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SCIENTIFIC INNOVATIONS CATALOGUE

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Penza State University

One of the most important goals of the university's development is its internationalization, which implies the university's entrance into the international educational and scientific space. The university has a great potential in the field of international partnership, which is due to the sufficient number of available contacts and concluded agreements.

Our partners abroad are higher education institutions and research centers, scientific foundations of foreign countries, executive authorities, centers that give qualification examinations and issue internationally recognized certificates, and organize an expertise of training courses and programs.

Training specialists for foreign countries – the export of educational services – occupies the central place in the international activity. Currently, the university has more than 1,500 students from 47 countries.

In recent years, the university students and teachers have been actively participating in academic exchange programs with foreign countries, including the Erasmus+ foreign grants programs. One-semester training and scientific internships for students and scholars from foreign countries also take place in our university.

The university actively participates in programs funded by foreign funds. Penza State University is a part of 3 scientific consortia that carry out scientific research within the framework of the Erasmus+ programs: Capacity Building in the field of higher education and Strategic Partnerships – HARMONY, SATE, and PROTEUS.

This catalogue presents some promising scientific innovations of leading scientists from Penza State University. We are open for cooperation and will be happy to establish new scientific relations for the implementation of joint scientific projects.

Rector of Penza State University

Aleksandr Gulyakov

Development of methods, devices and systems for the assessment of biological objects' state

PROJECT LEADER:

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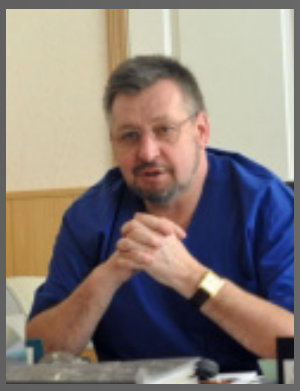


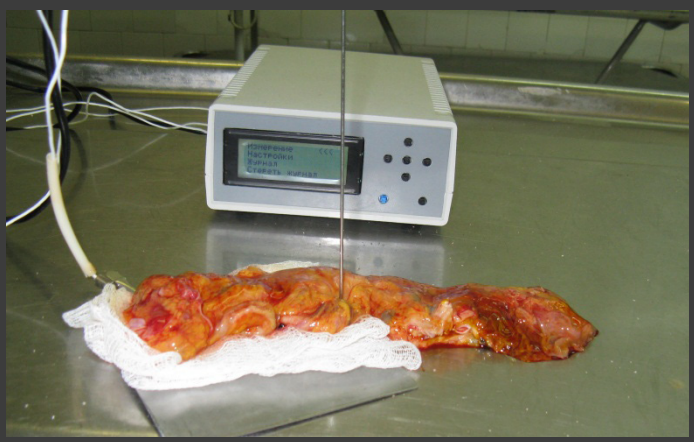
The project is aimed at the creation of a number of devices and systems for rapid diagnostics of biological objects using a fundamentally new method of joulemetrics.

At present, the electrochemical research methods are used to describe the properties of tissues. Formation of pathology in tissues and organs causes the change of their electrochemical properties. Biological objects, from the point of view of research electrochemical methods are quite complex systems. They usually are non-stationary, nonlinear, have a response to external stimuli, and hysteresis. Speaking on the use of conventional electrochemical research methods in relation to the task, one may note the following disadvantages associated with the restriction of their use:

- the complexity and duration of the research organization;
- a limited number of characteristics describing the object state;
- poor results' reproducibility from experiment to experiment.

In this regard, to solve this task it is offered to use the method of joulemetrics developed at Penza State University. A quantitative assessment of the state of organs and tissues is made in the form of work done by the external energy source to transfer the object from one state to another. Physically, this parameter is determined by time integration of the switching current product to the value of the electrode potential. From the point of view of the electrochemical properties, the method of joulemetrics is an index reflecting the conductivity, capacitive and diffusion properties of tissues.

The characteristics of the electrochemical processes with abdominal abscesses are experimentally studied at present. The joulemeter research of pancreas is conducted. It is established that the method allows quantifying the dynamics of pyonecrotic process. The connection between the joulemeter parameters and



Evaluation of tissue joulemetric values in pancreatonecrosis

Evaluation of inflammatory process activity by the drainage discharge

Development and research of tissue-preserving methods for electrochemical lysis of malignancies

microscopic changes in tissues is established. The joulemeter research is also conducted in the periodontal disease diagnosis. It is established that the method allows authentically revealing the presence of biochemical and bioelectrical changes in periodontal tissues caused by inflammatory processes.

The method is simple to implement, does not require a significant time-consuming, that allows to realize systems operating in real-time.

The instrument is urgently needed in the surgical wards in the treatment of patients with intracavitary inflammatory processes, in the ENT departments for the diagnosis of such diseases as sinusitis, pancreatic, for predicting acute suppurative lactation mastitis, etc.

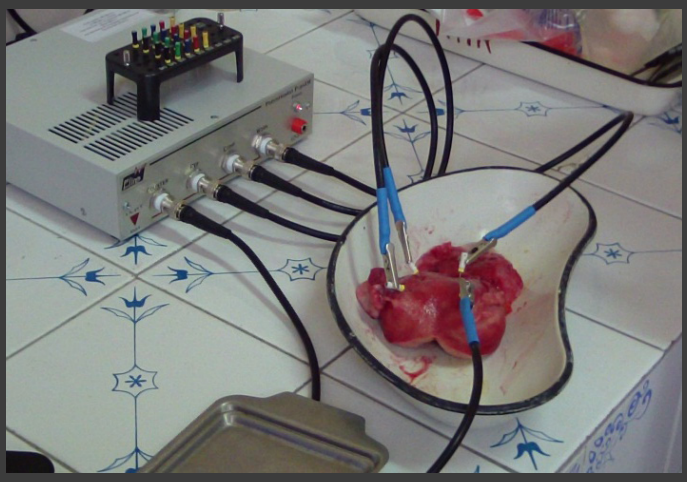
The aim of the project is the creation of the device for the electrochemical lysis of malignancies, which allows implementing tissue-preserving methods for treatment of various forms of benign and malignant tumors.

The electrochemical lysis (ECL) is quite successfully used for breast cancer treatment, at malignant tumors and metastases in the liver, benign prostate hyperplasia, cancer of the esophagus, lung, pancreas, and skin. However, nowadays, this method is not accepted in oncology due to the lack of significant pre-clinical studies and controlled clinical trials. In addition, the existing ECL method has several drawbacks, the lack of selectivity losses being the main one, resulting in damaging of a large mass of healthy tissue along with tumor tissue.

A new technique for the electrochemical lysis procedures is offered based on the use of multi-electrode system of switching currents, which allows carrying out the electoral lesion of the tumor tissue by electrical shock.

The novelty of the project is as follows. The use of bipolar current pulses (RF Patent) is proposed, which allows stabilizing and controlling the ion motion processes in the medium. The method for changing the current amplitude provides an opportunity to realize the selective isolation of entering into an electrochemical reaction substances on the electrode and their transfer, depending on the molecular weight and valence of ions. Thus, it is possible to select the exposure mode by pulse current at certain ionic bonds, thereby providing

The system package for the experimental study of electrochemical switching lysis



Carrying out the ECL procedures on distant organs

Development and research of a hydro-cuff tonometer

a selective damage of tumor tissue. A local effect on the tumor due the use of electrodes with different surface area (1:50-100 ratio) is also proposed. Thus, there is a concentration of the current density in the electrode having a smaller area, which is located in close proximity to the tumor (RF Patent). This ensures the selective effect of the electric current in the area of a malignancy.

The electric field switching is also proposed (RF Patent), in which due the use of a larger number of electrodes and their relative position, the formation of a maximum current capacity in the malignancy zone is achieved.

The proposed ECL technique is promising, and may be considered as a variant of a new method for organ-preserving treatment of various localizations of tumors.

The purpose of the project is the development and research of a hydro-cuff technique for assessing of hemodynamic parameters.

In a modern tonometer of the oscillator type the technology for obtaining oscillations is used based on the use of air to overpressure the cuff. From the viewpoint of pressure transmission, air environment is not optimal, since it's compressible. This leads to a substantial reduction of pressure pulsation amplitudes sensed by the pressure sensor, when the external pressure changes. The hydro-cuff technology for oscillation assessment is offered for the first time in the world (RF Patent).

The fluid is pumped in the cuff instead of air creating an overpressure. The cuff is made up of two chambers. The value of the difference pressure in the chambers allows fixing points for systolic and diastolic pressure values without the use of algorithmic methods for calculating them.

The experimental research results of prototypes of the hydro-cuff tonometer have shown that the estimation error of the arterial pressure does not exceed 3-5%, and can be increased by 1.2%.

