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MANAGEMENT OF INNOVATIONS IN SCIENTIFIC INSTRUMENTATION

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Breakthrough scientific research in the field of molecular genetic analysis, which refers to a risky, significant funding for state organizations, is described. Scientific instruments illustrating the development of one of the most promising areas of scientific instrumentation, which allows the creation of small-scale analytical systems with modern software for rapid analysis of a large variety of biological samples, are presented.

Keywords: biological sample, DNA sequencer, micro fluidic chip, polymerase chain reaction, fluorescence, capillary

1. SCIENTIFIC POTENTIAL OF CREATING INNOVATIVE PRODUCTS FOR THE PURPOSE OF IMPORT SUBSTITUTION

In today's world, the development of scientific instrumentation provides an innovative foundation for setting up hi-tech productions. After the end of the Cold War, many scientific organizations specialized in the field of instrumentation were eliminated. A number of scientific organizations that had the greatest competitiveness and high scientific and educational potential were able to receive funds by fulfilling state orders and international treaties, mainly with China. It should be noted that international agreements with China in the field of scientific instrumentation allowed to significantly increase the scientific and educational potential of China.

Breakthrough research implies risky funding, which is significant not only for private companies but also for governmental agencies.

Transnational corporations organize the whole production-technological cycle, which starts with scientific research and ends with the production of serial products A striking example of such a company is the American corporation Boeing, which adapts the company's existing technologies, both for civil and military equipment. The production and technological cycle used by Boeing excludes duplication in the conduct of R & D or the re-creation of an already developed technology. All market-demanded results of intellectual activity of Boeing employees are used to enhance competitiveness and production, as Boeing is the owner of all results of intellectual activity produced by the corporation. At the same time, the authors of the claimed results of intellectual activity receive remuneration for their use and are therefore interested in their commercialization. The production and technology cycle and the organization of technology transfer in Japan, South Korea and the EU countries are organized in the same way as in the USA [1].

In Russia, the conduct of scientific research and the production of final products in most cases is carried out by different organizations. The R & D results often do not find commercial use because the scientific organizations that conducted them do not have sufficient rights and financial resources to organize serial production of products. At the same time, industrial partners — producers of serial products do not have information about innovative technologies created by science institutions [2].

The low demand for the results of intellectual activity related to scientific instrumentation by Russian economy is also attributable to industry's low demand for Russian innovative developments, due to the business orientation at innovative technologies from outside Russia.

The Council for Scientific Instrumentation of the Federal Agency for Scientific Organizations of Russia (FASO) is authorized to rectify the situation with scientific instrumentation. The Council coordinates the efforts to implement the concept of scientific instrumentation development in the institutions and organizations of the Russian Academy of Sciences subordinate to the FASO of Russia.

Attempts to slow down the development of the Russian economy are reflected in anti-Russian sanctions. The economic import substitution programs in Russia are opposed to anti-Russian sanctions and neutralize their negative effect. Import substitution programs are a significant support for domestic producers. Solutions to many of fundamental scientific problems, when implementing import substitution programs, find practical application in the Russian economy and significantly affect the economic situation in the country.

In compliance with the instructions of the Chairman of the Government of the Russian Federation from 2015, 20 industry plans for import substitution have been approved, which contain more than 2.500 positions in various technological areas. The implementation of industry projects in such sectors as electronics, medicine, biotechnology, pharmaceutics and ecology allows Russian producers to enter foreign markets with competitive products and replace a number of foreign analogues on the Russian market. The planned total volume of output under import substitution programs by 2020 should amount to approximately 400 billion rubles, the volume of tax deductions — about 30 billion rubles [3].

Fundamental and applied research in the field of scientific instrumentation is related to the need to determine the chemical composition of substances to find their atomic or molecular structure, to quantitatively assess the physical and chemical properties of a substance, and to measure dynamic spatial parameters, electromagnetic field, and radiation processes. Fundamental and applied research in scientific instrumentation requires sizeable investments to purchase new expensive equipment used in today's test facilities, on which innovative technologies can be obtained by recording and processing huge databases. The new phase of the innovative development is based mostly on the use of new scientific results obtained on experimental equipment with new research methods; which as a result constitutes a set of new knowledge that is used in the educational process and is the basis for creating a new generation of scientific instruments. Scientific instrumentation makes it possible to create a hi-tech product that has a significant added value in the domestic and international market of innovative technologies.

