

## A COMPETITION OF MICROSYSTEM ENGINEERING IN RUSSIA

Modern status of technique of new generation and "critical" technologies in a number of the most developed countries is characterized by microsystem technology dynamic development from the beginning of the 90-th years ("microsystems technology" - MST) that determined the creation of a new scientific and technical direction - "microsystem engineering" ("microsystems engineering" - MSE).

The appearance of microsystem engineering (MSE) means a new revolution in the field of systems realizable on microlevels and ensuring the function not only in conditions of a fixed solid state but also in case when an object or a part of an object of microsystem or an environment contacting with it are in mutual time-space dynamics. The integration of modern mass production technology, inherent to microelectronics, into a production of traditional devices and mechanisms of increased complexity, characteristic for radioengineering, optics, machinebuilding, devicebuilding and biomedicine is new in this concept. This combination allows to produce unique multifunctional devices in microsizes and low cost. It is necessary to say, that any attempts of unification and clarification of terminology in the field of microsystem engineering were not undertaken up to now. A part of it has been borrowed from microelectronics, an other part has been borrowed from mechanical and electrotechnical disciplines. The qualitative and quantitative boundaries between separate terms have not been always conducted.

The term "microsystem engineering" appeared in Russian official documents after adoption of Critical Technologies List on federal level in 1996.

In 2001 the Russian Fund of Technological Development (RFTD) of the Ministry of Industry, Science and Technologies of the Russian Federation hold a competition on the subject: "Development of new generation devices on the basis of microelectromechanical systems" (E-mail: [gubarev@minstp.ru](mailto:gubarev@minstp.ru)).

The competition was conducted in following directions:

- Micromachines: power and motion sources, force drives and mechanisms.
- Microbiochemical systems: microdosers, micropumps, microvalves, microreactors and microfermentors
- Microtelecommunication systems: controlled microelectromechanical radiocomponents, adaptive microelectrooptomechanical "bench".
- Analytical microsystems.

The developed devices are intended for use in Medicine and Biochemistry, Telecommunications, Industrial Automation, Space Industry, Motor Transport, Monitoring of environment. At the beginning of 2002 the Russian Agency on Control Systems (RACS, <http://www.rasu.gov.ru>) hold a common competition on the fulfillment in 2002 of research, experimental-design and technological tests on the following sections of the federal aim-oriented program "The national technological basis" for 2002-2006:

- Microelectronic technologies;
- Technology of telecommunications;
- Technology of computing systems;
- Radio electronic, microwave and acoustoelectronic technology.

The following projects were included in the list of the competitive projects on the section "Microelectronic Technology" (concerning microsystem engineering and nanoelectronics):

- The development of production technology of micromechanical elements for microsystem engineering on silicon technology.
- The development of base production technology of micromechanical elements for microsystem engineering on fiberglass technology.
- The development of device-technological base of production of intellectual nanotechnological complexes for creation of nanoelements and terabit micromechanical storage devices.
- The development of device-technological base of zond and ionic nanotechnologies of the formation of elements with sizes less than 10 nm
- The development of device-technological base of the formation of nanotechnological elements on the basis of nanotube carbon structures.

In 2000 the Ministry of Higher Education in Russia opened the training of engineers for a new speciality - 201900 "Microsystem engineering".

In Russia the problems of microsystem engineering illuminates the scientific-technical and scientific-production journal "Mikrosystemnaya tehnika" ("Microsystem engineering") founded in 1999 (<http://www.microsystems.ru>). The interdisciplinary scientific, technical and production journal "Mikrosystemnaya tehnika" is issued under the assistance of the Ministry of Industry, Science and Technology of the Russian Federation, the Ministry of Education of the Russian Federation and the Russian Academy of Sciences. The task of the journal is to illuminate the modern status and perspectives of development of microsystem engineering, to consider the problems of development and to introduce microsystems in various fields of science, technology and production.