Without a substantial increase in the complexity of the device, it is possible to expand its functionality by introducing the evaluation of pulse wave velocity function, which provides additional competitive advantages.

The area of using the hydro-cuff tonometer applies to household and daily monitoring of the arterial pressure, the creation of evaluation systems of the cardiovascular state.

An appearance of the hydro-cuff tonometer

A prototype of the hydro-cuff tonometer

The main research results are presented in the following scientific articles:

1. Application of the hydrocuff technology for blood pressure evaluation Gerashchenko, M.S., Gerashchenko, S.M., Gerashchenko, S.I., Yankina, N.N. International Journal of Applied Engineering Research 2016 11 (4), pp. 2271-2274

2. A study of the relationship of joule-metric settings with the inflammatory changes in periodontal tissues Ivanov, P.V., Ziulkina, L.A., Gerashchenko, S.I., Gerashchenko, S.M., Yankina, N.N. Biology and Medicine 2016 8 (2), pp. 1-4

New technologies for two-dimensional speckle tracking in patients with acute myocardial infarction based on mathematical modeling

PROJECT LEADER:

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The relevance of this work involves the development of a sufficiently precise and accessible method for non-invasive diagnosis of myocardial necrosis localization and the technology for forecasting the severity of post-infarction cardiac remodeling in patients with acute myocardial infarction with ST-segment elevation, for a considerable period of time, based on mathematical modeling.

Scientific novelty consists in the creation of a three-dimensional model for data visualization obtained using the method of ultrasound diagnostics – two-dimensional speckle tracking (two-dimensional strain, TDS), which allows to quantify the spatial and velocity strain characteristics of 16 left ventricular (LV) segments in the longitudinal, radial and circular directions, as well as the rotation of the heart. On the basis of the instrumental heart survey using the advanced technology in healthy subjects and patients with myocardial infarction, a qualitatively new technology for interpretation of post-infarction remodeling mechanisms for the topical diagnosis and individual prediction will be established.

OBJECTIVES OF THE PROJECT

1. Evaluation of diagnostic efficiency of the TDS technology at the global and segmental levels by the statistical methods using the correlation, variance and ROC-analysis. Influence determination of structural and functional state of the main arteries on the contractility of the left ventricle.

2. Three-dimensional visualization of the global left ventricular contractility based on the segmental deformation and the rotation data obtained by the TDS technology. It is supposed to build spatial models of the LV contractility in healthy persons, and in case of damage of one or more segments as a result of myocardial infarction with ST-segment elevation.

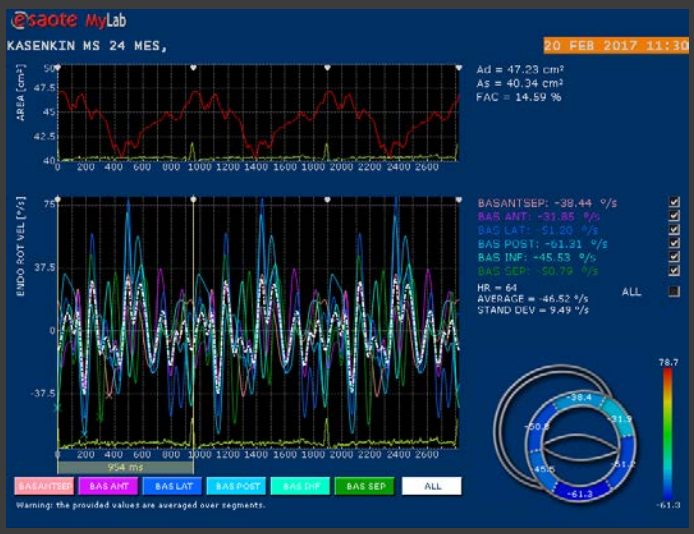
3. The study of the dynamics of myocardium deformation parameters and cardiac rotation according to the two-dimensional strain on the medical therapy background during 96 weeks of observation with intervals of 12-24 weeks of the evaluation with the purpose of the individual prognosis of post-infarction period.

4. The study of the relationship between the deformation characteristics of the left ventricle, markers of myocardial electric instability and heart failure.

EXPECTED RESULTS

As a result of the research work, the contractility database of the left ventricle in 250 healthy individuals and 200 patients with acute myocardial infarction, using the TDS technology will be formed. In the future, it is expected to conduct a long-term monitoring of patients for 96 weeks with a survey frequency of once every 12-24 weeks. Several schemes for the lipid-lowering therapy in this group will be used. Based on the spatial and temporal characteristics of myocardial deformation, a qualitatively new technology for interpretation of mechanisms of post-infarction remodeling depending on the size and location of infarction, and cardiac afterload for individual prediction will be created. In addition, a complex clinical and instrumental examination

of the cardiovascular system on each of the visits, including standard echocardiography, the study of structural and functional properties of the main arteries by radio frequency analysis, volume sphygmography, and applanation tonometry will be carried out. This is necessary for the multivariate analysis of pathological cardiac remodeling with the assessment of the impact of a long-term drug therapy. On the basis of the received database, it is planned to build a multi-dimensional regression model with the inclusion of different types of strain, rotation of the left ventricle as predictors; registration of false positive and false negative decisions in the assessment of diagnostic efficacy of the TDS technology. The method of mathematical modeling is planned to be used to solve the issue of determining the stress-strain state of the left ventricle walls as a boundary problem of mechanics using supercomputing, involving "Chebyshev" and "Lomonosov" supercomputers of the Research Computing Center at Moscow State University.



Then, a set of applications for ultrasonic devices for data visualization of the TDS technology, and assessment of severity of post-infarction remodeling will be developed. This will allow cardiologists, cardiac surgeons, doctors of ultrasound diagnosis to get an inexpensive and highly accurate method for topical diagnosis of acute myocardial infarction and subsequent prognosis of the disease in routine practice.

PURPOSE AND INTENDED USE

The assessment technology of global and local contractile function of the LV is designed to proactively identify areas of necrosis localization in patients with acute myocardial infarction, as well as for forecasting future character of post-infarction remodeling. This will quantify the violation of local contractility of the left ventricle, and their implications for global contractile function. The new technology for the efficient interpretation of spatial and temporal characteristics of myocardial strain is to be used by cardiologists, cardiac surgeons, and doctors of ultrasonic diagnostics in medical practice. Active introduction of packages of applied data analysis software, obtained by the TDS technology in patients with myocardial infarction, is aimed at identifying the target group of patients for further cardiac care, and determining the volume and types of intervention.

RESULTS

Nowadays, a database on indicators of global and segmental left ventricular contractile performance by the two-dimensional strain technology has been formed, including research protocols of 92 patients with acute myocardial infarction during the observation period of 7 days-36 weeks, and 65 healthy individuals. The study demonstrated high reproducibility indices of left ventricular contractility obtained by the TDS. It is found that the value of the global longitudinal strain and circumferential velocity in patients with myocardial infarction was significantly lower than in healthy subjects. The application of the TDS technique significantly extends the capabilities of the non-invasive dynamic monitoring of abnormal left ventricular remodeling in patients with acute myocardial infarction. In patients with an effective revascularization, indices of contractile activity and the global deformation are largely higher than the values obtained with a poor angiographic result. When studying the effect of the long-term therapy with 20 and 80 mg of atorvastatin on the parameters of the two-dimensional strain, the strain rate of deterioration of the LV has not been identified. Atorvastatin in high doses can reduce the thickness of the intima-media complex of the common carotid artery at a comparable dynamics of indicators of local and regional stiffness. According to Holter ECG monitoring in patients treated with 80 mg of atorvastatin, the improvement in a number of indicators of myocardial electric instability, and heart rate variability, has been revealed.

The main research results are presented in the following scientific articles:

1. Oleinikov V.E., Galimskaya V.A., Donchenko I.A. Assessment of characteristics of myocardial deformation in healthy subjects of various age groups by the X-STRAIN echocardiography // Kardiologiia. – 2012. – **№** 2 (52). – P. 65-69.

2. Galimskaya V.A., Donchenko I.A., Romanovskaya E.M., Oleynikov V.E. The features of myocardial deformation of left ventricle in patients with ischemic heart disease defined by the two dimensional strain method // Kardiologiia. – 2014. – **№** 9 (54). – P. 11-16.

3. Oleynikov V., Galimskaya V., Romanovskaya E. Evaluation of changes of global longitudinal strain in patients with STEMI after myocardial revascularization // Atherosclerosis. – 2016. – Vol. 252. – P. e189.

4. Oleynikov V., Galimskaya V., Romanovskaya E., Avdeeva I. Assessment of efficient revascularization on dynamics of velocity parameters in patients with STEMI // Atherosclerosis. – 2016. – Vol. 252. – P. e189-e190.