2. INNOVATIVE WORLD-CLASS DEVICES FOR MOLECULAR GENETIC STUDIES

2.1. General

The Institute of Analytical Instrumentation of the Russian Academy of Sciences (IAI RAS) has a unique experience, significant scientific and educational potential and carries out production of devices corresponding to the world level. IAI RAS conducts breakthrough scientific research in the field of creating devices for biological, genetic and medical research.

In conducting these studies, highly skilled specialists are involved: molecular biologists, physicists, chemists, doctors, engineers. The results of the research are used in chemistry, pharmacology, health, biotechnology, ecology, food production and environmental safety.

The scientific and educational potential, modern equipment and industrial base made it possible to create cooperation between the IAI RAS, Scientific Production Company SINTOL (SPC "SINTOL") and the industrial partner — the Experimental Factory for Scientific Engineering of the Russian Academy of Sciences (FGUP EZAN) for the implementation of the program of import substitution for scientific instruments molecular genetic analysis and sequencing devices.

The molecular genetic analysis devices and sequencing devices have replaced the products of American company Thermo Fisher Scientific (former Applied Biosystems) in the high-tech market of scientific instrument making. Domestic genetic analyzers are more attractive to consumers. Genetic analyzers are about twice as cheap as American ones for the price of equipment and supplies. Genetic analyzers are about twice as cheap as American ones for the price of equipment and supplies.

2.2. Devices for molecular genetic analysis

The first domestic ANK genetic analyzers use the polymerase chain reaction (PCR) method in real time (Polymerase chain reaction in real time). This innovative technology "AmpliTub" has no world analogues. banned in Russia for use in food and animal feed. The sets of GMO-Detect reagents are highly sensitive and comply with international standards. A set of reagents

Fig. 1. Devices for analysis of DNA and RNA on the basis of PCR in real time ANK-32

Fig. 2. Appearance of the "NANOFOR®05"

of the "Phytoscreen" technology allows to quickly identify DNA and RNA pathogens of plant diseases and pests. The set of reagents "OM-screen" does not have world analogues and allows to identify the 25 most dangerous and especially dangerous causative agents of diseases. The "SNP-Detect" reagent set allows detecting single nucleotide substitutions in DNA associated with a large list of genetic diseases, as well as providing information on individual characteristics of the organism.

A fundamentally new approach has been implemented that allows to measure the initial amount of specific DNA (RNA) in the test sample in a wide dynamic range from single to 10^9 copies.

The devices come in three versions: ANK-32, 48, 96 and are designed for analysis of 32, 48 and 96 samples, respectively (fig. 1).

The possibility of comparative quantitative analysis for five different types of DNA in one tube is provided simultaneously.

Instruments are included in the State Register of Medical Devices and Medical Equipment. Registration Certificate No. FS 022a2005 / 2163-05.

Application: medicine, sanitary and epidemiological control, agriculture, criminology, biotechnology, fundamental research in the field of nucleic acid analysis.

ANK-32, 48, 96 — the first domestic devices for DNA and RNA analysis, provided by domestic reagents for conducting research:

– Modified oligonucleotides;
– Probes for real-time PCR;
– PCR mixtures for research laboratories;
– Sets of reagents for real-time PCR;
– Sets of reagents for the isolation of DNA and RNA;
– Reagents for sequencing;
– Reagents for genetic analysis;
– Reagents for molecular biology;
– Consumables for PCR and genetic analysis.

