British Journal of Economics, Management & Trade
9(3): 1-16, 2015, Article no.BJEMT.19532
ISSN: 2278-098X

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Prospects for Creating Material Grounds for Information Economics on the Basis of Micro-Electronic Technologies and Sensor Enginery Utilizing NBIC-Technologies in Ukraine

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Authors' contributions

This work was carried out in collaboration between all authors. Author IM designed the study, wrote the protocol, and wrote the first draft of the manuscript. Author OK managed the literature searches, analyses of the study in information economy development in the world and Ukraine. Author YM managed the content analysis of classic papers and researches of the prospects of creating information technology material base in the world and Ukraine on the grounds of micro-electronic technologies and sensor enginery utilizing NBIC-technologies. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJEMT/2015/19532
Editor(s):
(1) Chen Zhan-Ming, School of Economics, Renmin University of China, Beijing, China.
Reviewers:
(1) Yang Weiwei, Beijing University of Technology, China.
(2) Anonymous, Tunisia.
Complete Peer review History: http://sciencedomain.org/review-history/10259

Short Research Article

Received 15th June 2015
Accepted 2nd July 2015
Published 21st July 2015

ABSTRACT

Aims: The Information Economy development is inseparably connected with the creation of material base on the grounds of micro-electronic technologies and sensor enginery in the world leading countries. However, each country elaborates its own the most prospective micro-electronic technologies and sensor enginery. The main aim of the research at analyzing the prospects of creating information technology material base in Ukraine on the grounds of micro-electronic

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technologies and sensor enginery utilizing NBIC-technologies. The is to find out, which technologies could be the foundation for Ukrainian innovation development in near future under conditions of new Nano-bio-info-cognitive (NBIC) technological revolution.
Study Design: The reviews were carried out in the period 2008–12 on the basis of studying the world countries micro-electronic technologies and sensor enginery development trends as well as on the basis of the research results obtained by Ukrainian academic institutions.
Place and Duration of Study: Scientific research center for industrial development problems of the National academy of sciences of Ukraine, Department of Foreign Economic Relations and Touristic Business between January 2015 and April 2015.
Methodology: Content analysis has been used as the main method of research, which allowed making a meaningful analysis of classic papers and researches of modern economists-practitioners devoted to the peculiarities of the modern prospects of creating information technology material base in the World and Ukraine with using of NBIC-technologies.
Results: Convergence and integration of nano-bio-info-cogno-technologies considerably increase capabilities of micro-electronic technologies and sensor enginery. The article analyses the prospects of creating material grounds for information economics in world countries and in Ukraine on the basis of micro-electronic technologies and sensor enginery utilizing NBIC-technologies. The article demonstrates that in the result of implementing comprehensive scientific-technical programs to develop micro-electronic technologies and sensor enginery during 2008 – 2012 in Ukraine new radiation detectors and sensors were designed, technologies to produce nano-ceramics were developed together with high-quality sapphire substrates, or photodetectors and infra-red emitters, or uncooled multi-element sensitive receivers, or science-intensive modern semi-conducting materials and sensor appliances on their basis. Prospects for implementing bio-sensor systems for monitoring purposes in environmental protection, medicine, pharmaceutics, food-processing in Ukraine were also demonstrated together with new materials and drugs generation for medicine and pharmaceutical industry.
Conclusion: We may conclude that in order to set up information economy material base, during 2008-2012 Ukraine undertook efforts to develop and implement the following modern microelectronic technologies.

Keywords: Material base for information economy; high-technology industries; micro-electronics; sensor enginery; NBIC-technologies.

1. INTRODUCTION

Micro-electronics has strategic importance for Ukrainian economy as it determines the technical level of industrial and household products, its competitive capability, stimulates other branches development, ensures the national defense capability. Ukraine is among 17 world countries that have mastered micro-electronic and sensor technologies. Recovery of the most technologically advanced directions in producing materials, appliances and electronic systems as well as their further development would ensure setting of high-tech economic structure and enhance the products competitiveness, solving important social problems in improving the population living standards.