5. Oleynikov V., Galimskaya V., Romanovskaya E., Tomashevskaya Y., Burko N. Radial deformation of the left ventricular myocardium in patients with STEMI with different outcomes of revascularization as a stabilizing factor of systolic function of the heart // European Journal of Heart Failure. – 2016. – 18 (suppl. 1). – P. 98.

Genetic variability of living systems as a condition for the sustainable existence of the biosphere: population factors and genetic mechanisms for maintaining intraspecies polymorphism, and structure of animal populations and communities in a highly fragmented and competitive environment.

PROJECT LEADER:

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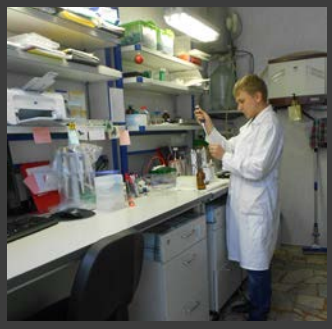
The Department of Zoology and Ecology of Penza State university conducts research aimed at solving the fundamental problem of modern biology, namely, establishing the factors and mechanisms of maintaining the genetic diversity of living systems, at the organismal and supraorganismal levels (populations, communities), as well as mechanisms for maintaining the integrity of the species. As a model of living systems to conduct the research, various types of vertebrates sensitive to the ever-changing environment in different ways are used. They are the representatives of the group of amniotes – rodents and bats (Spermophilus childbirth, Apodemus, Myodes, Sylvaemus, Microtus, Myotis and Eptesicus) and birds (Aquila childbirth, Circus, Milvus, Falco), as well as the representatives of the group of anamniotes – fish (genus Rutilus) and tailless amphibians (genus Pelophylax).



In the course of the research, the assessment of the genetic diversity of model species, the level of inter-population differentiation and possible gene flow between supraorganismal structures is carried out, the spatial and genetic structure of individual populations are described, the effect of the physical barriers on the structure of the populations and environmental barriers is determined, and the factors determining the reproductive success and the choice of resettlement policies are established. On the basis of a long-term monitoring of natural populations and the molecular genetic analysis of individuals, a metapopulation habitat structure of the area of some studied species and its role in resettlement and interspecies isolation are detected. Close and environmentally monovalent species help to identify factors of the fragmented and competitive environment, affecting the diversity of the population structure, the stability and success of the existence of single-species populations and multispecies communities, as well as the mechanisms of interspecies insulation at sympatric habitation.

The main research results are presented in the following scientific articles:

1. The Department has a solid material and technical base. Molecular genetics and microscopic laboratories with modern equipment, and vehicles used during the expeditions allow obtaining world-class scientific results.

2. Faerman M., Baral G.K., Boaretto E., Boeskorov G.G., Dokuchaev N.E., Ermakov O.A., Golenishchev F.N., Gubin S. V., Mintz E., Simonov E., Surin V.L., Titov S.V., Zanina O.G., FormozovN.A. DNA analysis of a 30,000-year old Urocitellus glacialis from northeastern Siberia reveals phylogenetic relationships between ancient and present-day arctic ground squirrels // ScientificReports. 2017. V. 7, 42639. doi:10.1038/srep42639.

3. Ermakov O.A., Levina M.A., Titov S.V., Levin B.A. mtDNA-based species identification of two widespread species of Roach (Cyprinidae, Rutilus) with extended sympatric zone// Inland Water Biology. 2017. Vol. 10. No. 1. P. 112–114. doi: 10.1134/S1995082917010060).

4. Ermakov O.A., Simonov E., Surin V.L., Titov S.V., Brandler O.V., Ivanova N.V., Borisenko A.V., 2015. Implications of hybridization, NUMTs, and overlooked diversity for DNA barcoding of Eurasian ground squirrels // PLoS ONE 10(1): e0117201.doi: 10.1371/journal.pone.0117201.

5. Titov S.V., Shmyrov A.A., Kuzmin A.A. Biotope principles of sympatry and interspecies hybridization in mammals (by the example of the genus Spermophilus) // Biology Bulletin. 2012. T. 39. № 1. C. 36-44. DOI: 10.1134/S1062359012010116.

Nanostructured semiconductor materials based on metal oxides for sensory, environmental and energy applications

PROJECT LEADER:

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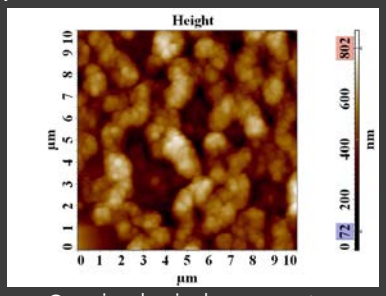
Fundamental studies of nanostructured semiconductor materials based on metal oxides is one of the most important tasks in the field of modern science materials. Thanks to unique electro-catalytic, adsorption and structural properties such oxides SnO2, ZnO, In2O3, and TiO2 now find wide application in sensors, catalysts, photocatalysts, luminophors, vacuum sensors etc.

Penza State University has been conducting research and development in the following fields:

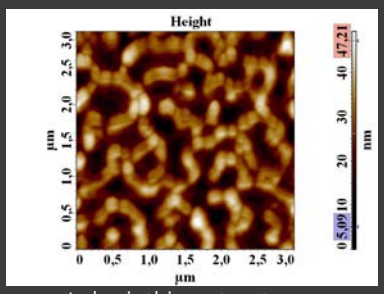
- development of nanomaterials with the percolation network structure for ultrahigh gas sensors in security systems;
- development of hierarchical nanomaterials for photocatalytic applications;
- development of multi-component oxide nanomaterials for vacuum sensors.

The first gas sensors were developed in the 50-s of the XXth century and performed either in the form of thick films of oxide semiconductors deposited on a dielectric substrate, or in the form of pressed samples of oxide powders with n-type conductivity and an internal heater. Then the sensors came created by the microelectronics technology based on thin films. The sensing elements of such sensors are polycrystalline materials. Intensive development of nanotechnology has led to the creation of highly porous gas sensors with sensing elements formed by particles of nanometer size, which manifested dimensional effects. The individual particles in the nanomaterial are combined in the aggregates, including the fractal type of spatial organization. However, the most interesting are nanostructured semiconductor materials based on metal oxides with percolation network structure, having ultra-high sensitivity to some types of gases.

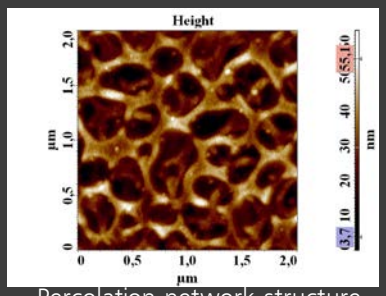
Penza State University in cooperation with Saint-Petersburg State Electrotechnical University conducts research and development aimed at the establishment of physical and chemical laws of synthesis of semiconductor nanomaterials based on metal oxides in the framework of the sol-gel technology. The nanomaterials are synthesized and studied on the basis of two- and three-component oxide systems with the structure of quasi-spherical aggregates, labyrinth and percolation network (Fig. 1).



Quasi-spherical aggregates



Labyrinthine structure

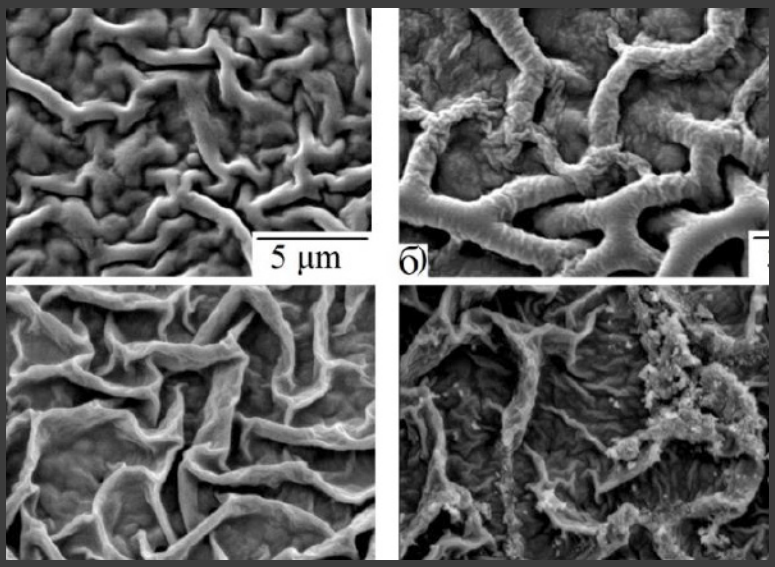


Percolation network structure

Fig. 1. AFM images of the surface morphology of nanomaterials based on tin dioxide-silicon dioxide with different kind of structure

It is shown that gas sensitivity of such nanomaterials is determined by their structure, qualitative and quantitative composition, and synthesis characteristics. Ultra-high sensitivity to ethanol vapor (touch response of 100,000 rel. units to 100 ppm of ethanol) has been demonstrated for the nanomaterials with percolation network structure corresponding to the percolation threshold.