The articles in the journal are systematized under the following main headings:

- MSE elements and microsystems - sensitive elements and converters of information for physical magnitudes, chemical elements, biological materials; biochips; executive devices - micromechanisms, microtools; power and motion sources - microdrives, microturbines; microelectromechanical, microoptomechanical and biotechnical microsystems; energy supply microsystems; technological microsystems.
- Design and simulation of MSE objects - SAD of MSE objects; simulation of MSE objects, including in view of scaling effect.
- Material and technological MSE fundamentals - traditional and perspective materials for MSE objects: materials of surface and volumetric micromechanics, adaptive ("clever") materials; special technologies of MSE: particle-beam (X-ray) microforming, LIGA-technology, fiberglass technology, nanotechnology, molecular electronics.
- Application of MSE objects - device and machine design – macrosystems with MSE element base; assembly of macrosystems with MSE element base; tests, certification and operation of macrosystems based on MSE; air and auto electronic components; mini- and microbotic systems, micromachines.
- Nanotechnology
- Molecular electronics and biotechnology.
- Information - conferences, meetings, exhibitions, science news and engineering, reviews of the special literature, educational literature on MSE etc.
- Pages of the Russian Fund of Basic Researches (RFBR).

The journal "Mikrosystemnaya tehnika" has been issued since 1999 and in 1999 only 1 number was issued, in 2000 there were 4 numbers, and since 2001 the journal is issued monthly (12 numbers per one year). The journal is distributed only at a subscription (Catalogue of Agency "Rospechat" index 79493). An abroad subscription is accepted by CISC "MK-Periodika" (E-mail: [info@periodika.ru](mailto:info@periodika.ru)) and CISC "KON-LigaPress" (E-mail: [export@Kone-Liga.ru](mailto:export@Kone-Liga.ru)).

The summaries of the articles in the Russian and English languages are located at the end of each number of the journal, and it is possible to get acquainted with the summaries at the journal site in Internet. This site supports and stimulates the creation of the stable community of Russian users around the journal "Mikrosystemnaya tehnika".

The publishing house "New technologies" together with the Institute of Problem Researches of the Russian academy of natural sciences issued an electronic archive issue of the journals "Mikrosystemnaya tehnika" for 1999-2001 in CD-R compact disc. The electronic color versions of the printed articles in a format PDF are also placed in this disc. The electronic archive of the journals is supplied with the uniform interface divided into sections and articles permitting to realize a search by numbers and sections of the journal very easily.

The first number of 1999 year paid great attention to survey materials on MSE condition, its major directions, perspectives of development. Four numbers of the journal were issued in 2000. Except the articles about the last scientific and technical achievements in the field of microsystem engineering (MSE) each number has some applied thematic colouring: the first number reviews flying mini- and microapparatuses, the second one outlines ground and space mini- and microapparatuses, problems of development and application of sensors and element base of microsystem engineering, the third number

pays attention to micro and nanotools, biochips, the fourth one is devoted to surface and underwater mini- and microapparatuses.

At present, the Russian experts obtain interesting outcomes in the field of microsystem engineering. The MSE main products, developed at the Russian enterprises and defining the development of Russian microsystem engineering are indicated in tables 1 and 2.

According to the judgement of the experts, the development of microsystem engineering for scientific and technical progress can have the same consequences as the emerging of microelectronics rendered the becoming and modern status of leading fields of science and engineering.

For the evaluation of condition and perspectives of development of microelectromechanical systems it is possible to enter the quality coefficient permitting to evaluate the levels of MEMS integration and represented as product TM, in which a number of transistors is T and a number of mechanical components is M. Let's illustrate possibilities of microsystem engineering. For example, for a serially produced accelerometer made in accordance with the technology with topological norms from 2 to 10 microns (containing from 100 to 200 transistors and 1 mechanical element) we shall get magnitude  $TM = 102$ ; and for dynamic management of a screen surface of display (containing 1 million of mechanical elements of a screen and 1 million of control transistors) we shall get  $TM = 1012$ . A plenty of electronic and mechanical components opens new epoch in creation of microsystem engineering under the existing technological level in microelectronics.

The microelectronic technology applied in all silicon based products is the basis of development of microelectromechanical systems.

LIGA microtechnology is being developed now in Russia. The physical technological problems requiring understanding and solving as well as the product examples and the areas of application of a process are developed by the experts of Kurchatov Source of Synchrotron Radiation.

Table 1.

The leading Russian enterprises  
of the direction of "Microsystem engineering".