The named problem was tackled by many renown scientists, including also M. Roco, W. Bainbridge, B. Tonn, G. Whitesides [1,2], who studied the issues of knowledge, technologies and society convergence; L. Foster [3] worked with the issues of using nano-technologies for microelectronics; A. Kazantsev, V. Kisilev, D. Rubvalter, O. Rudenskiy [4], P. Maltsev [5], F. Rahman [6], together with Ukrainian scientists M. Kizim, I. Matyushenko, Yu. Moiseienko, I. Buntov, O Khanova et al. [7-12] dealt with the development and prospects for NBIC-civilization. At the same time the growing implementation of NBIC-technologies into developed countries information economy's material basis requires review of the prospects for their use to develop micro-electronics and sensor enginery in Ukraine.

The article aims at analyzing the prospects of creating information technology material base in Ukraine on the grounds of micro-electronic technologies and sensor enginery utilizing NBIC-technologies.

2. METODOLOGY

Content analysis has been used as the main method of research, which allowed making a meaningful analysis of classic papers and researches of modern economists-practitioners devoted to the peculiarities of the modern prospects of creating information technology material base in the World and Ukraine with using of NBIC-technologies.

General scientific methods make up a methodological foundation of the research. They include: description, comparison, statistics review, system analysis and others, which help characterize this phenomenon development in a more comprehensive way. We also apply the methods of dialectic cognition, structural analysis and logic principles that provide for making authentic conclusions as regards the investigated topic. We used the historical method, analogies and synthesis method for the analysis of policies of developed countries, and Ukraine in the field of microelectronics and the creation of knowledge-based economy.

Official statistical data of the state institutions and international organizations, publications of reference character, analytical monographs, annual statistical bulletins, Ukrainian National Academy of Science reports as well as annual Ukrainian State Statistical Bureau reports serve as an information grounds for our research.

3. RESULTS AND DISCUSSION

3.1 Main Directions of Molecular Electronics Development in World Countries

Convergence and integration of nano-bio-info-cogno-technologies fantastically increase the capabilities of information technologies and micro-electronics, providing for qualitative change in their directedness and areas of application. Thanks to NBIC-technologies wide application technological break-troughs will be performed. They will be connected with a considerable progress in miniaturization, with increasing information processing appliances' speed and productivity – input sensors, logic and memory devices, displays and devices to transfer information; new means of information storage would be developed; biochips would be in wide use.

Moreover, NBIC-technologies would help create new technical means to implement prospective computation concepts, which would imitate human thinking process in a bigger scale. For example, at the end 1980-s in the US there emerged a proposal to modify computation concept in such a way that it should organically include the "style" of human brain information processing, which was based on "permanent joint interaction between systems, the activeness of which is expressed as interaction of space-time images in a multi-layer neurons' system" [13]. Those ideas underlay the interest to neuron networks that reemerged at that time. And what is more, it spurred the interest to complex variants of semi-conducting computer architecture, that would provide for many-fold increase of computation parallelism.

In those years Michael Conrad, a US leading specialist in the sphere of molecular electronics, published a detailed comparative analysis between human brain information specific features and Von Neumann computer. Conrad's approach had a specific feature, because he based his theory on general information perceptions not connecting them to any physical manifestation of appliances. Fundamental differences in information processing by a brain and by a computer could be formulated as follows: capability of a systematic structural programming; parallel or consecutive character of information processing; vertical or horizontal information flows, etc. [14].

Therefore, it was demonstrated that Von Neumann computer and human brain are two parallel alternatives for information processing.

The main information characteristics of reaction-diffusion devices (RDD) include:

1) In contrast to Von Neumann computer, reaction-diffusion devices are not the ones that could be programmed from outside. Their dynamics is determined by environmental conditions (and structure) and controlling factors' impacts;
2) Even the simplest devices demonstrate a very high degree of parallelism, mixed continuous discreet dynamics and vertical flows of information processing and transfer; even within the simplest system it is possible to differentiate:
   The level of information macro-micro-transformation, i.e., the level of entering output data; Dynamics at molecular (micro) level, that implement the method of information processing; the level of information macro-micro-transformation,

i.e., physical-chemical reading-off the results of problem solving;

3) The degree of chemical reaction-diffusion devices' self-organization is very high. Moreover, they manifest gradualism, i.e., small changes in the environment condition (its components concentration and temperature) entail only a comparatively small quantitative, but not sharp qualitative variation of dynamic modes in specific status areas. This feature, essentially, underlie the learning systems build-up;
4) Reaction-diffusion systems (RDS) have other specific features that determine the system's capability for adaptive behavior. They include the character of interaction with the environment, deep feed-back relations, etc.