Penza State University in cooperation with Sofia University "St. Kliment Ohridski" (Sofia, Bulgaria) has been developing gas sensors based on the thermovoltaic effect discovered in the non-uniformly doped zinc oxide. Typical images of ZnO-Me films (Me – Cu, Fe), obtained by the scanning electron microscope, are shown in Fig. 2.

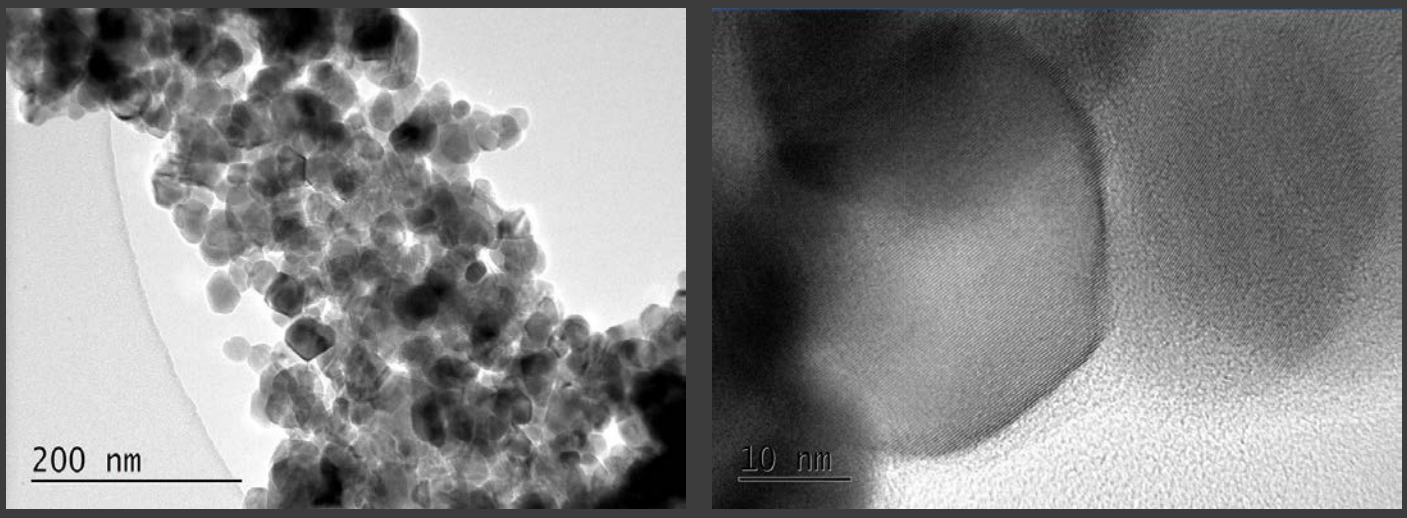


a) ZnO-Cu, two-times dipped; b) ZnO-Cu, three-times dipped;
c) ZnO-Fe, two-times dipped; d) ZnO-Fe, three-times dipped
Fig. 2. SEM images of the surface morphology of ZnO-Me films formed by two-times or three-times dipping in the sol

It is shown that the temperature dependence of the EMF increases linearly for ZnO/ZnO-Fe samples, the upper layer of which is formed by three-times dipping. It is found, that ZnO/ZnO-Fe samples, the upper layer of which is formed by two-times dipping, are characterized by a change in the EMF polarity, and its large temperature deviation from a linear function. For ZnO/ZnO-Cu samples, the upper layer which is formed by two-times or three-times dipping, there is the EMF temperature dependence close to the ZnO/ZnO-Fe samples.

Penza State University together with Saint-Petersburg State Electrotechnical University and Sofia University "St. Kliment Ohridski" (Sofia, Bulgaria) has been conducting development of functional nanocomposite materials based on zinc oxides for photocatalytic applications. Over the past few years such micropollutants as pharmaceuticals, pesticides, and personal care products have been found in concentrations of mg/l in the wastewater, surface water, and ground waters throughout the world. The presence of xenobiotics in water basins is also a significant problem. Possible sources of pharmaceutical pollutants are drugs consumed in households or health facilities, as well as wastes of pharmaceutical companies. The pesticides found in water sources, are the result

of a large-scale pest control in industry and agriculture. The emissions of these substances in the hydrosphere are toxic at any level of the biological hierarchy. Many xenobiotics are extremely stable, and their total elimination is difficult to achieve, even using the most modern water treatment plants. It is known, that membrane filtration and adsorption with the activated carbon is a high removal process of most micropollutants in water. However, these two processes are enough energy and materials consuming, and are ineffective in removing the polar organic pollutants from wastewaters. Therefore, the development of new high-performance photocatalysts based on zinc oxide is of great scientific and technological interest. The focus of this research area is the synthesis of samples by high-energy mechanical milling and their additional activation by high-energy electrons. Typical data transmission of electron microscopy of the mechanically activated zinc oxide samples are shown in Fig. 3.



a) x50.000 b) x200.000

Fig.3. TEM images of mechanically activated samples of zinc oxide at different magnifications

In view of the experimental data, it is shown that the processes of photodegradation of model organic pollutants (paracetamol and chloramphenicol) are approximately the first order reactions, and mechanically activated samples of zinc oxide show a high photocatalytic activity.

Increasing requirements for measuring and signal sensors, as well as the emergence of new problems related to the vacuum level measurement stimulate basic research to establish highly sensitive, miniature, energy-efficient and reliable vacuum sensors. The completed studies in Penza State University show that multi-component oxide nanomaterials with fractal structure actively interact with the atmosphere, resulting in the surface adsorbed molecules of different gases, such as oxygen, carbon dioxide, water vapor, etc. When the pressure is reduced below atmospheric, there the process of gas molecules desorption occurs that leads to a change in their electrical properties, such as change in resistance (Fig. 4).

Depending on the type of the formed structure (spherical aggregates, labyrinth, percolation network), a sensor response varies in a wide range of multicomponent oxide nanomaterials. Here, as in the case of gas sensors development the materials with the percolation network structure have the maximum sensor response

with cross-sectional dimensions of branches comparable with the dimensions of the space charge region.

Penza State University is interested in the joint development of the following topics with potential foreign partners:

- Gas sensors, including ultra-high ones based on nanostructured semiconductor oxide materials.
- Photocatalysts based on wideband semiconductor oxides for environmental applications.
- Energy efficient and miniature vacuum sensors based on the multicomponent oxide nanomaterials with fractal structure.
- Nonequilibrium physical and chemical processes within the chemical synthesis methods, including the sol-gel technology.

Penza State University offers the following problems to solve to potential foreign partners:

- Fundamental and applied research in the framework of joint projects on the stated topics.
- Joint participation in various international competitions and grants.
- Exchange of experience through the implementation of academic mobility.
- Preparation and publication of joint scientific articles in highly ranked journals indexed in Web of Science and Scopus databases.

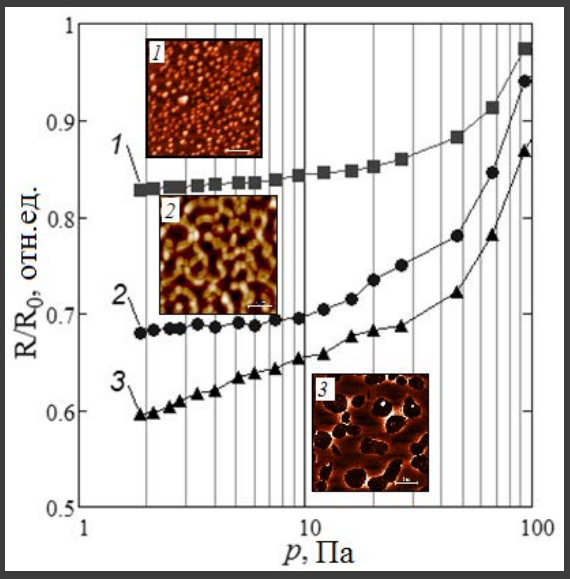


Fig. 4. The relative change in resistance of the sensitive elements of the vacuum sensor on the basis of SiO2-SnO2 (1 – with a spherical structure, 2 – with a labyrinthine structure, 3 – with a percolation network structure)

The main research results are presented in the following scientific articles:

1. AverinI.A., ProninI.A., DimitrovD.Tz.,Krasteva L.K., Papazova K.I., Chanachev A.S., Bojinova A.S., Georgieva A.Ts., Yakushova N.D., MoshnikovV.A. Theoretical and experimental investigations of ethanol vapour sensitive properties of junctions composed from produced by sol-gel technology pure and Fe modified nanostructured ZnO thin films / Sensors and Actuators A: Physical. 2014. – **№** A 206.– P. 88–96.