<b>Class of MSE products</b>	<b>Leading Russian manufacturing enterprises</b>
Sensory microsystems	the Moscow Institute of Electronic Engineering, the St.-Petersburg Electrotechnical University, the Ramensk Device building design office, the Taganrog State Radioengineering University.
Microelectromechanical systems and machines, energy supply microsystems	the St.-Petersburg Electrotechnical University, the State Research Institute of Physical Problems, the Institute of Automation and Electromasurement of the Siberia's RASc the Micron Corporation, the Central Research Institute of Robotics and Cybernetics.
Analytic- technological microsystems	the Institute of Analytical Device building of the RASc, the St.-Petersburg Electrotechnical University, the State Research Institute of Biological Device building, the Moscow State University, the Kurchatov source of synchrotronus radiation.
Miniature robotic systems	the Institute of problems of mechanics of the RASc, the Moscow State Technical University, the Central Research Institute of Robotics and Cybernetics

	the Moscow Institute of Radioengineering, Electronics and Automation
Simulation	the Moscow Institute of Electronic Engineering, the Moscow Institute of Radioengineering, Electronics and automation, the Institute of Mathematics of the Siberia's RASc. the Taganrog State Radioengineering University.

Table 2.

Assignment of microsystems for a new generation engineering.

Class of MSE products	Assignment	
	Civil	Special
Sensory microsystems	Miniature control systems, navigation and management microsystems	
	Automobile and railway transport	Space and rocket-artillery systems
	Multisensors, intellectual sensors, sensors with feedback, accelerometers, miniature autonomous systems of navigation (combined with GPS space systems), modules of monitoring of position of the antenna phased lattices, system of ejection and individual induction.	
Microelectromechanical systems and machines, energy supply microsystems	Miniature controlled element base	
	Civil device building	Special device building
	Micromechanisms, miniature controlled: condensers, resistors, mirrors, modulators; elements of microdrive, microoptics, microengines, Микромеханизмы, microgenerators, autonomous miniature power sources, microturbine, microsystems of energy recuperators.	
Analytic- technological microsystems	Miniature analytic-diagnostic chips and microchemical reactors	
	Biotechnology, medicine, petrochemistry, food- processing industry, microbiology, nanoelectronics.	Chemical defence, detection, research and utilization of especially dangerous substances, medicine
	Miniature autonomous systems for diagnostics of organism and substitution of organs, miniature analytical devices, microreactors, micro and nanoinstrument, microregulators, micropumps.	
Miniature robotic systems	Miniature autonomous controlled self-relocating systems	
	Microrobots for diagnostics medicine, nuclear power, chemical industry.	Microrobots for investigation and battle actions on ground, water, air and space.

Besides, the new microcomponent structures and method of their fabrication have been proposed and developed in Russia (Saratov). These new approach based on fiberglass technology. The outstanding opportunity of this technology has been demonstrated and used for fabrication of submicrometer X-ray mask; synchronous micromotor with contained permanent magnet; microcoil with 7 micrometer lines. Our technology gives an opportunity for fabrication of structures with extreme high aspect ratio, spiral-like conductor and so on. Developed technology does not use expensive X-ray lithography. The possible application of the described technology for production of different microcomponents for electronics and X-ray optics components, MEMS and other devices has been discussed.

The main directions of microelectromechanical systems development are incorporated, first of all, by used materials:

- Silicon (in all institutions of Russia);
- Carbide of silicon (St.-Petersburg);
- Ferroelectrical films (Novosibirsk, Rostov-na-Donu).

The last achievements are obtained in works on creation of high energycapacions micromotors, based on thin ferroelectrical films (Novosibirsk). The principle of step leaved micromotors work, based on the effect of electrostatic layer of metallic films on ferroelectricity surface is considered. Being made with the help of microelectronic technology these micromotors have exceptionally high energycapacions (beyond 0,3-1 J/m<sup>2</sup> at voltages 10-50 B) and precision of step (from 10 A<sup>-1</sup> to 100 mcm) The theoretical and experimental data, characterizing energy and mechanical parameters of such micromotors are given here.

