCI BSU: Republican Confucius Institute of Sinology at Belarusian State University, *11 Revolyutsionnaya str.*
INP BSU: Institute for Nuclear Problems of Belarusian State University, *11 Babruyskaya str.*
Restaurant «**Brussels**»: *32 Revolyutsionnaya str.*
Restaurant «**Staroye Ruslo**»: *7 Ulyanovskaya str.*

October 3, Thursday

11:00–13:00 Meeting on the sidelines (*Location: BSU*)
Chairman – Academician Oleg Ivashkevich, BSU, Minsk
11:00 Agreement signing ceremony between BIAM and BSU, BIAM and INP BSU

11:00–13:00 Registration (*Location: RCI BSU*)
13:00 Lunch (*Location: restaurant «Brussels»*)

14:00–14:30 Opening Ceremony (*Location: RCI BSU*)

Academician Oleg Ivashkevich, Vice-Rector of Belarusian State University, Minsk

Professor Anatoliy Tozik, Ambassador Extraordinary and Plenipotentiary, Director of Republican Confucius Institute of Sinology at Belarusian State University, Minsk

Professor Li Ping, General Director of China-Belarus High-Technology Aerospace Center for Research and Development, Minsk

Professor Ren Fei, Vice General Manager of Industrial Park "Great Stone", Minsk

Professor Wang Yajun, Executive Vice President of Beijing Institute of Aeronautical Materials, Beijing

14:30–16:00 Plenary section *(Location: RCI BSU)*
Chairman – Professor Vladimir Uglov, BSU, Minsk
14:30 Invited talk: **Hongbin Ding, Y. Wang and J.L. Shi**, Diagnosis on Non-Equilibrium Plasmas using Laser Thomson Scattering Approach
15:00 Invited talk: **Gennady Remnev, A. Baranova, A. Byuharkin, M. Zhuravlev, E. Kibler, V. Lopatin, I, Pyatkov, V. Ryzhkov**, Elec-

tron Accelerators and Collective Ion Acceleration for Medical Applications

15:30 Coffee

16:00–17:30 Plenary section *(Location: RCI BSU)*

Chairman – Professor Gennady Remnev, TPU, Tomsk

16:00 Invited talk: **Oleg Penyazkov, Valiantsin Astashynski**, Development of Plasma Physics and Plasma Technologies in A.V. Luikov Heat and Mass Transfer Institute of National Academy of Sciences of Belarus

16:30 Invited talk: **Vladimir Uglov, N.N. Cherenda, A.K. Kuleshov, V.I. Shymanski, S.V. Zlotski**, Novel Plasma Technologies Development in Solid State Physics Department of Belarusian State University

17:00 Invited talk: **Sergey Maksimenko**, Institute for Nuclear Problems of the Belarusian State University: Contribution to Materials Research

17:30–18:30 Poster section *(Location: RCI BSU)*

18:30 Welcome party *(Location: restaurant «Brussels»)*

October 4, Friday

09:00–10:30 Plenary section *(Location: RCI BSU)*

Chairman – Professor Junling Chen, IPP CAS, Hefei

09:00 Invited talk: **Jian Jiao, Jinhua Yang, Hu Liu**, Fabrication of Silicon Carbide Reinforced Silicon Carbide Composites by Melt Infiltration Processing

09:30 Oral talk: **Vladimir Denisov, N.N. Koval**, Works on the Generation of a Gas-Metal Plasma and its use for Surface Modification of Materials and Products, Performed in the Laboratory of Beam-plasma Surface Engineering of HCEI SB RAS

09:45 Oral talk: **Gennady Remnev, Vladislav Tarbokov**, Technological Area for Complex Hardening of Carbide Tools

10:00 Oral talk: **Chengyan Ren, Duo Hu, Fei Kong, Cheng Zhang, Tao Shao**, Effect of Surface Modification on Trap Distribution and Vacuum Surface Flashover of Polymeric Materials

10:15 Oral talk: **M.N. Bosyakov, V.G. Zalesski, I.L. Pobol, A.N. Majseenka**, Automated Equipment for Plasma Thermochemical Treatment of Metal Parts

10:30 Coffee

11:00–12:30 Plenary section *(Location: RCI BSU)*

Chairman – Professor Hongbin Ding, DUT, Dalian

11:00 Invited talk: **Rui Ding, H. Xie, F. Ding, L. Wang, J.L. Chen, D.L. Rudakov, H.Q. Wang, H.Y. Guo**, Modeling of Plasma-Wall Interaction in Tokamak Experiments with High-Z Materials

11:30 Invited talk: **Laizhong Cai, Xiaoxiao Zeng, Jianbao Wang, Jiupeng Song, Binyou Yan, Zhe Chen**, Fabrication and Test of the Interlayer of a New First Wall Structure For DEMO

12:00 Oral talk: **Chaofeng Sang, Rui Ding, Liang Wang, Zhenhou Wang, Dezhen Wang**, Modeling of the Plasma with Tungsten Divertor Interactions on EAST

12:15 Oral talk: **Cong Li, L. Sun, Z. Hu, D. Zhao, J. Liu, R. Hai, C. Feng, F. Ding, G.-N Luo, J. Hu, L. Wang, Y. Liang, H. Ding**, In Situ Laser-Induced Breakdown Spectroscopy (LIBS) Study on Plasma-Wall Interaction in EAST Tokamak

12:30 Meetings on the sidelines

13:00 Lunch *(Location: restaurant «Brussels»)*

14:00–16:00 Plenary section *(Location: RCI BSU)*

Chairman – Professor Yue Liu, DUT, Dalian

14:00 Invited talk: **Xiubo Tian, Houpu Wu, Chunzhi Gong**, Discharge and Deposition of Novel Bipolar High Power Impulse Magnetron Sputtering

14:30 Oral talk: **Q.Y. Nie, Z.L. Zhang**, The Modulation Strategy of Atmospheric Pressure Dielectric Barrier Discharge by Tailored Voltage Waveforms Excitation

14:45 Oral talk: **Chunzhi Gong, Yongjian Li, Xiubo Tian**, Effect of Auxiliary Enhanced Magnetic Field on Microstructure and Mechanical Behaviors of Multilayered CrN/AlCrN Coatings

15:00 Oral talk: **Ivan Egorov, A.V. Poloskov, A.A. Isemberlinova, G.E. Remnev**, Pulsed Electron Beam Irradiation for Agricultural Applications

15:15 Oral talk: **Yurii Sharkeev, K. Prosolov, O. Belyavskaya, A. Bolatool, J. Rau**, RF Marnetron Glancing Angle Deposition of Thin Calcium Phosphapte Coatings on Titanium for Medical Applications

15:30 Oral talk: **Chunlei Feng, Z.W Wang, H. Ding**, The Transport Behaviour Study of OH Radical by LIF in Atmospheric Pressure Surface Micro-Discharge

15:45 Oral talk: **J. Hu, X.B. Tian**, Evaluation of Discharge Behavior and Surface Properties of Ta-C Films by Modified Vacuum Arc Evaporation

16:00 Coffee

16:30–17:30 Plenary section *(Location: RCI BSU)*

Chairman – Professor Ren Fei, Industrial Park "Great Stone", Minsk

16:30 Invited talk: **Li Ping**, China-Belarus High-Technology Aerospace Center for Research and Development

17:00 Discussion

17:30 Coffee and snacks

19:00 Social event *(Location: Bolshoi Theatre of Belarus, 1, Parizhskaya Kommuna sq., Minsk)*

October 5, Saturday

09:00–11:00 Plenary section *(Location: RCI BSU)*

Chairman – Professor Sergey Maksimenko, INP BSU, Minsk

09:00 Invited talk: **Miao Qu, Sha Yan**, Application prospect of Compressed Plasma Flows in transient high heat flux testing for PFM

09:30 Oral talk: **Efim Oks**, Some Issues of the Development of Electron-beam and Ion-Plasma Equipment for Practical Use

09:45 Oral talk: **Ran Hai, X.C. Li, H.B. Ding**, Comparative Study on Self-Absorption of Laser-Induced Plasma in Different Environments

10:00 Oral talk: **Evgeniy Petrenko, A.S. Yudin**, Formation of multichannel breakdown in electric discharge drilling technologies

10:15 Oral talk: **A.A. Bukharkin, S.M. Martemyanov**, Low-grade Solid Fossil Fuels Electrophysical Conversion