2. Averin I.A., Pronin I.A., Bozhinova A.S., Georgieva A.Ts., Dimitrov D.Ts., Karmanov A.A., Moshnikov V.A., Papazova K.I., Terukov E.I., Yakushova N.D. The thermovoltaic effect in zinc oxide inhomogeneously doped with mixed-valence impurities / Technical Physics Letters, 2015. – Vol. 41. – No. 10. – P. 930–932.

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3-D Tomographic Microwave Imaging for Breast CancerDetection

PROJECT LEADER:

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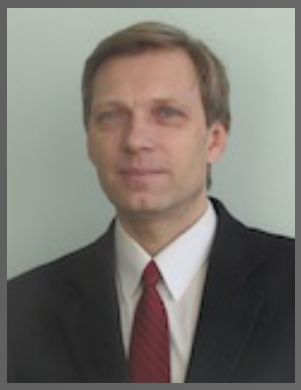
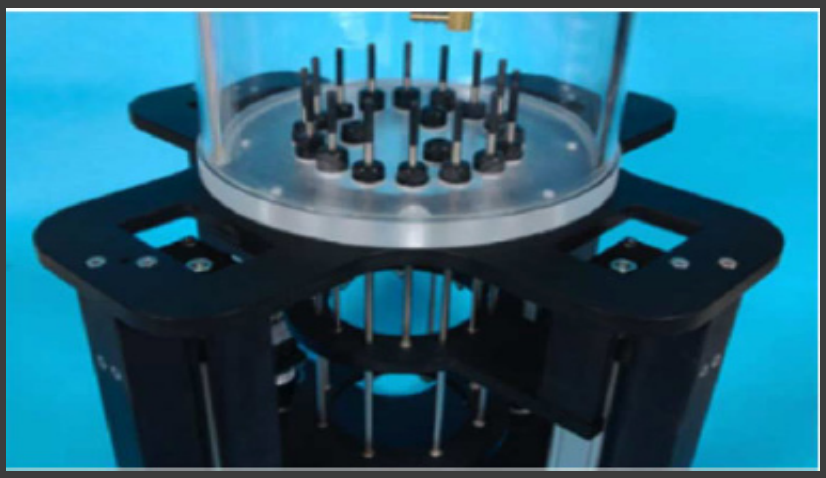


The Problem

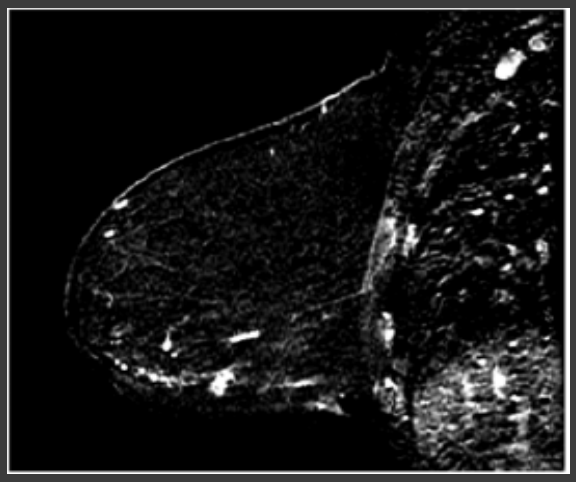
Microwave tomographic imaging has been investigated in various forms for several decades for applications in medical imaging. Examples of imaging for physical property differentiation include a tumor detection in the breast.

Microwave breast imaging (using electromagnetic waves of frequencies around 1 GHz) has mostly remained at the research level for the past decade, gaining little clinical acceptance. The major hurdles limiting patient use are both at the hardware level (challenges in collecting accurate and noncorrupted data) and software level (often plagued by unrealistic reconstruction times in the tens of hours).

We present new software for the fast 3-D Tomographic Microwave Imaging for Breast Cancer Detection Using Supercomputing.



Mamacell system

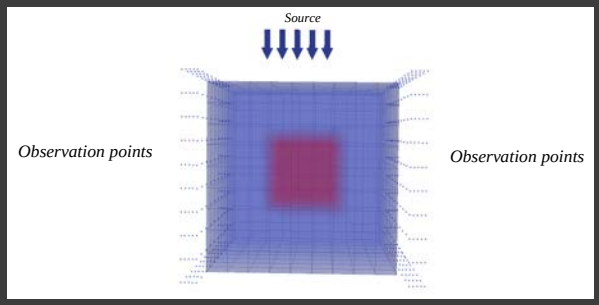


X-Ray pitcure: mammoraphy

Microwave tomographic imaging

Mammography is the front line screening modality but its weaknesses in terms of sensitivity and specificity are well documented. Largely because of cost, magnetic resonance is limited primarily to screening for high risk patients and staging for treatment.

The morphology of breast tissue is ideal for microwave imaging: fibroglandular tissue has been shown to have higher dielectric properties than fat but with properties that are still lower than tumors in most cases.



Mathematical model

The main problem is reconstruction of small inhomogeneities located inside of the body (over 5 mm) using measurements on the surface of the body.

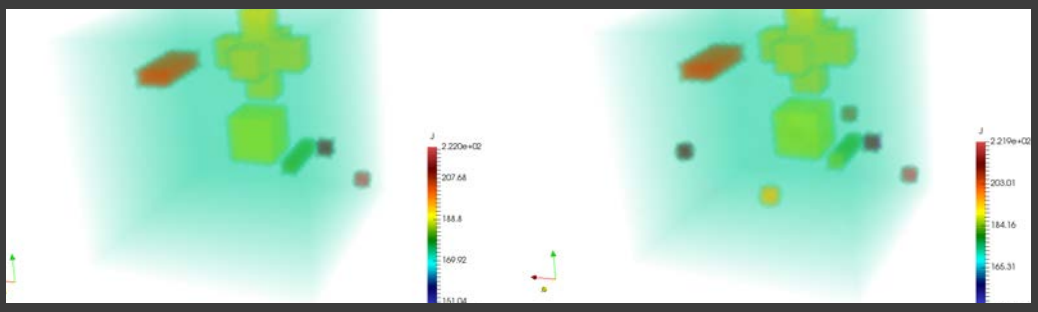


Fig. 1. Result of reconstruction of inhomogeneity:
exact data (on the left) and data with errors (on the right).

Solution of test problem for various inhomogeneities

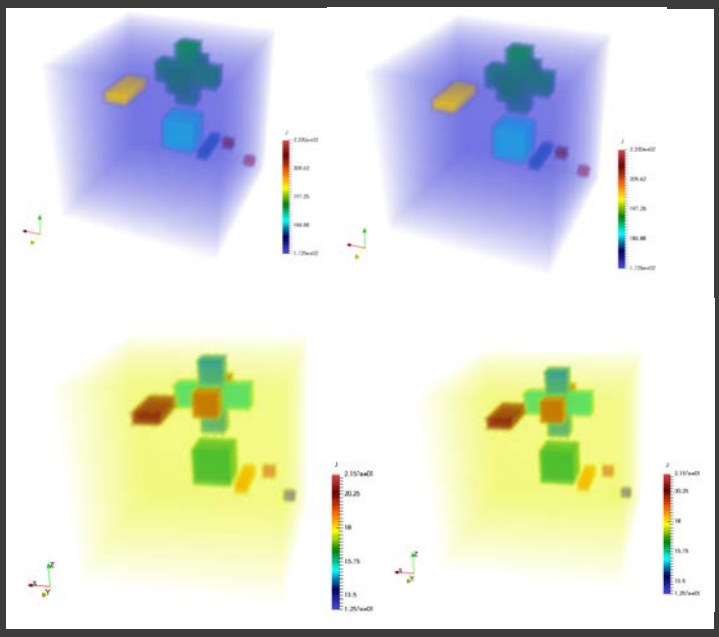


Fig. 2. Exact solution (on the left) and reconstructed solution (on the right).
Blue color – reconstruction using real part of permittivity, yellow color - reconstruction using the imaginary part of permittivity.

Results of the project

Mathematical method is presented for reconstruction of small inhomogeneities located inside of the body (over 5 mm) using measurements of electromagnetic field on the surface of the body.

Computational parallel algorithm and the code are created for solving the problem using supercomputers. The sofware is used with mamacell system for the fast 3-D tomographic microwave imaging for breast cancer detection.

Pyrolysis plant in a reducing atmosphere

PROJECT LEADER:

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A pyrolysis pilot plant in URTO reducing atmosphere is intended for organic containing solid waste processing by pyrolysis. The technological part is arranged in the form of a process module, a tertiary treatment unit and an exhauster.