The St.-Petersburg Electrotechnical University has developed not only carbide-silicon sensors which have world popularity, but also presents the results of using wide-gap diamond-like silicon carbide, which offers the advantage of the enhanced stability (both thermal and chemical), as a material for microheaters and IR radiating systems, as well. The thermal proceses are considered that occur within the basic structure: a membrane supported SiC resistor that forms a basis for a number of microsystems such as temperature or flow rate meters, microradiators and microheaters. Some equivalent thermal circuits have been developed, basing upon which we have obtained designs for a IR microradiator, several hot-wire sensors as well as for a thermal reactor of an analyzing/processing microsystem. Those thermal and electric performance data are given in the paper, in addition, and presented as the design and performance of a microheating coagulating system intended for medical applications.

Besides, the principles and basic chnracteristics of a microaccelerometer on surface acoustic waves (SAW) with a frequency output are reported. A kinematic of the differential type accelerometer, various variants of topology of a crystal and possible methods of manufacturing are considered. Potential limitations on a range of acceleration and characteristics are given. Advantages of accelerometers on SAWs are investigated: a compensation of a tem-change. The special attention is given to the analysis of resources of periodic structures in optical ranges of wavelengths with use of Bragg effect.

The traditional microelectronic technology is used in the Moscow State Institute of Electronic Engineering for the development of microsensors, and besides it, the main characteristics and designs of the named sensors are developed there. The new directions in design of complex microsensor systems held in SMS TC are discussed:

- surface micromechanics technology;
- multichip module technology;
- development of single-purpose integrated circuits of transformation of sensors' signals.

More than that, the integral microgyroscope of vibrating type on the base of multilayer structures of silicon and glass is developed. The design realizable on the base of multilayer structures is suggested. Using integral technology method this design permits to create the device having high faithful characteristics. The equivalent scheme of microgyroscope parasite dements is composed and the definition methods of elasticity module and parameters of stress-deformed state of multilayer structures are represented. The definition method of ratio between the layers parameters is suggested.

The Moscow State Technical University develops navigation devices based on monocrystalline silicon The development was carried out at BMSTU in cooperation with other organizations. The design modifications of pendulous units for seven accelerometers as well as the design of rate sensor measuring units are presented in the paper. The brief review of manufacturing process designed for measuring units of navigation devices based on monocrystalline silicon is given. A possible use of the servoaccelerometer, having silicon pendulum, as a geophone sensor is considered.

The construction of micromechanical vibration gyro accelerometer structurally designed in the form of pendulum with capacitive readout and electrostatic torqner is considered. The output signal of the device will contain the components proportional angular velocity and linear acceleration

The results of developments of the Ramenskoye Design Company (RDC) in the area of silicon

accelerometers and multi-sensors are represented. The main features of the siliconbalanced accelerometers and accelerometer with a frequency output, as well as results of the first multi-sensor and electrostatic accelerometer testing are considered.

The Taganrog State Radioengineering University carries out the work in the field of construction of microelectronic sensory systems for a solution of a number of concrete problems in hydroairplanes. The structure of microelectronic sensory systems for decision of some problems pertaining to the national economy are represented.

The examples of their practical use are conducted. The main technical characteristics of received developments and possibilities of TC TRU by creation of microelectronic sensory systems are outlined.

At present the amount of Russian scientific institutions occupied by nanomechanics (nanotools and nanotubes) was increased.

Summarizing the modern status in the field of stimulus and factors promoting the development of microsystem engineering in Russia, let's underline the most important things:

- Availability of scientific and technological culture generated during the becoming and development of micro and optoelectronics;
- Availability of base equipment, capacities and organizational infrastructure of microelectronic production, suitable for realization of objects of microsystem engineering;
- An active market of sensory systems of various functionality and designs;
- A tendency to integration of micro and biotechnology process;
- An appearance in the market of data reduction systems and management of perspective generation of integrated circuits with neuro-like structure ensuring a new level of "intellectual" possibilities and rapid action of microsystems while preserving or improving the former mass gabarit and power parameters;
- Perspectives of a new active market in the field of miniature unexpensive diagnostic life support systems on the basis of the concept of an economic feasibility of mass preventive maintenance of disease to its treatment;
- A formation of an equipment market for microlevel technologies (similar to microelectronic) at the expense of broad development of biotechnology and hardening of the performance requirements for radioactive, toxic, explosive substances, that determines the transition to the use of supersmall amounts of substances in the limited volumes.