10:30 Oral talk: **Vladimir Ovcharenko, Yu Baohai**, Pulsed Electron-ion-plasma Irradiation as a Tool to Reduce the Defectiveness of Instrumental Metal Ceramics

11:00 Coffee

11:30–12:30 Round table discussion *(Location: RCI BSU)*

12:30 Meetings on the sidelines

18:00 Conference dinner *(Location: restaurant «Staroye Ruslo», 7 Ulyanovskaya str., Minsk)*

List of posters:

1. **C. Cao, X. Huang, Z. Cao, X. Gao, C. Cui**, Experiments of Real-Time Siliconization during Discharge on Tokamak
2. **Y. Liu, Yu-E Hu**, Effect of Neutral Gas Temperature on Discharge Characteristics in Low Pressure Rf Argon Glow Discharges
3. **Cailong Fu, Qi Wang, Liying Sun, Ding Wu, Hongbin Ding**, Numerical Study of Tungsten Plasma Emission Spectra From the Low Charge State in The Laser Ablation Plasma
4. **Roman Sazonov, G. E. Remnev, I. S. Egorov, A. V. Poloskov, L.R. Merinova, G. E. Kholodnaya**, Development of Technology for the Oxidative Destruction of Hormonal and Hardly Oxidizable Organic Compounds
5. **Alexandra Baranova, Gennady Remnev**, Radiation technology for bio waste treatment
6. **Artem Yudin, N.K. Kapishnikov**, Mini-plant for destruction of reinforced concrete wastes
7. **Nikolay Rempe**, Equipment and technologies for coating metals by electron-beam surfacing in vacuum and gas with atmospheric pressure
8. **Yurii Ivanov, E.A. Petrikova, I.V. Lopatin, O.S. Tolkachev, M.E. Rygina**, Modifying of the eutectic silumin surface by the electron-ion-plasma method
9. **Anton Teresov, Yu.F. Ivanov, E.A. Petrikova, O.S. Tolkachev, D.A. Romanov**, Boration of high-chromium austenitic steel surface by electron-ion-plasma methods
10. **Li Guo, Jing Zhang, Dingxin Liu, Michael G. Kong**, Microbial Inactivation in Model Tissues Treated by Surface Discharge Plasma
11. **T.Z. Miao, M. Zhu, Y.B. Cao, P. Wu, Z.M. Song, G.S. Zhang, J. Sun**, Study on Anode Plasma Spectra with Strong Current High-Energy Electron Beam
12. **X.X. Zhu, W.B. Tan, X.Z. Li, J.C. Su, L.G. Zhang, Z.Y. Shen**, Studied the Effect of Plasma on High Power Microwave Transmission Channel in Ku Band

LASER THOMSON SCATTERING DIAGNOSIS ON NON-EQUILIBRIUM PLASMAS

H.B. Ding*, Y. Wang and J.L. Shi

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Recently Laser Thomson Scattering (LTS) approach has been developed for diagnosis of the plasma parameters for the Non-equilibrium reactive plasmas in Plasma Spectroscopy Laboratory of Dalian University of Technology. In our experiments, the electron number density and electron temperature in an expanding cascaded arc Ar/N2 plasma were measured by the LTS combined with the Optical Emission Spectroscopy (OES). The LTS measurements indicate that with the increase of N2 gas the electron temperature has a very complicated behavior. This is due to the collective interactions between the super-elastic collision and electron impact excitation. The super-elastic collision between the free electrons and the highly excited vibrational nitrogen molecules can heat the electrons while the electron impact to nitrogen molecules leads to that the electron kinetic energy is transferred to the nitrogen molecule internal energy. The investigations evaluate how the plasma deviates from the local thermodynamic equilibrium (LTE) and indicate that the addition of N2 gas leads to the enhancement of the deviation from LTE.

1. Y. Wang, et. al, IEEE Transactions on Plasma Science (2019). Available online at http://ieeexplore.ieee.org.

ELECTRON ACCELERATORS AND COLLECTIVE ION ACCELERATION FOR MEDICAL APPLICATIONS

G. Remnev*, A. Baranova, A. Byuharkin, M. Zhuravlev, E. Kibler,
V. Lopatin, I. Pyatkov, V. Ryzhkov
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Electron accelerators with an energy of 10^4-10^7 eV are already widely used in medicine, agriculture and agricultural production, ecology and other areas. The potential for their practical use, and in particular pulse accelerators with extreme high pulse power is much wider. In some important areas, such as the solving important tasks of environmental problems for the treatment of wastewater, flue gases, certain areas of medicine and some others, there is practically no alternative. The report presents an overview of the work carried out at the Tomsk Polytechnic University on the development of pulsed electron accelerators. The work in the field of development of a medical accelerator for the production of ultrashort isotopes (UHF) for medical purposes is presented for the first time. High-energy light ion beams are generated using nanosecond pulsed electron beams. The high rate of acceleration of ions 2-3 MeV/cm makes it possible to create compact accelerators for equipping medical diagnostic centers. Other areas of practical application of accelerators where the pulsed beam has advantages are presented.

The work was supported by RSCF grant number 17-19-01442.

NOVEL PLASMA TECHNOLOGIES DEVELOPMENT IN SOLID STATE PHYSICS DEPARTMENT OF BELARUSIAN STATE UNIVERSITY

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V.I. Shymanski, S.V. Zlotski
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Plasma technologies for material science are actively developed in the solid state physics department for a long time. One of the most important direction of plasma treatment of materials is connected to high-energy compression pulsed plasma flows impact. The special quasi-stationary plasma accelerators as well as magnetoplasma compressors of compact geometry were produced in Institute of Heat and Mass Transfer of National Academy of Science of Belarus. The used plasma flows possess a high energy density and long pulse duration (more than 100 s) that is enough for surface materials modification and increase the role of physical processes occurring in liquid phase. A set of experiments conducted with steels, aluminum alloys, titanium alloys shown the disperse structure and even nanostructures formation. Such types of plasma treatment allowed to increase mechanical, tribological properties of the surfaces.

A new direction of plasma modification of materials was attributed to formation of metal alloys, solid solutions and composed structures. In this case a “coating/substrate” system is subjected to plasma impact. The long time of the pulse duration of the plasma flows increases the role of the melted layers mixing and provides the elemental composition change. The main results shown the formation of solid solution in titamiun, zirconium, tungsten with a composition not reached in the traditional methods of alloying.

Additional field of plasma technologies application is a protective coating synthesis by mean of vacuum-arc deposition and magnetron deposition. It results in producing the coating based on the solid solution of transition refractory metals with a high hardness and adhesion strength. This approach is used for cutting tools modification. Besides, a new class thin films with nanocomposite or multilayered structure based on the immiscible nitride phases was developed. Such films shown high thermal, radiation and corrosion resistances, improved elastic properties.

INSTITUTE FOR NUCLEAR PROBLEMS OF THE BELARUSIAN STATE UNIVERSITY: CONTRIBUTION TO MATERIALS RESEARCH

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A short introduction into history and main fields of research activity of the Institute is given. A set of most important results achieved in the Institute during past years both in fundamental and applied research is presented. The talk is focused on the several topics related to fabrication and studying of new materials:

- nanoelectromagnetics, - a new approach integrating methods of classical electrodynamics and present-day condensed matter physics aiming with studying of electronic and electromagnetic properties of nanostructures;
- CVD synthesis of carbon nanostructures and their applications in coatings, thin films and composite materials and ceramics;
- 3D-printed materials and structures for electromagnetic applications
- New materials and structures for aerospace applications

Participation of the Institute in international research collaboration is also discussed.

FABRICATION OF SILICON CARBIDE REINFORCED SILICON CARBIDE COMPOSITES BY MELT INFILTRATION PROCESSING

Jian Jiao[1,2*], Jinhua Yang[1,2], Hu Liu[1,2]

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SiC_f/SiC composites are able to deliver the high temperature capability of ceramics with the strength and reliability which is required for gas turbine engine applications, but weigh less than current alloys. Therefore, the performance including fuel consumption, emissions and noise will be improved because of they require less cooling over traditional nickel-based components.

SiC_f/SiC composites are typically consisting of SiC fibers, interphase and SiC matrix. SiC fibers are made by spinning polycarbonsilane, followed by curing and pyrolysis steps to convert the fibers into ceramic materials. Key characteristics of as-produced polymer-derived ceramic fibers are their small diameters, their ultra-fine microstructure with nearly equiaxed grain sizes in the low nanometer range, and their continuous lengths in multifilament bundles. The thermal stability of the nano-size β-SiC grain determines the heat-resistance limitation of the fibers. Therefore, the correlation of the grain size and the fiber strength was built in this work, and the failure mechanism was discussed as well.