Wastes fall into the reactor without oxygen using the boot device, in which discharging is created by the exhauster through the gas distributor. The gas cleaning system provides the afterburning in a cyclone furnace, primary treatment in a catalyst cartridge, and particle deposition in a fluid scrubber and a cyclone.

The heat exchanger and the scrubber decrease the temperature of output gases to the temperature of 26 to 35°C, that further come to the "Crown" plant for ion-plasma tertiary treatment.

The plant scheme provides the loading up to 200 liters of waste simultaneously.

As a result of the development work, a prototype of a mobile energy autonomous pyrolysis plant in a reducing atmosphere has been created.

In accordance with the agreed with the customer plan-schedule, from 20 to 26 September 2013 the acceptance tests were produced at two experimental sites of Penza State University and Scientific and Production Center of Start Production Association.

The acceptance tests results are presented in the protocols and acts. The environmental impact assessment was carried out by:

- the regional center of the state environmental control and object monitoring for the storage and destruction of chemical weapons in the Penza region, which produced a hazard class definition of source materials and processed products, in accordance with the PND F T 14.:2:3:4.11-04 T 16.1:2.3: 3.8-04;
- the laboratory of environmental protection and industrial hygiene (Start Production Association, Zarechny, Penza region), which produced the quantitative chemical atmospheric air and industrial emissions analysis, in accordance with GN 2.1.6.1338-03, GN 2.1.6.2309- 07;
- the analytical ecotoxicology laboratory of A.N. Severtsov Institute of Ecology and Evolution of Russian Academy of Sciences, which produced a quantitative determination of the content of toxic polychlorinated dibenzo-n-dioxins and dibenzofurans in the air atmosphere, in accordance with the PND F 13.1.65-08.

All specified centers and laboratories are equipped with modern devices and have the appropriate accreditation certificates.

Gas emissions, solid reaction products on the URTO plant at sawdust disposing of chipboard, sand

contaminated with mineral oils, recycling wastewater of JSC Mayak (Penza), chlorine-containing waste of JSC Khimprom (Volgograd) are non-toxic to all of the substances. The developed technological scheme allows, if necessary, to recuperate the solid residual products for further processing.

During the acceptance testing the control compositions destruction effectiveness has been demonstrated. According to the analyses' results, the initial products were assigned to II, III and IV hazard classes. After processing, the toxicity of coke ash residues has been declined to hazard class IV.

The conducted technical and economic analysis of various recycling technologies shows high perspectives of pyrolysis in terms of environmental safety, versatility and cost-effectiveness. At the same time, their share of the number of the main methods disposing of highly toxic substances and waste in the developed world does not exceed one or two percent now.

We know thermal methods of solid waste processing by the pyrolysis method developed by many foreign and domestic firms, such as ATI INCINERATEURS MULLER (France), CJSC TOURMALINE (Russia), Research and Production Company Energy, In-Tech-Synthesis, Energy and Technology, LCC SCIENCE, ROST-L and others.

The problem is that most wastes contain chlorine, which reacts with organic pyrolysis products with formation of persistent toxic compounds (furans, dioxins). Capturing of these compounds from the smoke is not a cheap process, having some difficulties. To solve this problem, along with the flue gas filtration, water purification in the scrubber, the additional module for the flue gas treatment with "cold" plasma has been used. This compares favorably the proposed technology from the existing analogues.

In accordance with the performance indicator for "Sverhkrit" research and development work, it was necessary to develop and implement 3 modern methods, protection and production technologies to ensure protection of the population and the environment from the negative influences and threats caused by chemical and biological nature factors (4 have been introduced), to produce 2 prototypes developed for the first time (3 have been manufactured), and get 2 patents proving the originality of the technological solutions (2 have been obtained).

Thus, the following conclusions can be drawn from the material presented:

1. Research and development work is done in full and in accordance with the specifications.

2. The materials on registration, content and completeness comply with requirements of the terms of reference and regulatory documents.

3. The developed method of the high-temperature pyrolysis provides non-toxicity of gas emissions, solid reaction products of the test substances. After processing, the product toxicity, having I and II hazard classes, has been reduced to IV.

4. The created installations are mobile energy autonomous systems, which ensure the efficient processing and disposal of household and industrial waste, as well as the elimination of the contained highly toxic chemicals. According to its characteristics, they correspond to the best world analogues.

A multilayered metallic material with special properties and the technology of its obtaining

A new class of multilayered materials of high corrosion resistance with an internal protector is proposed. The principle of protection against pitting proposed by the authors is fundamentally a new one. The choice of layers of multilayered materials intended for operation in oxidizing and non-oxidizing environments is substantiated. The application areas of multilayered materials are determined.

Introduction

Currently, the annual direct loss of metals as a result of corrosion in Russia alone is up to 12% of the total mass of the metal fund, which corresponds to a loss of up to 30% of the metal produced during the year. On a global scale, corrosion losses are 4-6% of the national income of highly developed countries. Indirect losses associated with the failure of structures, the shutdown of technological processes and the depressurization of equipment, cause even greater economic damage. This leads to the need of improving protection methods against corrosion, as well as the development of new corrosion-resistant materials and their products.

Modern nuclear, chemical, petrochemical, and oil refining industriesare characterized by the use of high-power technological installations and technological media with high corrosive aggressiveness, which results in the increased metal consumption of equipment. According to Japanese experts and the International Association of Corrosion Engineers (NACE) , more than 60% of failures in process equipment are due to the influence of temperature and corrosive environment, and annual corrosion losses are estimated at $2.2-2.5 trillion. In particular, over the past year they amounted to (billion dollars): in the US ~ $445, in Germany — $95, in Russia>$50. This corresponds to a loss of up to 30% of the annual produced metal. It should also be noted that the main damage caused by corrosion is caused not only by the loss of the metal itself, but also by the high cost of products destroyed by it, the costs of corrosion protection measures, equipment downtimes, loss of products, technological disruptions, environmental problems.

Thus, the problem of corrosion destruction remains extremely relevant throughout the world. The widely used corrosion-resistant mono- and bimetallic materials currently in use cannot fully improve the service life of the material in aggressive and highly aggressive environments. The development of new steels and alloys, based on an increase in the content of alloying elements, molybdenum, nickel and chromium, is almost exhausted.

Multilayered metallic materials with an internal protector capable of increasing the service life in highly aggressive environments by 10 times or more may be of great interest in this regard.

Results

The basis of the technical solution is a multilayered material containing components with different electrochemical potential, transforming the course of corrosion processes during the transition from one layer to another. The transition is made from pitting corrosion in the upper layer to contact corrosion of a given sacrificial layer. In the case of unilateral exposure of an aggressive environment, four- and three-layered compositions are used. Four-layered compositions are used for products operating at high internal or external loads and pressures, (Fig. 1a). The first three layers, the total thickness of which does not exceed 5 mm, provide corrosion protection of the material, and the fourth one — the mechanical strength (it produces the strength calculation of the entire structure). If the material does not experience significant loads, three-layered compositions are used. In this case, the thickness of the third layer is determined by the strength calculation (Fig. 1b).

The choice of the material of the layers depends on the composition of the medium and the electrochemical potentials of the metals composing the layers. The location of the protector between the layers being protectedis principally new.

Let us consider two cases:

- in the first one, the multilayered material contacts with the working medium containing aqueous solutions of alkalis, acid salts or acids whose anions are not oxidants;
- in the second one, the multilayered material contacts with the working medium containing aqueous solutions of alkalis, acid salts or acids whose anions are oxidants.

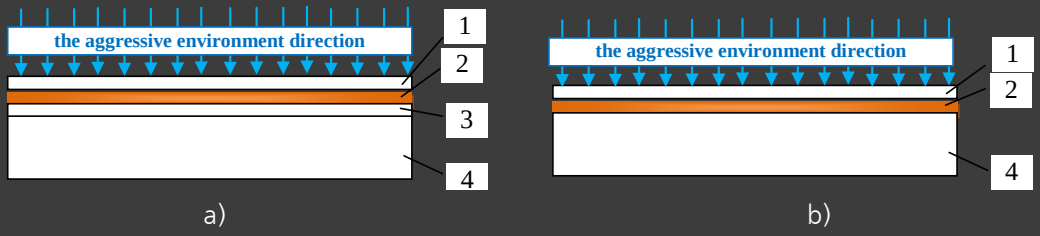


Fig. 1. Examples of four-layered (a) and three-layered metallic materials with an internal protector: 1 – a layer with a high electrochemical potential, providing mainly pitting corrosion; 2 – a layer with a low electrochemical potential ("a sacrificial layer"- an internal protector) is highlighted in brown; 3 – a layer with a high electrochemical potential; 4 – a layer to calculate the entire metal structure strength (a bearing layer).