2.3. The first domestic DNA sequencer "NANOFOR®05"

Of the whole range of scientific instruments produced by IAI RAS together with the Scientific Production Company SINTOL, it is especially worth noting the serial production of several instruments for basis stages of molecular genetic research, jointly with the Institute's industrial partner EZAN. The instruments are used in molecular genetic research, from sample preparation and separation of nucleic acids to their specific indication and sequence decoding. IAI RAS made Russia's first genetic analyzer (DNA sequencer) "NANOFOR®05" (fig. 2) intended for automatic DNA sequencing by Sanger's method, DNA and RNA fragment analysis, analysis of fluorescent-tagged biological and bioorganic compounds, and genome library quality assessment [4, 5]. "NANOFOR®05" is a medical product, which is successfully used (medical certificate RU No. P3H2015/3474 of December 28, 2015).

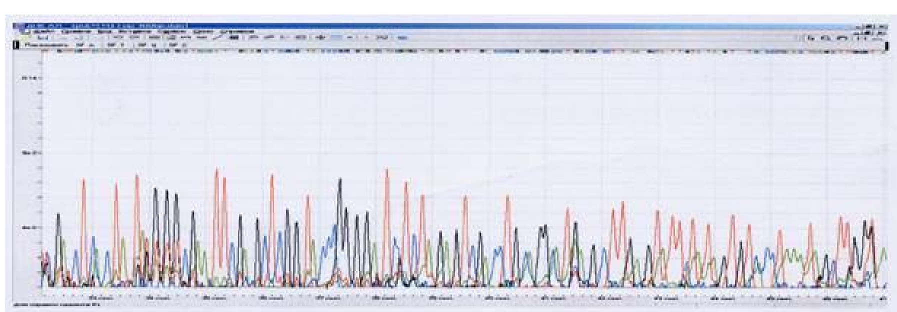

Fig. 3. "NANOFOR®05" depicts a sequence fragment of pGEM3Zf(+) plasmid DNA

In terms of its capabilities, the device is not inferior to the best foreign analogues (ABI Prizm 310 Applied Biosystems, USA) at a much lower price. "Nanophor-05" was created within the framework of the program of the Ministry of Education and Science of the Russian Federation "Research and development in priority areas of science and technology development".

Genetic analyzer "NANOFOR®05" is seven colors laser-induced fluoresce capillary electrophoresis system. Using "NANOFOR®05" it is possible automatically determine DNA sequence as well as DNA fragments lengths (fig. 3).

Peculiar features "NANOFOR®05" allows:

– Automatically reload capillary by sieving gel;

– Electro kinetic inject DNA samples into capillary from any position of 96-sample plate;

– Carry out electrophoresis of DNA fragments with the control of current, voltage, temperature;

– Detect the fluorescence signal in spectral range from 510 to 710 nm;

– Analyze up to 96 samples using user-made program.

Software adapted for Windows and has two blocks:

– Fragments analysis block;

– Sequence analysis block.

Software allows:

– Set the experiment parameters;

– Control main parameters during experiment;

– Analyze data using automatic and manual modes;

– View the "row" data.

"NANOFOR®05" can be used in the fields of application: medical diagnosis, treatment monitoring of socially significant diseases, sanitary and epidemiologic control, food analysis, biotechnology, valuable animal and plant species selection, criminalities (genetic identification), basic research related to nucleic acid analysis.

"NANOFOR®05" has main technical characteristics — table 1. "NANOFOR®05" has legal protection [6].

2.4. Systems designed to extract nucleic acids

IAI RAS develops sample preparation systems designed to extract nucleic acids, protein, toxins from

Table 1. Characteristics of "NANOFOR®05"

Detector	Fluorescence detector at spectral range from 510 to 710 nm
Laser	Solid-phase, l = 488 nm, power P = 100 mW
Separation efficiency	Single base separation efficiency for single stranded DNA fragments up to 600 nucleotides length with more than 98 % accuracy
Time of analysis, hours	2–2.5
High-voltage supplier	Voltage: from 1 to 15 kV, currency: 1–150 μA , instability: 0.03 % max
Sample plate	96-samples plate, 12 places for additional reagents with volume from 0.5 to 3 mL
Capillary	Standard coated capillary, internal diameter 30–80 μm, outer diameter 360 μm, length up to 1000 mm
Thermostat	Thermostat with Peltier elements, capillary temperature set from 30 to 60 (± 0.003) °C
Working regime	Automatic reload of gel under pressure up to10 atm, automatic probe separation using user made program with real time monitoring of main parameters of experiment
Power, kW	0.3
Weight, kg	48
Dimensions, mm	600 × 630 × 630

various samples. These systems can be flowing and stationary, using disposable cartridges and tablets. The system of sample preparation of nucleic acids for analysis of PCR, preparation of protein for electrophoretic analysis, analysis of samples for inorganic impurities, system for ultrasonic filtering of insoluble substances in density, size and mass has been developed in IAI RAS.