The interphase, by which stresses transfer from matrix to SiC fibers and deflects microcracks, is a critical part of composites. BN single layer or BN/SiC double layers were prepared *via* Chemical Vapor Infiltration (CVI) processing in this work. And the interphase was characterized carefully by SEM, TEM, AFM, XRD, SIMS, ^{11}B MAS NMR. Hexagonal Boron nitride (*h*-BN) interphase with a graphite-like structure was confirmed.

Eventually, SiC_f/SiC composites were fabricated *via* Prepreg-MI process. The bulk density was 2.7 g/cm^3 and the apparent porosity was lower than 5%. The in-plane tensile strength, flexural strength and interlaminar tensile strength were >300 MPa, >750 MPa and >35 MPa, respectively.

WORKS ON THE GENERATION OF A GAS-METAL PLASMA AND ITS USE FOR SURFACE MODIFICATION OF MATERIALS AND PRODUCTS, PERFORMED IN THE LABORATORY OF BEAM-PLASMA SURFACE ENGINEERING OF HCEI SB RAS

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The report is devoted to work carried out in the laboratory of beam-plasma surface engineering of HCEI SB RAS and directed at studying the processes of generating gas-metal plasma in self-sustained and non-self-sustained low-pressure discharges and their using for hardening of the surface of materials and products.

In this paper low-temperature plasma generation systems made on the basis of an arc discharges and a low-pressure glow discharge with a hollow cathode with a vacuum chamber volume of more than 0.2 m^3 are presented. In a non-self-sustained glow discharge a beam-plasma formation is created. The beam-plasma formation is the plasma medium generated in the presence of an electrode system, providing self-sustained discharge burning, and by injection into the discharge system of charged particles beam. The injection of charged particles, for example, electrons, significantly changes the characteristics of the discharge and, therefore, the parameters and composition of the plasma. The additional electron beam activates particle interactions in the plasma near the substrate and causes additional chemical and physical reactions on the surface of the material.

The report describes the features of using of presented plasma generation systems for hardening of the surface of products of various dimensions from structural and tool steels.

The work was supported by the Russian Foundation for Basic Research (project No. 18-38-00836).

TECHNOLOGICALAREAFOR COMPLEX HARDENING OF CARBIDE TOOLS

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The surface treatment of hard alloys by ion beams with a high pulsed power (up to 10^8 W/cm^2) causes ultrafast melting and recrystallization of a layer up to 10 μm thick. Due to the high rate of subsequent cooling (up to 10^7 K/s), phases with enhanced elastic-strength properties (for example, WCO, W_2 (CO)) are formed and remain stable in the surface layer. Such processing enables to increase the service life of hard alloy tools by 1.5-3 times.

The discusses the creation of a technological area for hardening carbide tools based on two pulsed high-current accelerators with a capacity of up to 1000 cutters per shift depending on the size of the tool. We analyze are the prospects for the creation of a combined installation for a complex modifica-tion of a hard alloys tool with various wear-resistant coatings with enhanced adhesion.

EFFECT OF SURFACE MODIFICATION ON TRAP DISTRIBUTION AND VACUUM SURFACE FLASHOVER OF POLYMERIC MATERIALS

Chengyan Ren[1,2,*], Duo Hu[1,2], Fei Kong[1], Cheng Zhang[1,2], Tao Shao[1,2]

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[2] University of Chinese Academy of Sciences, China

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The surface trap parameter and distribution could significantly affect the surface flashover characteristic of insulation mateirials in vacuum. To further understand the influence of traps on flashover of polymeric materials, the surface trap parameters, trap energy level and trap density, were regulated by surface modification. Firstly the atmospheric pressure plasma jets were used to treat the fluorinated ethylene propylene (FEP) film to control trap density, and electron beam irradiation was used to change surface trap energy level of polymethylmethacrylate (PMMA). Then effect of different processing conditions on the insulation properties of material surface was studied. The trap parameters were tested and caculated by means of isothermal surface potential decay (ISPD), and space charge distribution in FEP film body was also measured by means of pulsed electro-acoustic (PEA). At last surface flashover experiment under DC and pulsed voltage in vacuum was performed using finger-type electrodes, and the relationship between surface trap parameter and flashover voltage was analyzed in diffrent treatment conditions.

The results show that some inorganic groups containing silicon element are introduced on the surface of FEP, and the trap density increases in different degrees while the trap energy level changes slightly. The space charge distribution has a positive correlation with the trap density. The trap level increases after electron beam irradiation with diffrent energy and treatment time while the trap density changes slightly. The increase of trap level and trap density could improve the vacuum surface flashover voltage to a certain degree by surface modification.

1. H. C. Miller. Flashover of insulators in vacuum: the last twenty years. IEEE Trans. Dielectr. Electr. Insul., 22(6), pp.3641- 3657, 2015.

2. R. Wang, H. Lin, Y. Gao, C. Ren, K. Ostrikov and T. Shao. Inorganic nanofilms for surface charge control on polymer surfaces by atmospheric-pressure plasma deposition, J. Appl. Phys., 122, p. 233302, 2017.

AUTOMATED EQUIPMENT FOR PLASMA THERMOCHEMICAL TREATMENT OF METAL PARTS

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To fulfill the conditions of operation of modern industrial equipment, full automation of the technological process is required. It is ensured by the use of modern PLS controllers with specialized software.

The industrial equipment for plasma thermochemical treatment developed and manufactured by orders of enterprises at the Physical-Technical Institute consists of several main components such as a working vacuum chamber, a control cabinet, a pumping system, a water cooling system, connecting cables, a controller and a personal computer.

The working gases are argon, nitrogen and hydrogen. The last one is obtained autonomously from the electrolyzer.

The operation of the installation and the control of the treatment process are carried out automatically according to the specified software. The software is developed at the PTI taking into account the requirements of the customer, grades of machined steels or cast irons and the degree of loading of the chamber. The user is given the opportunity to change it.

All stages of the installation operation (evacuating the chamber, heating the charge, holding and cooling) are automated. When processing identical charges of parts, a mode adjustment is not required. It is enough for the technologist to choose a previously developed processing mode, and the program will independently carry out all the required operations.

The graphic protocol of the process and its progress (start time, start of each step, error messages etc.) are saved with the possibility of viewing and printing.

MODELING OF PLASMA-WALL INTERACTION IN TOKAMAK EXPERIMENTS WITH HIGH-Z MATERIALS

R. Ding[1,*], H. Xie [1], F. Ding [1], L. Wang [1], J.L. Chen [1], D.L. Rudakov [2]
H.Q. Wang [3], H.Y. Guo [3]

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Plasma-wall interaction (PWI) and subsequent impurity transport are key issues in fusion research. Plasma induced erosion can seriously limit the lifetime of the wall components, while eroded particles can be transported into the core plasma causing dilution of the fusion plasma and energy losses due to radiation, especially for high-Z impurities. Since high-Z materials such as W will be used for ITER divertor and very likely in future fusion devices, the understanding of related PWI processes is indispensable and only can be achieved in a combined effort of experiment and modeling.

This contribution will give an overview of the key questions in PWI modeling and introduce the main simulation tools. The 3D Monte Carlo code ERO considers plasma-wall interaction processes like sputtering, reflection and deposition as well as impurity transport taking into account friction, Lorentz force, cross field diffusion, and various atomic processes like ionization, recombination, etc [1]. The ERO code has been applied to simulate recent experiments in DIII-D tokamak with well-characterized high-Z material coating samples and in EAST tokamak with an upper full W divertor.

The critical role of background low-Z impurities and the sheath in determining high-Z material erosion and re-deposition in a mixed materials environment has been revealed. The net erosion rate of high-Z materials is significantly reduced due to the high local re-deposition ratio, which is mainly controlled by the electric field and plasma density within the magnetic presheath. Modeling of the EAST experiments shows that the transport of C impurities not only dominates the W sputtering source but also determines the overall erosion and deposition balance in the mixed materials surface. Higher C concentration in the background plasma leads to more C in the mixed surface layer and thus lower W erosion rate due to the dilution effect [2]. The reerosion of W by returned eroded particles can simultaneously increase the W sputtering and reduce C ratio in the mixed surface layer.