In the case of a multilayered composite of the first type, a material that has sufficiently high corrosion resistance and exhibits passivity in a given medium is selected as the material of the first (outer) layer in contact with the working non-oxidizing environment. When this layer comes into contact with an aggressive environment that does not contain oxidants, a certain stationary potential E1 is established on it.

As a result of the action of the medium, hot spots appear in the outer layer in the form of pitting, which increase the depth over time, and reach the second layer. The material of the second layer is chosen in such a way that the value of its stationary electrochemical potential E2 under conditions of a contact with the working medium is lower than the stationary electrochemical potential of the metal of the first layer.

When reaching the pitting corrosion of the metal of the second layer, a steady-state potential E12 is established, due to the contact difference of the metal potentials of the first and second layers. In this case, the pitting located in the radius of the protection against it, having penetrated the first layer, ispassivized, and its further growth does not occur. The metal of the second layer becomes the anode, and the metal of the first layer is the cathode. The second layer becomes a protector, i.e. a sacrificial electrode, and gradually dissolves. The anodic dissolution reaction can proceed until the formation of a cavity (lenses) of considerable dimensionsin the protector, up to several tens of centimeters, depending on the ratio of the electrochemical potentials of the layers. On the material of the first layer, depending on the composition of the medium, hydrogen evolution, oxygen reduction or other electrochemical reactions take place.

Anode:

$Fe \rightarrow Fe^{+2} + 2e$

Cathode:

$2H^{+} + 2e \rightarrow H_2$

$Fe^{+3} + e \rightarrow Fe^{+2}$

The composition of the third layer is similar to the first one. When the cavity depth in the protector is equal to its thickness, the third layer also becomes a cathode, like the first one. The rate of corrosion of the second layer can increase, and the process thus proceeds up to the complete dissolution of the protector. If the products of the reaction are insoluble substances, they can slag the individual pitting, and reduce the rate of corrosion destruction of the three-layered material as a whole.

Fig. 2 using an example of a four-layeredcomposition shows a scheme for the development of corrosion in a medium containing aqueous solutions of alkalis, salts of acids or acids whose anions are not oxidants.

For a multilayered composite of the second type, in a medium containing oxidants, a material having a sufficiently high corrosion resistance and exhibiting passivity in the medium is also selected as the material of the first (outer) layer in contact with the working medium. The stationary electrochemical potential of the second layer must be higher than the electrochemical potential of the first layer; in addition, the

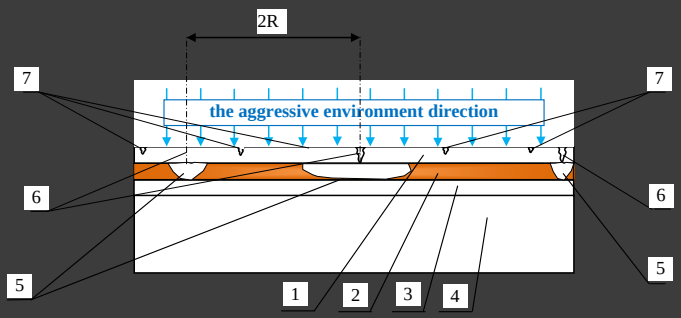


Fig. 2. Scheme for the corrosion growth in a multilayered material in a medium which does not contain the oxidants: 1 – an outer layer in contact with the working medium; 2 – an internal protector; 3 – the third layer; 4 – a bearing layer; 5 – lenses of corrosion products in the protector; 6 – pitting, through which the corrosive medium interacts with the internal protector; 7 – pitting, where passivation occurred due to the electrochemical interaction of the inner protector; R – the radius the inner protector action

material of the second layer should have a lower hydrogen overvoltage than the material of the outer layer.

During the operation, pittingis formed in the outer layer, which eventually reaches the second layer. Between the layers there is a contact potential difference. The metal of the second layer retains its passive state. Anodic dissolution of the metal of the first layer will be inhibited due to the formation of sparingly soluble reaction products. The potential of the metal of the first layer will shift to a region of more positive potentials E31, which will lead to its additional passivation and, as a consequence, stop the growth of pitting.

In this case, the corrosion potential of the steel of the outer layer will retain a stable positive value corresponding to the passive state. During operation, the passive film can be dissolved in the outer layer as a result of a chemical reaction.

Fig. 3 usingan example of a four-layered composition shows a scheme for the development of corrosion in a multilayered material in a medium containing aqueous solutions of alkalis, acid salts or acids whose anions are oxidants.

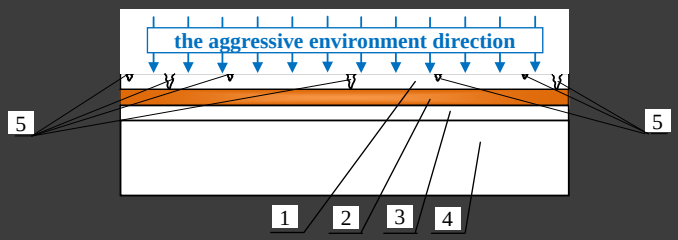


Fig. 3. Scheme for the corrosion growth in a multilayered material in the oxidizing medium: 1 – an outer layer in contact with the working medium; 2 – an internal protector; 3 – the third layer; 4 – a bearing layer; 5 – pitting in the outer layer, including passivized being in contact with the internal protector.

The composition of the material of the third layer is identical to that of the outer first layer. The table shows a number of structural metals and alloys in order of increasing the corrosion potential of Ecor in sea water. From the table data it follows that the low-carbon steel grades Steel 10, 15, and 20 have the potential more negative, compared to the high-alloy steels 12X17, 12X18N9, and 10X17N13M2T, which are in a passive state. This means that low-carbon steels can be used as a protector in combination with high-alloyed corrosion-resistant steels for media containing aqueous solutions of alkalis, acid salts or acids whose anions are not oxidants.

It also follows from the table that high-alloy steels 12X17, 12X18N9, and 10X17N13M2T in the active state have a potential more negative compared to copper, titanium, and Hastelloy. This means that high-alloy steels can be used as a protector in combination with these metals and alloys for media containing aqueous solutions of alkalis, acid salts or acids whose anions are oxidants.

In the case of double-sided effects of aggressive media, multilayered compositions may consist of five, seven or more layers (Fig.4), provided that the number of internal protectors is not less than two.

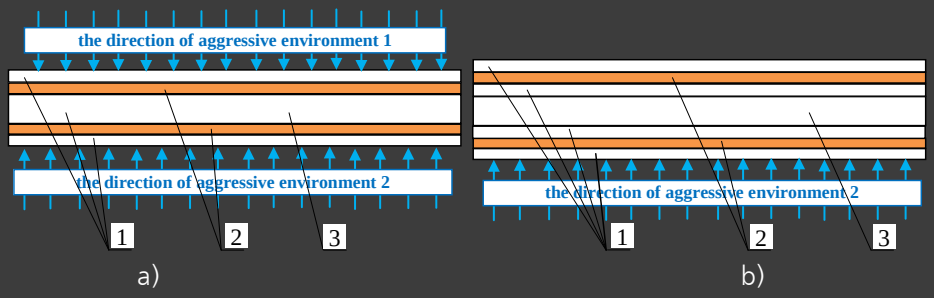


Fig. 4. Multilayered materials with five (a) and seven (b) layers under bilateral interaction of the corrosive medium:
1 – layers with a high electrochemical potential; 2 – internal protectors; 3 – a layer to calculate the entire metal structure strength.

If it is necessary to increase the life of a multilayered material with an internal protector for an indefinite period, a design with two, three or more internal protectors may be proposed (Fig. 5). The sequence of development of corrosion processes in each of the layers will be similar to the previously mentioned ones, correspondingly increasing the service life by 10, 100 and more times. Thus, a material with a regulated service life has been created.

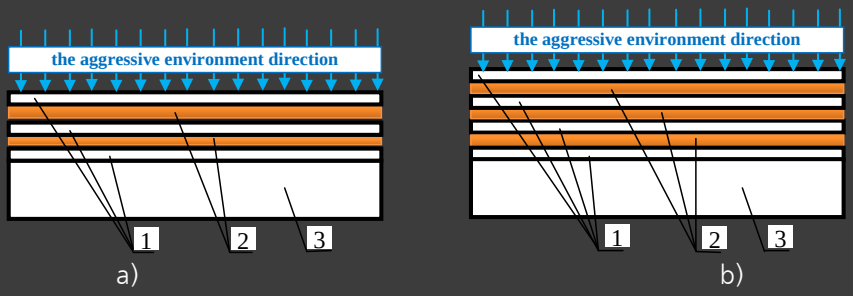


Fig. 5. Multilayered materials with two (a) and three (b) layers of internal protectors under unilateral interaction of the corrosive medium: 1 – layers with a high electrochemical potential; 2 – internal protectors;
3 – a layer to calculate the entire metal structure strength.