2.5. Perspective technologies on microchips for molecular genetic studies

Miniaturization, automation, and integration of analytical systems are the key trends in the development of instrumentation for biological sample test methods. The latter suggests combination of various methods, for instance with immunoassay and mass spectrometry methods, which provides ampler information on samples. In terms of miniaturization and automation of the systems, the most attractive are microfluidic technologies which allow to pass to a qualitatively new level of analysis and to implement "digital" methods for studying a biological sample. These methods provide a high sensitivity of detecting the target analyte in a compact instrument design.

The world market of microfluidic devices is growing, and experts estimate it at about $5.95 billion by 2020. Nearly one half of organizations working for microfluidic device manufacturing are concentrated in the USA, and about 40 %, in Europe, primarily in Germany, France, the UK, and the Netherlands. The highest market growth in the near future is predicted for systems focused on pharmaceutical research and point of care diagnostic systems. At the current time, a significant part of microfluidic devices (over 50 %) is used in pharmaceutical research (search for medications) and in Life Sciences, and about 14 %, in clinical and veterinary diagnostics [7].

Microfluidic devices are in demand for molecular analysis methods (nucleic acid amplification and sequencing). Some foreign-made microfluidic system models are presented on the Russian market (for instance for digital Polymerase Chain Reaction, dPCR), but in general, the market is actually not filled with these products, because there are macro counterparts that are actively sold by foreign companies, although microfluidic technologies have evident advantages. In the format of the microfluidic chip, integration of the main stages of the analysis can be performed and sample preparation (including sample purification, isolation of the target analyte such as nucleic acids), amplification and recording of its results can be carried out. The process phases are automated on a microfluidic chip using built-in or external functional devices (microvalves, pumps, dosing units, controllers, sensors, and detecting systems).

In a general case, a bio sample to be analyzed can be separated on a microfluidic device into four classes: 1) cells, 2) metabolites, 3) nucleic acids and 4) proteins. Each class may be presented from the point of view of its importance for diagnostics (including medical diagnostics, i. e. of infections and diseases) and appropriately studied. The cells, metabolites, nucleic acids and proteins can be analyzed for complete diagnostics in a rather short time.

The dPCR methods enabling detection of nucleic acids at the particular molecules' level have become widespread due to advanced technologies of microtreatment and modification of materials, and development of microfluidic devices and detecting systems. For instance, the dPCR method can be implemented in fixed chambers (such as in the Mx3005P (or Mx3000P) systems, QPCR System Agilent Technology) [8]; in "digital" panels (such as Dynamic Array and Digital Array by Fluidigm [9]; OpenArray Real-Time PCR Platform by Applied Biosystems [10]); microfluidic devices (for instance with SlipChip components [11]) etc. Using special flappers in micro devices, a sample can be divided into thousands of parts where dPCR will be conducted. This approach has been currently implemented in commercial instruments, such as Fluidigm BioMark™ Real-Time PCR and Fluidigm EP1™ end point PCR [9]. Another successful line of development is generation of methods and instruments for amplification of nucleic acids in a sample isolated from the environment with a thin oil or polymer film. Such methods were named "droplet" methods [12]. Although the "droplet" microfluidic methods have not been sufficiently implemented by now in commercial dPCR systems due to engineering and procedural problems, still there are several versions of off-the-shelf instruments: 1) QX200™ Droplet Digital™ PCR System (Bio-Rad) [13] enables generating ~ 20 000 monodisperse droplets from 20 μl of a PCR reaction mix; 2) RainDrop® Digital PCR System (Raindance Technologies Inc, USA) [14] conducts 80 000 droplets per second in 8 channels simultaneously.