1. *R. Ding et al., Nucl. Fusion 56 (2016) 016021*
2. *H. Xie et al., Phys. Plasmas 24 (2017) 092512*

FABRICATION AND TEST OF THE INTERLAYER OF A NEW FIRST WALL STRUCTURE FOR DEMO

Laizhong Cai[1*], Xiaoxiao Zeng[1], Jianbao Wang[1], Jiupeng Song[2], Binyou Yan[2], Zhe Chen[1]
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[2]*Xiamen Tungsten Company, Xiamen, Fujian, China*
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First wall, which is facing to plasma directly and experiences energetic particles, neutron radiation, steady state heat loads and transient heat loads, is one of the key components in fusion reactors. Another primary concern on the first wall in DEMO is the tritium accumulation in the plasma-facing areas. Based on the requirements of tritium self-sufficiency and safety regulation of tritium, it is very important to control the buildup in plasma facing components (i.e. first wall) and decrease the tritium inventory. In this work, a sandwich-like first wall structure with a tritium prevention interlayer is fabricated and tested. The interlayer is applied to combine the plasma facing material (W) and reduced activation ferritic/martensitic (RAFM) and also to prevent the permeation of hydrogen and its isotopes.

The top coating layer of the first wall, tungsten, is fabricated by chemical vapor deposition(CVD). And CLF-1, a kind of RAFM, is used as the substrate of the first wall structure. With a big difference between thermal expansion coefficients CVD-W and CLF-1, the interlayer between them has to mitigate the stress. And the tritium prevention capability of the interlayer is necessary due to the great importance of controlling the tritium buildup and improving the fuel efficiency. SiC and TiN are selected as the interlayer materials due to their good performance as good tritium barriers.

During the fabrication of the interlayer, TiN is deposited by CVD with the reactive gas of $TiCl_4$ at 900 ^{o}C. Several coating methods such as RF magnetron sputtering, CVD, plasma assisted chemical vapor deposition(PACVD) and chemical vapor infiltration(CVI) have been used to produce the interlayers of SiC in this work.

After the fabrication of the samples, general inspection and material analysis are done immediately. Thermal cycling tests with 11 cycles at 700 ^{o}C are performed for preliminary investigation. Then plasma exposure tests with steady state and transient heat loads under a particle flux of $2x10^{24}$ m^{-2} s^{-1} are also carried out. The results show that only the structures with a TiN interlayer are good after the thermal cycle tests and plasma exposure tests. The fabrication technique of SiC need to be improved or additional coating layer could be required.

MODELING OF THE PLASMA WITH TUNGSTEN DIVERTOR INTERACTIONSON EAST

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Tungsten (W) and Carbon (C) areusedas the plasma-facing materials for upper and lower divertors on EAST, respectively. The C impurities are mainly from the lower divertor. In this work,the transport of the C impurity and its effects on the divertor plasma and W divertor erosion are simulated under the lower-single null (LSN) configuration on EAST [1]. It is found that the existence of Cimpurity can reduce T_e and heat flux to the target significantly, no remarkable upper W divertor sputtering is found due to small amount of C can transport from lower divertor to upper divertor.

The edge plasma simulation is coupled to the new developed fuel retention code HIIPC [2] to assess the fuel retention in tungsten divertor, which is a critical safety issue for the future fusion device. EAST USN discharge is chosen to illustrate the application of the coupled code, and to predict the fuel retention during realistic cycle of plasma discharges from attached to detached divertor regime [3]. The simulation results confirm that the divertor operation regime has great impact on the fuel retention.

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IN SITU LASER-INDUCED BREAKDOWN SPECTROSCOPY (LIBS) STUDY ON PLASMA-WALL INTERACTION IN EAST TOKAMAK

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Plasma-wall interaction (PWI) research is an active field for long-pulse operation in current magnetic confinement nuclear fusion devices, such as Experimental Advanced Superconducting Tokamak (EAST). It is an urgent requirement to investigate several key PWI issues, such as the fuel retention and deposition on plasma facing components (PFCs), by *in situ* diagnostic methods, such as laser-induced breakdown spectroscopy (LIBS).

In this work, the Mo first wall in EAST with ITER-like magnetic field configuration is investigated by LIBS method for the PWI research. The D fuel retention on the Mo first wall has been monitored during long-pulse operation scenarios of EAST by an *in situ* LIBS system. Simultaneously, the local edge D plasma conditions have been measured from the edge plasma optical emission spectroscopy (OES). Both LIBS and OES results are quantitatively analysed by using the absolute calibration method. The results show that the LIBS D_α intensity on the Mo first wall strongly related to the OES D_α intensity from the region of scrape off layer and edge plasma. The edge D particle fluence of ~10^{24} D/m^2 and D retention amount of ~10^{19} D/m^2 on the first wall are achieved in long-pulse discharges with duration time of tens of seconds. The results would improve the understanding of fuel retention on the first wall in EAST and demonstrate the prospect of LIBS approach to *in situ* investigate fuel retention in the upcoming fusion device like ITER.

DISCHARGE AND DEPOSITION OF NOVEL BIPOLAR HIGH POWER IMPULSE MAGNETRON SPUTTERING

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A novel power supply for bipolar pulse high power impulse magnetron sputtering has been developed. The power supply may run in conventional high power impulse magnetron sputtering (HiPIMS), bipolar pulse high power impulse magnetron sputtering (BP-HiPIMS) and mutiple bipolar pulse high power impulse magnetron sputtering (DBP-HiPIMS). In the BP-HiPIMS or DBP-HiPIMS mode, a positive pulse is applied right after the negative pulse. This will induce the new dynamics of ions/plasmas and substarte curent. As an example, the discharge characteristics of Cr target in Ar atmosphere in both BP-HiPIMS and novel DBP-HiPIMS mode were studied. The results showed that the average ion current flowing through the substrate was significantly enhanced with the increase of the reverse pulse voltage. Compared with the conventional BP-HiPIMS mode, the DBP-HiPIMS mode led to higher average substarte current at different reverse pulse voltages. When the reverse pulse voltage was 100V, the average substarte currengt in DBP-HiPIMS mode was 30-50% higher than that of conventional BP-HiPIMS mode depending the bias applied to the sample.The films including CrN, TiN, Cr, etc have been deposited to demonstarte the advantage of the novel BP-HiPIMS mode.

THE MODULATION STRATEGY OF ATMOSPHERIC PRESSURE DIELECTRIC BARRIER DISCHARGE BY TAILORED VOLTAGE WAVEFORMS EXCITATION

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In comparison with various configurations in generating non-equilibrium cold atmospheric plasmas, dielectric barrier discharges (DBDs) have shown unique features with higher plasma densities, lower gas temperatures, higher production rate of reactive chemical species, and more effective restriction on discharge currents to obtain stable discharges. Therefore, DBDs of different configurations are widely studied in various aspects. The effective independent tuning of key plasma parameters is quite important for both application-focused and fundamental studies. In this paper, the modulation strategy basing on the tailored voltage waveforms excitation is proposed to optimize the plasma parameters in DBD system. The driving voltage waveform is composed by a radio frequency fundamental wave and superimposing some odd harmonics, and the effects of the number of harmonics, phase shift as well as the fluctuation of harmonics on the sheath dynamics, impact ionization of electrons and key plasma parameters are investigated. The results have shown that the electron density can exhibit a substantial increase due to the effective electron heating by a spatial-asymmetric sheath structure. And the strategic modulation of harmonics number and phase shift is capable to raise the electron density significantly but without a significant increase in gas temperature. Moreover, by tailoring the fluctuation of harmonics with steeper slope, a more profound efficiency in electron impact ionization can be achieved, and thus enhancing the electron density effectively. It has been demonstrated that the modulation strategy via tailored voltage waveforms can provide a valid approach to independent control over both electron density and gas temperature in atmospheric DBD system.

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EFFECT OF AUXILIARY ENHANCED MAGNETIC FIELD ON MICROSTRUCTURE AND MECHANICAL BEHAVIORS OF MULTILAYERED CrN/AlCrN COATINGS

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CrN/AlCrN nano-multilayer films can combine the advantages of CrN and AlCrN coatings through film structure modulation using multi-arc ion plating technique. Auxiliary enhanced magnetic field may improve arc spots velocity and be beneficial to flexible struction modulation.