Therefore, reaction-diffusion environments practically have all characteristics, necessary for building up devices on their basis that have high behavioral complexity, could have capacity of learning and solving tasks of high computation complexity. Comparison between information characteristics of Von Neumann computer, a human brain and a reaction-diffusion device provides for a conclusion that RDD is considerably closer to brain than to a digital device (even if a digital device is realized on the level of ordinary multi-processor parallel system). A brain by its information characteristics is incomparably richer than any artificial device. The completeness of intellectual problems solving by brain (the problems of high computation complexity) is fantastic. However, remarkable similarity of information characteristics of the distributed systems that function on the basis of non-linear dynamic mechanisms, provide for assuming that it is possible to create devices that imitate brain functions, at least in some limited areas of brain intellectual activities.

In the course of the last decades of the last century a new area of investigation emerged, which was called "Molecular electronics". Fig. 1 presents the main directions of its development ([13], p.423).

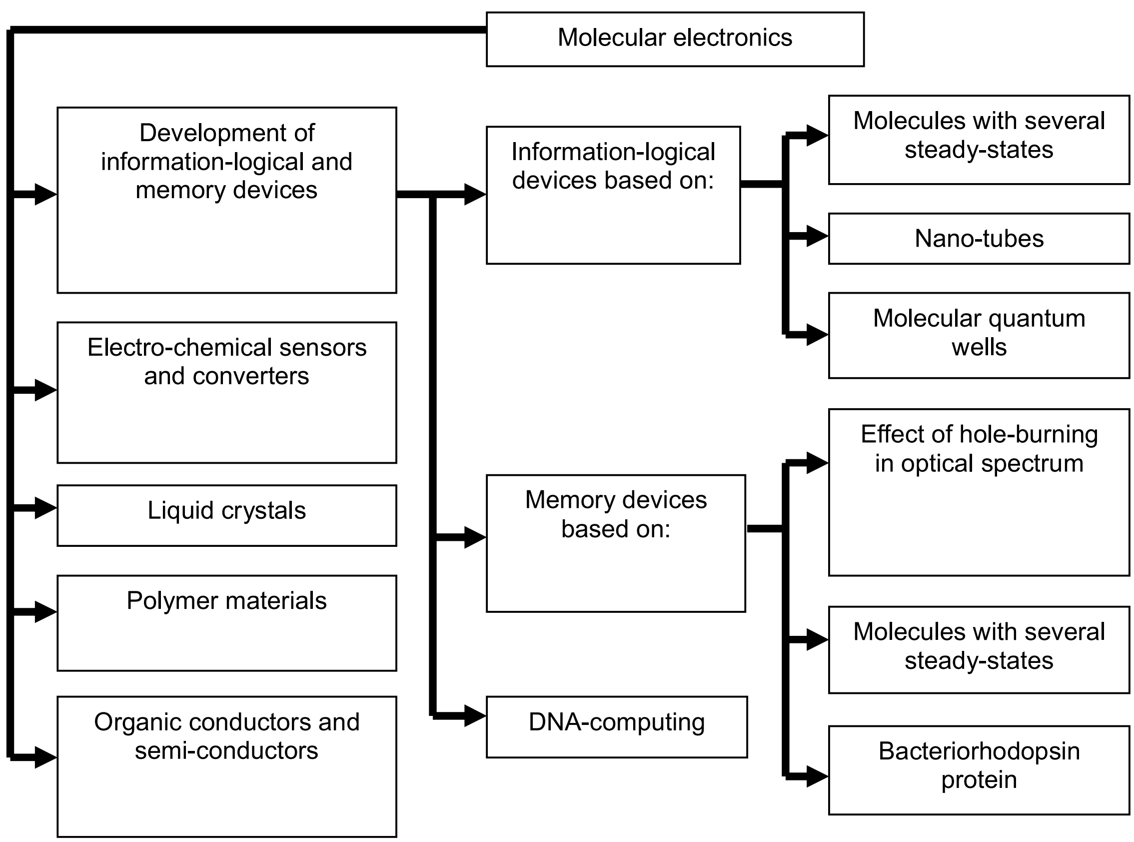

Fig. 1. Main directions of molecular electronics ([13], p.423)