IAI RAS carries out research aimed at making microfluidic-platform instruments with highly sensitive optical detecting systems, and at developing methods for biological sample rapid analysis. By now, prototypes of microfluidic analytical systems have been created, and test models of single-channel and multichannel microfluidic chips have been developed and obtained a) for bio sample separation by electrophoresis methods [15], b) for cell research by optical microscopy methods [16], and c) for "droplet" microfluidic techniques [17].

The development of microfluidic technologies and the manufacturing control, manufacturing methods is carried out jointly with the St. Petersburg National Academic Research University of the RAS [18].

Studies on the electrophoretic separation of labeled fragments of nucleic acids, assay of sulfonamide anti-

Fig. 4. Electrophoretic microfluidic analyzer (EMA)

biotics, insulin detection by the competitive immunoassay method, amino acids separation etc. have been conducted on microfluidic chips of glass materials since 2005; nucleic acid amplification methods, in particular using isothermal amplification, have been developed for MFC of polymeric materials.

Combining various methods of biological sample analysis in the microchip format enables implementation of the PCR method with real-time detecting on a microchip when finding the cDNA of the tumor marker cytokeratin 19, with a rapid amplification quality test performed by electrophoretic separation of amplification products on a microfluidic device [19]. This approach allows the creation of modern small-size analytical systems for the rapid analysis of wide-scale biological samples.

Nucleic acid amplification and sequencing systems require sample preparation, i. e. nucleic acid extraction. An automated system for nucleic acid extraction on the basis of a disposable cartridge has been created to solve the problem of preparation of real biological samples (environment objects, blood etc.) The stages implemented in the cartridge are sample lysis, separation of nucleic acids on magnetic particles, and purification and concentration of nucleic acids. Development in this direction, i. e. combining a nucleic acid separation cartridge with a microfluidic device for multiplex amplification, will enable to improve the accuracy and reliability of analysis, to reduce its duration, and to get rid of possible errors associated with "manual" sample preparation.

Porous structures may be used for example as component filtering and separation devices, electroosmotic pump elements, highly sensitive sensing elements etc. When porous structures (for instance porous glasses [20]) are used as sensing cells, a higher sensitivity can be achieved compared to planar sensors due to the large effective surface area of a porous medium. The research conducted by IAI RAS and the Silicate Chemistry Institute of the RAS enabled creation of a prototype microfluidic device for competitive immunoassay of bio samples with an integrated sensing cell on the base of sodium borosilicate glass SBS [21]. The proposed approach may be used for making microfluidic biosensor devices for detecting other proteins.

IAI RAS produces analytical systems based on micro fluidic chips (fig. 4). Micro fluidic analytical systems (MFAS) are the latest generation of general-purpose analytical systems for research and for routine analysis. Implemented in the analytical systems based on microfluidic chips is the advanced instrument architecture concept lab-on-a-chip (laboratory on a chip). The microfluidic chip format combines several different devices enabling all handling of a sample and reagents at the nanoliter and picoliter volume (transportation, dispensing and mixing), conducting chemical reactions, and separation of the product obtained (for instance by capillary electrophoresis methods). The detectors may be provided on a micro chip or outside it. Such systems have several advantages compared to traditional analytical systems. The most evident of them are smaller volumes of the sample and reagents, which is important for expensive samples and substances, high speed of analysis, ability of miniaturization of the analytical system, and ability of full automation of all analysis phases.

MFAS use microfluidic chips of glass and polymeric materials. Microscale structures in glass microfluidic chips are made by optical lithography and subsequent acid etching; for polymer models, laser microprocessing or master mold casting techniques are used. A microfluidic chip may have different topologies (architectures) — a network of micro channels, reactors, micro pumps, sensors, membranes, and mixers — depending on the analysis method selected.

IAI RAS has developed and prototyped analytical systems based on microfluidic chips for capillary electrophoresis and micro chip devices for polymerase chain reaction (PCR). Updating of the developed analytical systems, practicing quick analysis methods on microfluidic chips, and development of new topologies and designs of microfluidic chips are going on. Polynucleotide and oligonucleotide analysis methods with the use of fluorescent tags have now been created.