An Inductance coil is installed behind the CrAl target in order to further enhancing the magnetic field, then CrN/AlCrN nano-multilayer films are deposited onto M2 high speed steel and 304 stainless steel specimens by the magnetic enhanced multi-arc ion plating technique. The morphology and crystalline structure of the as-deposited films are analyzed and the effect of magnetic intensity on adhesive strength, wear resistance, hardness and corrosion resistance of the films are also studied with different coil current.

The results show that the large particles of the films surface decrease obviously compared with that without magnetic field enhancement. The films are crystallized into a rocksalt-type cubic structure, and exhibit (111) and (311) preferred orientation. Meanwhile increase of the coil current can improve the compactness of the films. With the coil current increasing from 0.3A to 1.2A, both micro-hardness and corrosion resistance increase because of much denser microstructure, however both adhesive strength and wear width increase first and then decrease due to high film stress induced by excessive ion bombardment.

PULSED ELECTRON BEAM IRRADIATION FOR AGRICULTURAL APPLICATIONS

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The report analyses factors of electron beam irradiation in the topic of agricultural applications. We discuss the dependence of biological effects, like disinfection, disinfection and germination characteristics from electron beam parameters: dose exposition (continuous and pulsed), electron kinetic energy spectrum, depth profile of the absorbed dose and power factor. The work describes the results of empirical experiments [1] with microorganisms, insects and wheat grain proceeded by pulsed electron beam and X-ray (150-300 keV) with the dose up dozens kGy. The Astra-M repetitive source of pulsed electron beams was used for irradiation [2].

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RF MARNETRON GLANCING ANGLE DEPOSITION OF THIN CALCIUM PHOSPHAPTE COATINGS ON TITANIUM FOR MEDICAL APPLICATIONS

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Calcium phosphate (CaP) coatings are the widely researched trend which has resulted in set of applications in the field of bone regeneration. It is due to the fact that the metallic implants become encapsulated by fibrous tissue, which in turn not only prolongs the healing time, but also leads to implant loosening and eventually premature failure of implantation. Physical vapor deposition (PVD) of thin films, allowing the deposition of porous and/or columnar-like structured coatings, has been available for some years. In turn, the use of an oblique angle geometrical configuration, or as it is also referred as glancing angle deposition (GLAD) method, is frequently exploited for formation of three-dimensional columnar micro- or nanostructured surfaces. An emerging method for bioactive coating deposition in the field of PVD is radiofrequency (RF) magnetron sputtering method.

We show the influence of GLAD geometry on the morphology and structure of thin calcium phosphate films deposited by RF magnetron sputtering method. The method allows us to manipulate the coating roughness on the submicron and nanoscale levels. A significant change in the coating morphology was revealed when the substrate tilt angle was set to 80º. It was shown that an increase in the coating crystallinity for samples deposited at a tilt angle of 80º corresponded to formation of crystallites in the bulk structure of the thin film. Cross section SEM revealed inner structure of deposited coatings and predominant growth towards the particle flux was easily detectable. The GLAD of complex calcium phosphate material can lead to the growth of thin films with significantly changed morphological features and can be utilized to create self-organized nanostructures on various types of surfaces.

THE TRANSPORT BEHAVIOUR STUDY OF OH RADICALS BY LIF IN ATMOSPHERIC PRESSURE SURFACE MICRO-DISCHARGE

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Surface micro-discharge (SMD), one type of cold atmospheric pressure plasmas (CAPs), promises a bright future for numerous applications spanning the fields of aerospace, environmental protection and biomedicine due to its desirable features. Significantly, the reactive chemical species are key enablers and responsible for the biomedical effects. Of all the CAP sources under investigation, the SMD array configuration offers a large area discharge with a considerable discharge volume, enhances the plasma uniformity and provides an alternative to atmospheric pressure plasma array technologies

This work presents the transport behaviour investigation of OH radicals in an atmospheric pressure pulse-modulated surface micro-discharge in helium. Laser-induced fluorescence is employed to measure the time development of OH radicals density distribution during the pulse duration and the inter-pulse period. It is shown that convection caused by electrohydrodynamic force enhances and dominates the transport of OH radicals from the surface plasma layer to the afterglow region with a distance up to 8 mm away from the dielectric surface. Interestingly, after the plasma switches off, OH density decreases quickly near the electrode but the downstream distribution region keeps constant, showing that the impact of convection is still present during the post-discharge. Additionally, the propagation velocity of OH declines monotonously with time. The maximum value is estimated as 1.86 m/s during the first 1 ms when the plasma is on. The influence of power delivered to plasma is investigated, and the results indicate that the OH density everywhere in the detection zone is directly proportional to the applied power. However, the input power has no significant influence on the propagation velocity and delivery distance, suggesting that it is unrealistic to increase the delivery distance of reactive species by increasing the power delivered to plasma.

EVALUATION OF DISCHARGE BEHAVIOR AND SURFACE PROPERTIES OF TA-C FILMS BY MODIFIED VACUUM ARC EVAPORATION

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Ta-C film was a wear-resistance yet super-hard coating with excellent comprehensive performance. The conventional deposition method (conventional vacuum arc evaporation (CVAE)) produced less carbon ions in the plasma during the deposition process. The properties of the films were unregulated. The modified vacuum arc evaporation (MVAE) was mentioned as the highly energetic process and the microstructure should be regulated flexibly.

Aseries of ta-C films were performed by MVAE.The influence of pulse currents, ranging from 200 A to 1000 A, on the arc discharge and surface properties of the ta-C coatings was investigated. The increment of the pulse current resulted in the increase of the substrate current from 0.47 to 1.09, indicating increased plasma density near the substrate region. Similarly, the highest of C^+/Ar^+ (1.57) was measured at the pulse current of 1000 A. Nevertheless, the lower ratios (I_D/I_G) were achieved at the pulse currents of 500A than 1000 A, indicating higher concentration of sp^3 bonds. According to the ion peening model, excessive energy provided by the increased carbon ions might migrate into the ta-C coatings and resulted in graphitization of the coatings. With respected to the hardness and mechanical properties, a proper modification by pulse current should be taken. To overcome the disadvantage of the low adhesion quality, a graded transition layer was provided. All coatings exhibited the adhesion of HF 1.

APPLICATION PROSPECT OF COMPRESSED PLASMA FLOWS IN ELMS-LIKE TRANSIENT HEAT FLUX TESTING

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Various intense pulsed particle beam generators are used to test and to study responses of plasma facing materials (PFMs) in TOKAMAK to transient high heat flux (HHF) induced by edge-localized-modes (ELMs). The parameters of pulse plasma beam (QSPA-T) and intense pulse electron beam (JUDITH II) are recognized as the closest to the parameters of ELMs. For the plasma pulse parameters of CPFs (compression plasma flows) are similar to the ones of ELMs, it may be used to study the ELMs induced transient heat damage on PFMs experimentally.

To estimate the feasibility, thermal shock tests were performed with CPFs and intense pulse electron beam (IPEB) on pure tungsten at different energy density and different pulses. Two kinds of cracks were observed: primary cracks caused by the brittleness of the W and thermal stress from temperature gradient under both two beams, and secondary cracks caused by thermal stress from resolidification under CPFs, and by irreversible plastic deformation or thermal fatigue under repeated pulses under IPEB. Grain growth was observed in samples undergoing IPEB irradiation, but CPFs. As in case of QSPA-T irradiation, many kinds of melting damages were observed on the samples undergoing CPFs bombadment, including molten flow traces on the surface and formation of columnar crystal grain in resolidification region. The ablation damages including droplet ejection and mass loss also were observed after irradiation of CPFs. Therefore, CPFs is suitable for studying melting and ablation behavior and cracking behavior after melting under Type I ELMs-like transient heat flux loading. However, it is difficult to obtain the accurate energy deposition on the target due to ablation and vaporization. To find a proper approach of getting accurate pulse energy deposition is the premise of utilizing CPFs for PFM testing.

SOME ISSUES OF THE DEVELOPMENT OF ELECTRON-BEAM AND ION-PLASMA EQUIPMENT FOR PRACTICAL USE

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The report presents the recent results of the development and upgrade of a number of original electron-beam and ion-plasma equipment. It reflect the current trends in the development of equipment for beam and plasma technologies and that may be of interest for the formation of joint Chinese-Russian-Belarusian scientific and technical programs with the ultimate goal of use in real industrial production. The technological equipment presented in the report includes:

- plasma generators and sources of boron ion beams based on a planar magnetron discharge in the self-sputtering mode of operation, as well as on the basis of a vacuum arc discharge. Possible areas of practical use: hardening of structural materials, doping of semiconductors;
- source of pulsed beams of deuterium ions on the basis of a vacuum arc with a gas-saturated cathode. Possible areas of practical use: neutron generators for various industrial technologies;
- forevacuum plasma cathode electron sources on the basis of a discharge with a hollow cathode and on the basis of a cathode arc. Possible areas of practical use: electron beam heating, melting, brazing, welding, surface hardening, sintering powders of dielectric materials.