The material is designed for the production of tanks, buckets, barrels, cylinders, reservoirs, vessels, including ones for nuclear power plants, apparatus, process equipment and pipelines, casings and components of boilers, reactors, turbines, pumps for corrosive liquids and gases, casings of furnaces and heating chambers, elements of heat exchange and recuperation equipment, underwater parts of river and sea vessels shell, structural elements of drilling equipment and drilling platforms, and other products operated in aggressive environments, including at elevated temperatures.

Materials containing two or more layers of different compositions can be obtained using different technologies. These include foundry plating, hot batch rolling, cold cladding, explosion welding, surfacing. One of the most effective industrial methods of their production, especially in the case of joining dissimilar materials, is explosion welding.

Welding by explosion is a high-speed method of pressure welding, in which a permanent joint is formed as a result of the impact of welded elements. The source of energy is an explosive. In the initiation of the explosive, the detonation front propagates in which decomposition into gaseous products takes place. There is a pressure jump, under the action of which the element being thrown acquires a high velocity and collides with the fixed element. In the collision zone, the pressure can reach from 10 to 20 GPa. There is a joint plastic deformation of metals in a relatively narrow layer up to 1 mm thick. The high-temperature plasma produced by the high-speed collapse of the surfaces being joined clears them from oxide films, adsorbed gas, and activates the atoms of the surface layers, while high contact pressure crushes all irregularities and roughness, ensuring high strength of the one-piece connection.

The advantages of explosion welding can be formulated as follows: the possibility of obtaining compounds from homogeneous and dissimilar metals and alloys, including sharply differing physical and mechanical properties (melting point, thermal coefficient of linear expansion, strength, plasticity); the main and clad layers in the explosion welding process do not change the chemical composition, and the mechanical properties change in a narrow zone with a width of 3 ... 6 mm adjacent to the connection line; explosion welding is carried out in a solid phase, which allows the joining of materials forming brittle intermetallic compounds; the possibility of obtaining compounds of up to 20 m2 or more, the thickness of the base layer, limited only to the thickness of the rolled product or product, the thickness of the cladding layer from fractions of a millimeter to several millimeters; the possibility of obtaining multilayered materials for one technological cycle of welding; no need for complex and expensive equipment; relatively low cost of consumables and low energy consumption; the possibility of obtaining flat, cylindrical blanks and cladding of curvilinear surfaces.

For the production of three-layered materials, the welding scheme shown in Fig. 6 was used. Plates 3 and 4 were successively installed on technological supports on a fixed plate 5. The height of the supports corresponded to the values of the gaps h1 and h2. V-shaped staples (stallions) made of metal, similar in composition to one of the welded materials, were used as supports.

To ensure a high quality of welding around the perimeter, the plates 3 and 4 had a size of 40 mm larger than the fixed plate. In the process of welding there was a cutting along the perimeter of the

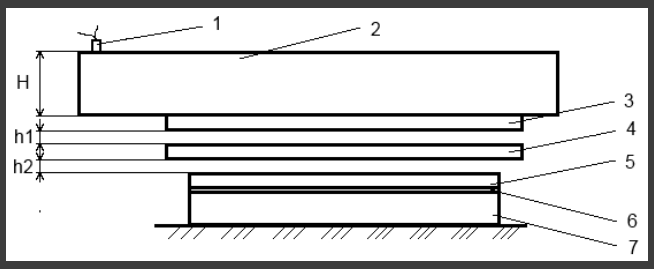


Fig. 6. Scheme for explosion welding of a three-layered material: 1 — an electric detonator; 2 — an explosive charge; 3, 4 — throwing plates; 5 — a fixed plate; 6 — a layer of inert material; 7 — a steel base; H — the thickness of the explosive charge; h1, h2 — technological clearances.

fixed plate. To prevent the fixed plate from seizing against the base, an inert material 6, for example polyethylene, was laid between them. The charge of explosives was placed on the outer surface of the upper throwing plate in a special container.

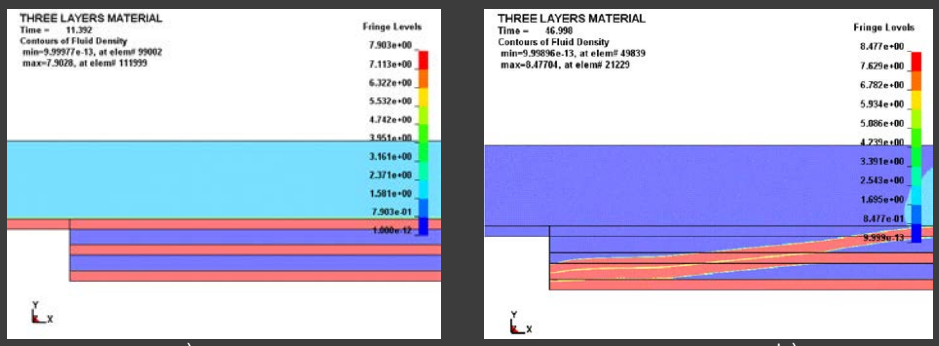
In the explosion welding of a four-layered material, the number of plates being thrown was increased, and the lower plate was also the fourth layer. The thickness of the three-layered materials was from 6 to 24 mm, and of the four-layered materials — from 16 to 75 mm. The area of blanks ranged from 1 to 9 m2.

For the designation of technological regimes, the explosion welding process was preliminarily modeled with the use of the multipurpose program LS-DYNA, designed to solve three-dimensional dynamic nonlinear problems of a deformable solidmechanics, fluid and gas mechanics, heat transfer, and theirrelated problems. The simulation was carried out using a multi-component Eulerian approach. Each element contained a certain part of the material presented in the system under consideration. To describe the behavior of

the explosive, the Wilkins-Geiroch model was used. It allowed simulating the detonation of the explosive. In addition, the equation of state was specified. We used the model MAT_HIGH_EXPLOSIVE_BURN, including the Jones-Wilkins-Lee equation. The volume strain was determined by the natural logarithm of the relative volume. Up to the time of compression shrinkage, unloading occurs linearly with a slope corresponding to the magnitude of the bulk modulus for the unloaded state.

Fig. 7 shows an example of graphical results of modeling of a three-layered material of 08X18H10T + steel 10 + 08X18H10T composition.

Simulation of the explosion welding process allowed to estimate the value of contact pressures, the heating temperature of contact surfaces as a result of plastic deformation and the effect of hot plasma,



a) b)

Fig. 7. 2D modeling results in LS-DYNA explosion welding of a three-layered material at the initial time (a), and 40 μs after the explosive detonation (b)

and, accordingly, essentially to reduce the number of experiments, to obtain consistently high-quality three- and four-layered compositions of the multilayered material with the "internal protector" in a wide range of thicknesses and sizes.

In particular, the following composite laminates were obtained: 08H18N10T + steel 10 + 08X18N10T, 12X18N10T + steel 20 + 12X18N10T, 12X18N10T + St3 + 12X18N10T, 08X18N10T + steel 08Kp + 08X18N10T, 12X18N10T + St3 + 12X18N10T, 08X18N10T + steel 10 + 08X18N10T + 09Г2С, 10X17H13M3T + steel 10 + 10X17H13M3T + 09Г2С, 08X18H10T + steel 08кп + 08X18H10T + 09Г2С.

The explosion welding operations were carried out at the specialized testing areas of Penza State University, the Institute of Structural Macrokinetics and Materials Science Problems of the Russian Academy of Sciences, and Bitrub International, Ltd. (Fig. 8a, b, c).After explosion welding, 100% visual and ultrasonic tests were performed on all samples (Fig. 8d).

According to the Skolkovo Center for the Commercialization of Innovations in various industries,the world market volume of the created multi-layered corrosion-resistant material is more than 900 million dollars, 33% of which are in the energy industry, 25% in the oil refining industry, 21% in the chemical industry, 14% in the nuclear industry, and 7% in the shipbuilding industry.

Conclusion

1. Depending on the degree of aggressiveness of the medium, the life of the equipment rises by10 times and higher in comparison with corrosion-resistant steels of the austenitic class. The multilayered metal material includes a possible minimum amount of expensive components. At the same time, it is possible to carry out an inexpensive and safe external diagnostics of corrosion processes, including the ultrasonic testing technique.

2. The created multilayered metal material is a completely new product. There are no its direct analogs. The main areas of its application are chemical, oil, gas industries, and nuclear energy. The resulting material is in the same segment as tantalum and platinumaccording to performance indicators, and is at the level of traditional chromium-nickel corrosion-resistant steelsin the price segment.