MFAS — electrophoretic microfluidic analyzer is intended for quantitative quick analysis of liquid sample composition by the capillary electrophoresis method on a micro chip with a laser-induced fluorescence detector. MFAS applications: medical diagnostics, ecology, chemistry, biotechnology, criminal investigation and emergency forensic examination, food analysis, pharmacology (table 2).

Table 2. MFAS essential characteristics

Detector	Laser-induced fluorescence detector (solid-state laser, excitation wave length: 473 nm; spectral range of fluorescence signal recording: 510–650 nm)
Two-channel high voltage source	1. Voltage: (100–2000) V; current: 1–1000 μA; instability: not to exceed 0.03 % 2. Voltage: (10–500) B; current: 1–1000 μA; instability: not to exceed 0.03 %
Sample injection	Electrokinetic
Operating mode	Automatic, to a preset program, with continuous monitoring of the sample separation process and experiment parameters
Overall dimensions, mm	320×190×150

EMA uses single-channel microfluidic chips of glass or polymeric materials (fig. 5). Application of a 3–5 μL sample to a microfluidic chip is with a micropipette (microdispenser). All other operations are automated. Samples are dispensed and injected by the electrokinetic method, which permits analyzing volumes of 50 pL or higher by the capillary electrophoresis method. Separation products are recorded by a laser-induced fluorescence detector and displayed on a computer screen in real time. Monitoring and recording of all electrophoretic separation parameters are performed simultaneously.
Overall dimensions — 60×15 mm, thickness — 4 mm. Separation channel: length — 38 mm; width — ~50 μm, depth — 15 μm.
Volume of loaded sample — up to 5 μL.
Volume of injected sample (for a single analysis) — ~50 pL.

Analysis results are provided in fig. 6.

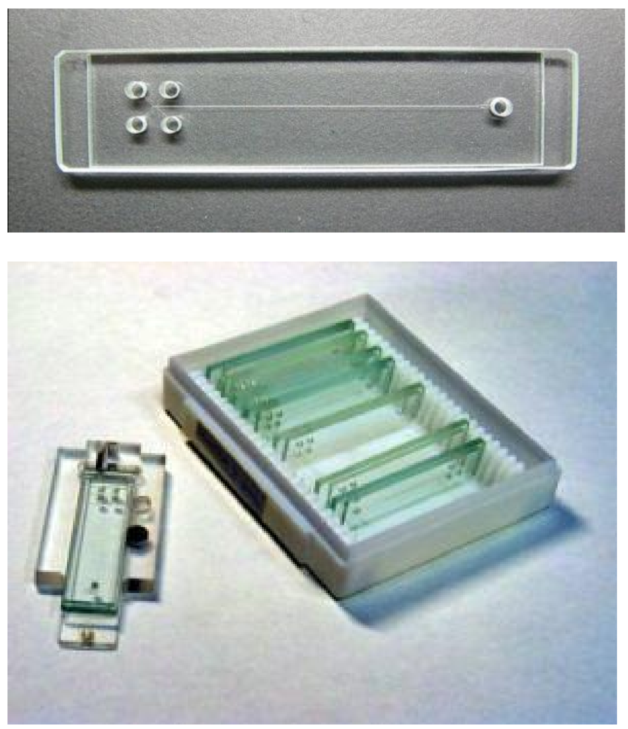

Fig. 5. Glass microfluidic chips (single-channel) for electrophoretic methods

2.6. Microfluidic devices

IAI RAS development and manufacturing of microfluidic devices from glass and polymeric materials for biological sample research:

microfluidic devices for hydrodynamic separation of microparticles; with integrated electrodes (for dielectrophoresis etc.); for study of bio objects by optical microscopy and spectroscopy techniques.