For each of the presented equipment, a description of the principle of operation is given, the parameters and characteristics of the devices are presented, and some examples of their successful use are demonstrated.

COMPARATIVE STUDY ON SELF-ABSORPTION OF LASER-INDUCED PLASMA IN DIFFERENT ENVIRONMENTS

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The onset of self-absorption of laser-induced plasma poses a problem for converting emission line intensities to concentrations, which is one of the main bottlenecks in quantitative Laser-induced breakdown spectroscopy (LIBS) measurements. In this paper, the effects of atmosphere and laser fluence on self-absorption reduction of the plasma induced on tungsten-copper alloy target were investigated with nanosecond infrared (1064 nm) laser pulse over a range of 2.9 to 18.2 J/cm^2. The time-resolved features of self-absorption, and temperature and electron density of the plasma were characterized in atmospheric air and argon, respectively. The experimental results show the effect of self-absorption can be significantly reduced by increasing the laser pulse energy. The argon atmosphere is more helpful for self-absorption reduction [1]. The time-resolved diagnostics of emission spectra in the early stage of the plasma formation are very effective to prevent self-absorption to improve the LIBS analytical performance.

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FORMATION OF MULTICHANNEL BREAKDOWN IN ELECTRIC DISCHARGE DRILLING TECHNOLOGIES

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The report is devoted to the study of the organization breakdown of rocks which is in a liquid medium by forming discharge channels simultaneously in several interelectrode gaps for a single voltage pulse - multichannel breakdown.

We investigated the effect of electrical conductivity of the working environment, the type of rocks and inductance of the wires connecting the electrodes to the capacitors bank for the possibility of forming multichannel breakdown. According to the results of the experiments, we found out that the multichannel breakdown was carried out more likely with a greater inductance of the wires connecting the electrodes to the capacitors bank. It was also found that the volume of the broken-off material with the combined inductance of the electrodes is greater than that with a separate one.

Thus, we have shown the possibility of breakdown of sandstone and black granite in several interelectrode gaps per pulse in the environment of transformer oil and technical water.

Further experiments are being discussed to determine the degree of influence of each factor, namely: the polarity of the pulse, the energy stored in the pulse, the pulse front. Selection of the optimal parameters of the above factors can bring the technology closer to industrial scale in such areas as deep and ultra-deep drilling wells of geothermal energy and drilling in Arctic conditions.

LOW-GRADE SOLID FOSSIL FUELS ELECTROPHYSICAL CONVERSION

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The work is devoted to the study of the conversion of low-grade fossil fuels to liquid and gaseous combustible products directly at the site of occurrence. The conversion is carried out due to heating due to Joule heat in the rock. The flow of current in solid fuels is possible after the formation of a conductive channel under the action of high voltage.

The results of our studies show that it is possible to form a conductive channel at reasonable levels of high voltage (up to the first hundreds of kilovolts). Adding this method to the well-known technological processes of oil production, it is possible to achieve significant interelectrode distances (up to hundreds of meters).

As a result of the conversion, liquid and gaseous combustible products suitable for further processing are obtained. Under the most optimal conditions, the content in the gas phase of non-combustible components up to 10%, high-energy up to 25%. The liquid phase contains up to 30% of gasoline-kerosene fractions. The composition of the products and the ratio of the liquid and gaseous phases depends on the feedstock and the heating mode.

PULSED ELECTRON-ION-PLASMA IRRADIATION AS A TOOL TO REDUCE THE DEFECTIVENESS OF METAL-CERAMIC ALLOYS

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This work reports on the formation of ultrafine structure in the surface layer of a metal-ceramic composite using pulse ion-electron irradiation in plasma of inert gases and the effect of the structure modification of the surface layer of the composite on its physical and strength properties. It is found that the pulse ion-electron irradiation in inert gas plasmas forms multilayered ultrafine structure in the surface layer of the composite. The upper sublayer is characterized by the oriented nanosized columnar ceramic crystals. The intermediate sublayer has the oriented submicrocrystalline ceramic crystals. There is dendrite structure in the bottom sublayer being transition to the initial structure of the composite. The depth of the modified surface layer and the fraction of ultrafine ceramic particles in it increase with the increase of atomic mass of the inert gas and simultaneous decrease of its ionization energy. The wear resistance and bend strength rise and the friction coefficient decreases as a result of structure refining in the surface layer.

The data obtained in this work on the effect of pulsed electron-ion irradiation in inert gas plasmas on the structure of the surface layer of a metal-ceramic alloy made it possible to experimentally investigate and establish the effectiveness of irradiation as a tool to reduce the defectiveness of the metal-ceramic structure (pores, micro- and macrocracks etc.).

EXPERIMENTS OF REAL-TIME SILICONIZATION DURING DISCHARGE ON TOKAMAK

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For tokamak experiments, one of the significant issues is how to control plasma and surface interaction, reducing hydrogen recycling and other impurity level and improve plasma performance. Deposition of silicic thin films on plasma-facing components of fusion devices is considered to be one of the most advantageous methods of wall conditioning [1, 2]. Previous experiments with low-Z material injected into plasma scrape-off layer also indicate improvement on plasma performance [3, 4]. Therefore a real-time siliconization technique that injecting silicon into plasma during discharge was performed on HL-2A, to study its influence on the plasma operation performance.

In experiments, SiD_4 was employed to performed the real-time siliconzation. The gas injection point at midplane low-field-side of HL-2A was set, and piezoelectric valve was used for gas puffing control. These experiments were performed after the plasma current ramped up to plateau at ohmic mode, L-mode and H-mode, respectively. After silicon was injected, the line-averaged plasma density increased obviously. The oxygen emission intensity (OV) decreased, especially obvious drop was observed at the silicon injection moment. The H/(H+D) ratio that given by deuterium-alpha and hydrogen-alpha emission also decreased at the silicon injection moment, which indicated reduction in retention. In particular, in H-mode discharge, the Zeff decreased and reached less than 2 (Zeff(min.) is 1.72), and lasted more than 40ms.

Real-time SiD4 injection during plasma discharge plateau phase has been implemented, and a higher plasma performance was obtained. The important findings are that the impurity fluxes was reduced as well as the hydrogen retention, and the plasma-surface interaction was effectively controlled.

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EFFECT OF NEUTRAL GAS TEMPERATURE ON DISCHARGE CHARACTERISTICS IN LOW PRESSURE RF ARGON GLOW DISCHARGES

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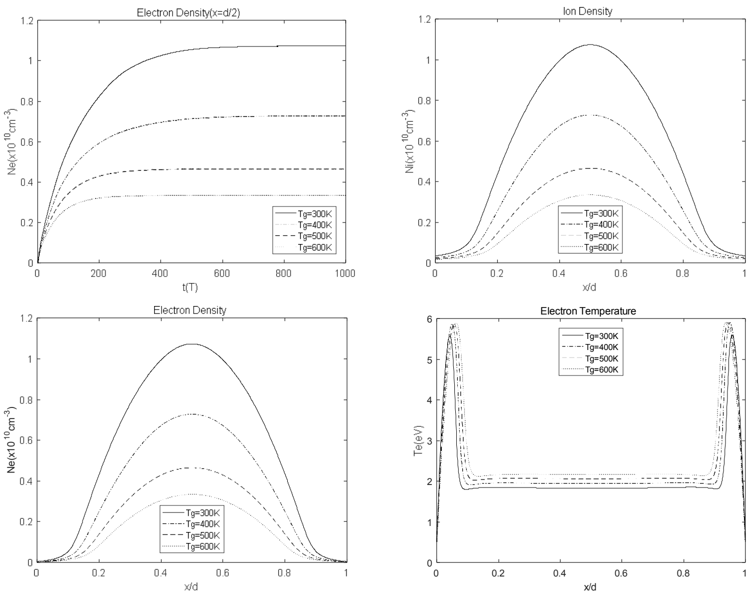
A one-dimensional fluid model is employed for investigating the discharge characteristics in low pressure RF argon glow discharge. The model includes the continuity equations of the electrons and the ions, the energy equation of the electrons and the Poisson equation for the electric field. In the model, the drift-diffusion approximation is adopted. The boundary conditions include the secondary electron emission. The model is solved numerically by means of a finite difference method and the numerical results are obtained for the neutral gas temperature 300, 400, 500 and 600K, respectively. From analysis of the results, the effect of the neutral gas temperature on the discharge characteristics is studied.



NUMERICAL STUDY OF TUNGSTEN PLASMA EMISSION SPECTRA FROM THE LOW CHARGE STATE IN THE LASER ABLATION PLASMA

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Laser-Induced Breakdown Spectroscopy (LIBS) has been considered as a crucial tool for element analysis in plasma wall interaction (PWI) of fusion devices. In this work, a one-dimensional gas-dynamic numerical model has been optimized to simulate the spectral lines of W and W+ ranging from 180 nm to 450 nm. The numerical results show that the intensity of spectral lines of W is strongerthanthat of W+ during the time from 10 ns to 160 ns. The plasma bremsstrahlung emission (continuous background) dominated in the early time of laser ablation but exponentially decreases from 10 ns to 160 ns.The relationship between plasma temperature and bremsstrahlung emission is found.In addition, plasma shielding is considered in this model. The numerical results indicate that the plasma shielding effect can be affected by the duration of the laser pulse in the same laser irradiance. What's more, the temporal information in plasma center is calculated, such as the electron temperature, the density of W+ and W2+. The ratio of W^+ and W_2^+ in plasma center varies with the laser irradiances. We hope these would provide a good guidance for optimizing LIBS application for PWI diagnosis of fusion devices

DEVELOPMENT OF TECHNOLOGY FOR THE OXIDATIVE DESTRUCTION OF HORMONAL AND HARDLY OXIDIZABLE ORGANIC COMPOUNDS

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One of the serious environmental problems is the increase in the content of various hormonal and hardly oxidizable organic compounds in underground and surface waters. The number of reports of the negative impact of such compounds on hydrobionts and their environment increases. Some hormonal and hardly oxidizable organic compounds can move directly through water or along trophic chains to birds, mammals and humans. At the same time, the biological decomposition of hormonal and hardly oxidizable organic compounds is hindered by their toxicity with respect to microorganisms [1].

This paper presents the possibility of implementing a technology for the oxidative destruction of hormonal and hardly oxidizable organic compounds. The technology is based on the use of pulsed electron beam effects on an aqueous solution in combination with modern sorption, ion-exchange and biological purification methods.

Currently, a mobile complex for household wastewater treatment based on the Astra-M pulsed electron accelerator [2] with a capacity of up to 1 m^3/hour [3]. The complex is undergoing pilot operation at the facility of the largest gas company in Russia.

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RADIATION TECHNOLOGY FOR BIO WASTE TREATMENT

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A cost-effective method has been developed to obtain environmentally friendly protein feed additives based on oyster mushroom mycelium using radiation-microbiological pretreatment of the substrate (wood and plant waste). A pulsed electron beam provides sterilization and partial destruction of biological material. It excludes the development of extraneous microflora in the substrate, including mold fungi, and, therefore, provides a high yield of fruiting bodies.

The possibility of creating a mini-factory using this method based on a pulsed electron accelerator was also considered.

MINI-PLANT FOR DESTRUCTION OF REINFORCED CONCRETE WASTES

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The idea is to create a mini-plant for environmentally friendly, waste-free, industrial processing of non-conforming or used reinforced concrete structures (wastes) into recyclable building materials (intact reinforcement of Class A-IV, A-V and crushed stone fractions 5-20, 10-40, 20-40, 40-100 mm) for the purpose of their further use in construction or sale. It includes production of reinforced concrete elements by using these components and waste water with fine concrete dust. This dust is the byproduct of the reinforced concrete destruction process (Fig 1).

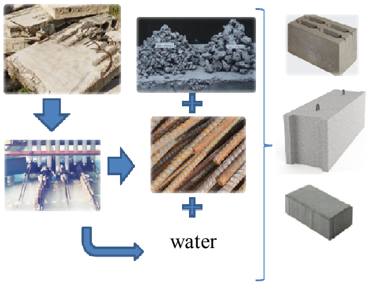

Fig 1 - Scheme of waste reinforced concrete processing

Reinforced concrete wastes and non-conforming products are fed to an electrical discharge destruction plant, at the output of which one can obtain cleaned reinforcement, concrete rubble and water with finely dispersed concrete dust. Concrete rubble after additional mechanical crushing is dispersed into the necessary fractions. The resulting materials can be sold as commercial products or reused for the production of less critical concrete and reinforced concrete products [1], such as paving slabs or foundation and wall blocks for low-rise building.

We estimated the equipment capacity from 4 to 16 m^3 per work shift (8 hours) recycled reinforced concrete wastes, depending on the blocks and reinforcement configuration. One can get from 12 to 44 tons of new concrete market products from recycled materials. For example, basement blocks with a total weight of up to 39 tons can be made using only concrete rubble.

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EQUIPMENT AND TECHNOLOGIES FOR COATING METALS BY ELECTRON-BEAM SURFACING IN VACUUM AND GAS WITH ATMOSPHERIC PRESSURE

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A common method of protecting or restoring metal parts that were subject to mechanical, thermal, or chemical attack is electron-beam surfacing (EBS). This paper presents a description of developments in the field of EBS. The characteristics of the electron-beam equipment and some of the surfacing technologies are described. Plasma-cathode guns that do not contain hot electrodes are used. This makes them less sensitive to chemically active and refractory vapors of the materials being processed. Two groups of equipment for EBSare presented: for surfacing in vacuum conditions and at atmospheric gas pressure [2]. Equipment for EBSin vacuum is based on guns with electron beam energy up to 50 keV. A description of the installation and technology ofvacuum coating onto the metal industryproducts - air blast furnace tuyeres, crystallizers.

Surfacing at atmospheric pressure was carried out by a focused beam with an electron energy of 150 kVejected into the atmosphere. Coatings containing carbides of refractory metals were deposited. The coatings had a crystalline structure, their thickness was 120–200 μm, the microhardness averaged 12 GPa. The coatings and the transition layer were heat resistant up to 900 °C.

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MODIFYING OF THE EUTECTIC SILUMIN SURFACE BY THE ELECTRON-ION-PLASMA METHOD

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The aim of the work is to develop a technique of multiple enhancement of the tribological properties of the surface layer of silumin consists in the formation of a «film (metal)/(silumin) substrate» system and subsequent irradiation of the surface with an intense pulsed electron beam. The material under study wasAK12Al-Si alloy (Al - 12%Si). Processing of siluminwas carried out on the «COMPLEX» setup. Titanium was used as the alloying element. The number of alloying cycles 1; 5 and 10. Thedeposited titanium film thickness in each processing cycle is 0.5 microns. The multi-cycle surface alloying process was carried out in a single vacuum space and consisted in the sequential implementation of the following types of material treatment: ion cleaning and heating in an argon plasma; plasma-assisted electric arc deposition of metal (titanium) film; electron-beam treatment of the «film (titanium)/(silumin) substrate» system using a low-energy intense pulsed electron beam. The formation of a multiphase submicro-nanocrystalline structure up to 50 μm thick in the surface layer is revealed as a result of the studies. The wear resistance of that exceeds the wear resistance of the sample volume by 15 times.

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BORATION OF HIGH-CHROMIUM AUSTENITIC STEEL SURFACE BY ELECTRON-ION-PLASMA METHODS

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The comprehensive surface modification of high-chromium stainless steel 12Cr18Ni10Ti, combining electroexplosive alloying with titanium and boron and subsequent irradiation with an intense pulsed electron beam was carried out. The formation of a multiphase submicro-nanocrystalline surface layer with a thickness of up to 70 µm was revealed. It is shown that the boron concentration in the surface layer changes non-monotonously, reaching a maximum value (≈ 19 at.%) at a distance of (10-15) µm from the alloying surface. It has been established that the hardness and wear resistance of the modified steel layer exceeds the hardness of the initial state by 7 times, wear resistance – by more than 9 times.