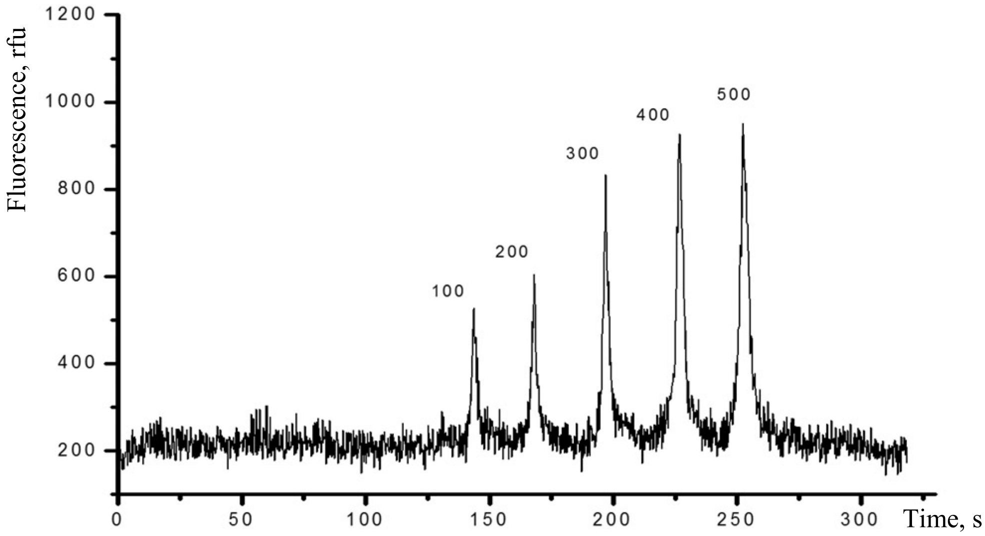

Fig. 6. Separation of DNA molecular weight markers (100, 200, 300, 400 and 500 base pairs)

Microfluidic devices for various versions of conducting a polymerase chain reaction

1. Liquid PCR. End-point recording (fig. 7)

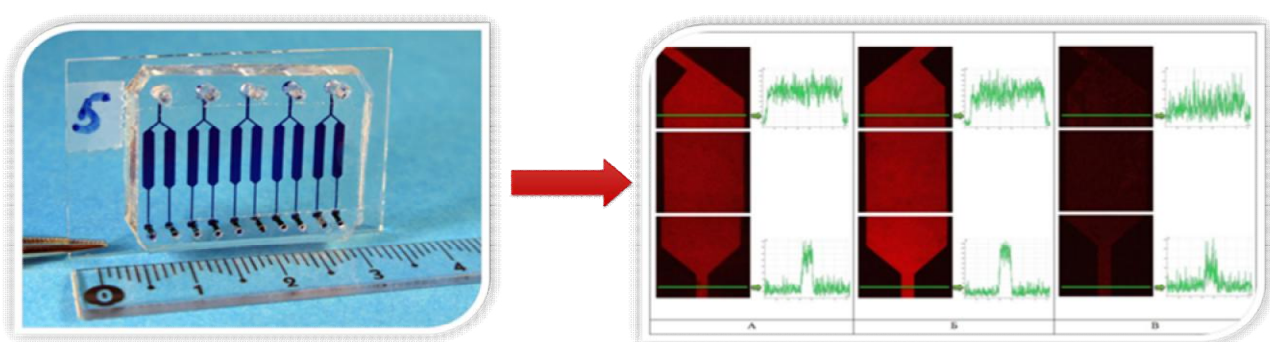

Fig. 7. Integrated polyolefin film (end-point recording)

Material / technology: polydimethyl siloxane PDMS Sylgard® 184 (Dow Corning, USA) / Soft-contact lithography technique.

Design and its features: five pairs of reaction chambers ~160 μm deep and ~1.4 μL in volume each. Integrated polyolefin film to prevent fluid evaporation through the material when heated; encapsulation with a protective glass plate by plasma treatment.

2. Colony technique (PCR in polyacrylamide gel) (fig. 8)

Fig. 8. Sealing by bonding with polymer compounds

Material / technology: glass of Grade K8 / Photolithography and acid etching technique.

Design and its features: four reaction chambers 200 μm deep, ø 14 mm (right); three reaction chambers 200 μm deep, ø 12 mm (left). Sealing by bonding with polymer compounds, PAAG immobilized in the chambers.