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MICROBIAL INACTIVATION IN MODEL TISSUES TREATED BY SURFACE DISCHARGE PLASMA

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Microbial cells in chronic wounds seriously delay wound healing and thus the inactivation of microbial cells is a critical step in the therapeutic process. Cold atmospheric-pressure plasma (CAP) can efficiently inactivate microbial cells and could be developed into an effective strategy for topical antimicrobial treatment. However, the details of microbial inactivation in tissues by CAP, including the effective depth of the plasma and the variation of the microbial species, are still unclear. Therefore, in this study, agarose gels containing microbial cells were used as a model of infected tissues and were treated with surface discharge plasma with the working gas of argon and 1% air. It was found that the depths of microbial inactivation were proportional to the plasma treatment time and were also related to the microbial species. The ROS penetration was dependent on the plasma treatment time, the diffusion process, and the existence of microbial cells. The plasma-generated ROS caused microbial cells to release ROS, which slightly increased the ROS penetration depths. This study of microbial inactivation by plasma in model tissues could increase the mechanism of plasma inactivation and as a treatment in the biomedical field.

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STUDY ON ANODE PLASMA SPECTRA WITH STRONG CURRENT HIGH-ENERGY ELECTRON BEAM

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This paper studies on anode plasma spectra with strong current electron beam. The results show that comparing with cathode spectrum, there is a vast spectrum of elements from anode materials.The reasons are thatstrong current high-energy electron beamtransform kinetic energy into thermal energy on the surface of the material, which makes the surface of the material high temperature. Then the material vaporiazes to produce gaseous particles, which are ionized into large amounts of plasma. Finally, these plasma emit intense spectra. Furthermore, the material loss of stainless steel as anode material is much higher than that of Ti. It is expected that the spectral intensity of stainless steel (Fe,Cr) is much higher than that of Ti, whichis confirmedby experiment. In addition, there are a lot of other elements in the spectrum, mostly H,C2, Na. It is believed that these spectra come from gas ionization absorbed on the anode surface. Experiments show that these spectral intensities do not decrease significantly with increasing sophistication at one work per minute.Therefore, these gases are likelyto be supplemented by the gases in the vacuum and the absorbed gases within the material.The work will be helpful to study and inhibit anode plasma.

STUDIED THE EFFECT OF PLASMA ON HIGH POWER MICROWAVE TRANSMISSION CHANNEL IN KU BAND

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Ku band HPM (High Power Microwave) is transmitted by circular waveguides with clamped type quick release flanges linking between them in our laboratory. Both theoretical simulations and experiments show that plasma is produced at the flange juction, which absorbs HPM, and increases the loss of the HPM transmission channel. In our theoretical simulation, it is found that plasma at the flange can be significantly reduced and the transmission channel loss can be effectively reduced by changing the clamped type quick release flange into the choke groove flange. In the experiment, the integral power of HPM radiation field is improved obviously with choke groove flange waveguides transmission.

中白航天高新技术产业研发中心有限公司

China-Belarus Aerospace Hi-tech Industry R&D Center Co.,Ltd

中白航天高新技术产业研发中心有限公司

Китайско-Белорусский высокотехнологичный аэрокосмический центр исследований и разработок

中白航天高新技术产业研发中心有限公司是由中国航天科技集团有限公司和陕西省人民政府支持，西安航天科技工业有限公司联合所属五所一厂发起，区域20余家先进企业和科研机构共同携手，依托航天优势技术，聚集国家高端人才，以技术创新、产业引领、商业运营为导向，立足中白工业园，瞄准一带一路高新技术产业示范工程，服务白俄罗斯和欧亚经济体国家高科技、高新技术及其产业发展，而注册组建的国际创新机构和实体公司。

Китайско-Белорусский высокотехнологичный аэрокосмический центр исследований и разработок был основан Китайской аэрокосмической научно-технической корпорацией при поддержке Народного правительства провинции Шэньси, Сианьской аэрокосмической научно-технологической промышленной компании, созданной по инициативе пяти институтов и одного завода. Более 20 региональных передовых предприятий и научно-исследовательских учреждений работают вместе, используя аэрокосмические технологии, привлекая высококлассных национальных специалистов, руководствуясь технологическими инновациями и придерживаясь лидерских позиций в своей отрасли. Мы вносим свой вклад в реализацию демонстрационного и высокотехнологичного проекта на базе промышленного парка «Великий камень», обслуживание высоких технологий в экономике Беларуси и Евразии, развитие высоких технологий и промышленности, а также создание международных инновационных институтов и организаций.

中白航天高新技术产业研发中心有限公司，依托中国航天科技集团有限公司西安航天科技工业有限公司在深空探测、载人航天、探月工程、北斗导航等国家重大科技专项研制中形成的百余项世界级先进航天应用产业产品与技术成果，以及国家国防科技重点实验室、航天特种增材制造中心、国家泵阀技术中心、先进制造技术中心以及氢能工程技术中心等国家级平台，在节能环保工程、能源动力工程、高端装备、新能源与新材料应用四个产业化领域，拥有专利2000余项，产品覆盖全球50多个国家，年销售收入超过30亿美元。

Компания ООО «Китайско-Белорусский высокотехнологичный аэрокосмический центр исследований и разработок», опираясь на Китайскую аэрокосмическую научно-техническую корпорацию и Сианьскую аэрокосмическую научно-техническую промышленную компанию в области освоения дальнего космоса, пилотируемую космонавтику, лунную программу, «Бэйдоу» навигацию и др., имеет более 100 передовых продуктов и технологических достижений мирового класса для аэрокосмической промышленности в области развития национальной науки и техники. Наши ключевые национальные платформы, такие, как Национальная научно-техническая лаборатория в области обороны, Центр аэрокосмического производства специальных материалов, Национальный центр технологий производства насосов и клапанов, Центр передовых технологий производства и Центр водородных технологий, проекты по энергосбережению и защите окружающей среды, энергетике, высококачественного оборудования, новой энергии и новых материалов, применяемых в четырех отраслях промышленности, с более чем 2000 патентов, охватывают не менее 50 стран и имеют годовой доход от продаж, превышающий 3 миллиарда долларов США.

今天，立足中白工业园的中白航天高新技术产业研发中心有限公司，依托航天科技集团各研究院，携手西安国家航天民用产业基地、中船集团、宝光集团、国家开发银行等金融、高校、科研院所及优势企业。联合白俄罗斯科学院、乌克兰南方设计局、乌克兰科学院、哈萨克斯坦科学院俄罗斯科尔德什中心等世界一流产学研机构。聚集全球智慧，开展多领域科技研发与创新探索。

Сегодня Китайско-Белорусский высокотехнологичный аэрокосмический центр исследований и разработок, опираясь на научно-исследовательские институты Аэрокосмической научно-технической группы, работает совместно с Сианьской национальной базой аэрокосмической и гражданской промышленности, Китайской судостроительной группой, Baoguang Group, Китайским банком развития и другими финансовыми учреждениями, университетами, исследовательскими институтами и отраслевыми предприятиями. Наш центр объединит свои усилия с Национальной академией Наук Беларуси, конструкторским бюро «Южное» им. М.К. Янгеля, Академией наук Украины, Национальной академией наук Казахстана и исследовательским центром имени М. В. Келдыша. Наш центр соберет знания всего мира и осуществит проведение научно-исследовательских и инновационных исследований в различных областях.

节能环保领域，为石油化工、电力、冶金、城市固废危废处理等行业提供完善的技术解决方案.在热能工程领域研究加热炉、焚烧炉、高效节能燃烧系统等方案和产品.氢能工程领域，开展低成本制氢、氢燃料电池、加氢站方案等核心技术与产品研发.推进氢能产品在白俄罗斯和欧亚经济体国家的示范应用.增材制造领域，开展标准化、体系化的技术与核心设备研发,并将其推广应用于白俄罗斯及周边国家制造企业.

В области энергосбережения и защиты окружающей среды мы представим комплексные технические решения, необходимые для нефтехимической, электроэнергетической, металлургической промышленности, сферы переработки твердых бытовых отходов и других отраслей. В области теплоэнергетических объектов исследуем нагревательные и мусоросжигательные функции печей, высокоэффективные энергосберегающие системы сжигания и другие аналогичные процессы. В области водородной энергетики мы намерены разрабатывать такие технологии, как производство недорогого водорода, водородных топливных элементов и схем заправки водородом. Все это поможет реализации демонстрации применения водородных энергетических продуктов в экономике Беларуси и Евразии. Мы будем проводить исследования и разработки в области аддитивного производства, стандартизированных и систематических технологий основного оборудования, продвигать их на производственных предприятиях Республики Беларусь и соседних стран.