3. Drop-based microfluidics (fig. 9)

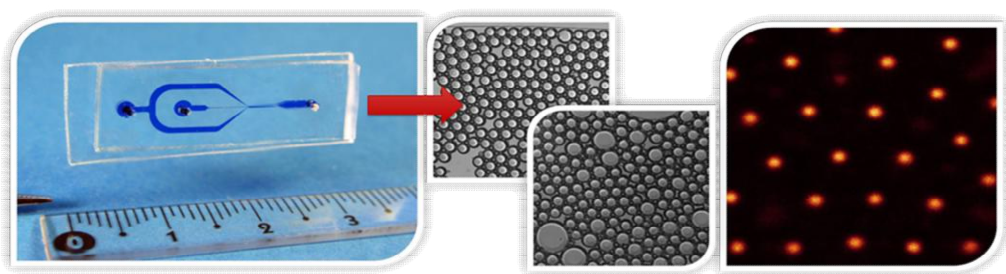

Fig. 9. Microfluidic chip with a drop (emulsion) generator. Soft-contact lithography technique

Material / technology: PDMS Sylgard® 184 / Soft-contact lithography technique

Design and its features: microfluidic chip with a drop (emulsion) generator, sealing with protective PDMS film by a plasma treatment method, thermal annealing.

3. COMMERCIALIZATION OF INNOVATION AS A BASIS FOR A POSITIVE SCENARIO FOR THE DEVELOPMENT OF SCIENTIFIC INSTRUMENTATION

The scientific instruments offered by IAI RAS enable setting up up-to-date small-size analytical systems with advanced software for rapid analysis of a wide diversity of biological samples.

Instruments created in the IAI RAS for molecular genetic research, including "NANOFOR®05", were exhibited at exhibitions and were awarded medals and diplomas of numerous exhibitions, including:

– "Molecular diagnostics-2014", March 2014, Moscow;

– VII Congress of the Russian Society of Medical Genetics, May 2015, Moscow;

– The exhibition "Interlabdiagnostika-2015", September–October 2015. Moscow;

– II All-Russia scientific-practical conference (with the international participation) "Socially significant and especially dangerous infectious diseases", November 2015, Sochi;

– "Healthcare 2015", December 2015, Moscow;

– "Analytics Expo 2016", the 14th International Exhibition of Laboratory equipment and chemical reagents, April 2016, Moscow;

– The First International Specialized Exhibition "Import substitution", September 2016, Moscow;

– XI International Exhibition "World of Biotechnology 2017", February 2017, Moscow.

Scientific devices of molecular genetic research, including "NANOFOR®05", have found their application in organizations representing the following fields of research:

– Research Institute of Medical, Biological, and Agricultural Profile;

– Universities of medical, biological, agricultural profile;

– Bureau of Forensic Medical Examination of the Ministry of Health of Russia;

– Forensic centers of the Ministry of Internal Affairs of Russia;

– Laboratories of the Investigative Committee of Russia;

– Private genetic laboratories that determine paternity;

– Centers for the Prevention and Control of HIV and AIDS of the Ministry of Health of Russia;

– Clinical hospitals of the Ministry of Health of Russia;

– Medical Scientific and Practical Centers;

– Breeding and seed centers of agro-industrial complex.

Successful implementation of the scientific instrumentation development concept coordinated by the Council for Scientific Instrumentation and funded by the Federal Agency for Scientific Organizations will help to implement a positive scenario of the development of Russian scientific instrument making, thus contributing to imports phase-out under the anti-Russian sanctions [22].

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ИННОВАЦИИ В НАУЧНОМ ПРИБОРОСТРОЕНИИ

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Описаны прорывные научные исследования в области молекулярно-генетического анализа, которые относятся к рискованному, значительному для государственных организаций финансированию. Представлены научные приборы, иллюстрирующие развитие одного из наиболее перспективных направлений научного приборостроения, которое позволяет создавать малогабаритные аналитические системы с современным программным обеспечением для экспресс-анализа большого разнообразия биологических проб.

Кл. сл.: биологический образец, секвенатор ДНК, микрофлюидный чип, полимеразная цепная реакция ПЦР, флюоресценция, капилляр