During 1980-90-s it was demonstrated that molecules' assembles possessing the determined characteristics, are prospective objects to develop information storage and processing devices, i.e., chemical environment could be used in computation or in memory devices. In its essence, it was a transfer from molecular devices ideology (i.e., systems, where separate molecules serve as element base) to the devices, which are built-up on the basis of chemical environment, i.e., macro-objects, which at the same time preserve separate advantages of molecular objects. Those two main trends – using molecular environments and synthesis of big switchback molecules - entailed creation of acting information processing molecular devices in the second half of 1990-s.

In absorption spectra of different compounds there appear bands that correspond to substances' molecules transfer into one of the excited states. If the excited state life is sufficiently long and if it could be transferred into a molecule main reverse state with the help of any physical impact, then such chemical compounds could be used for information recording and storage.

Technically, the simplest way is to use quasi-two-dimensional film of a substance, which is most suitable for that. Efforts in that direction entailed creation of a number of acting dummies of memory devices. For example, Robert Berge developed different variants of random access memory for computers on the basis of unique bacteriorhodopsin protein. Bacteriorhodopsin is a light sensitive protein contained in purple membranes of halo-bacteria Halobacterium Halobium. Halo-bacteria reside in salty water reservoirs or sources of salt production. Bacteriorhodopsin molecules have violet color and create photo-synthetic center for halo-bacteria. Having absorbed light quantum, it acts as proton pump providing for adenosine triphosphate (ATP) synthesis. Bacteriorhodopsin molecule structure is a cyclic combination of 7 polypeptide spirals, inside of which there is light-sensitive fragment – chromophore. During light absorption molecule structural rebuilding occurs.

Bacteriorhodopsin protein possesses unique for proteins stability. It is capable to preserve unchanged its stability in the form of dry residue, and in polymer films, having the thickness of mono-layer from 5 nm up to several dozen microns.

Fundamental property of bacteriorhodopsin molecule– photochemical cycle – is a sequence of exited states (intermediates), which the molecule passes after its excitation with light radiation. Intermediates' spectra considerably differ from each other. In the course of photo cycle the protein optical characteristics– the indicators of refraction and absorption - also change. Therefore, natural bacteriorhodopsin protein at room temperature behaves as photo-chrome environment with limited time of information storage.

At the beginning of 1990-s Robert Berge, using that feature of bacteriorhodopsin, developed a cryogen optical random access memory device for digital computers. The information in them was recorded on a film of bacteriorhodopsin-holding polymer and was read-off from it with the help of laser rays with different radiation frequencies. During 1990-s and beginning from 2000-s the Berge group also developed holographic associative memory, which provided for information reading-off that had only limited volume (e.g., image recovery by only its fragment). But the main efforts were concentrated on developing volumetric optical memory of super-high capacity.

In contrast to previous variants of memory devices, where information is recorded on flat bacteriorhodopsin film, in 3-D memory information is stored in the whole environmental volume. At the same time, volumetric memory on the basis of bacteriorhodopsin – is a technically complicated electronic-optical device that includes several lasers with emission in different spectrum domains. Activation of a page (thin layer) inside the memory environment volume occurs with the help of red lasers, which excite all the bacteriorhodopsin molecules that are present on the page environment layer. Then through liquid crystal transparency only the selected elements of the space are lighted, the ones, which correspond to bit "1", and the rest bacteriorhodopsin molecules shift to ascending status, i.e., they keep the bit value "0". In order to read-off the data, the page gets activated by a system of green lasers. Full memory clearing, i.e., transferring all the molecules into a major state, is performed with the help of blue laser.

Short life of bacteriorhodopsin's intermediates and parallel simultaneous information processing on the page result in the fact that time of read-off recording could be reduced to several dozen Gb/sec. According to the evaluation, the volume of 3 cm3 could store enormous information of hundreds Gb. At the same time, creating such system is the most complicated scientific and technical task, and therefore till now the main solutions are tested on the acting dummies with memory capacity not exceeding several dozen kB. Developing devices on the basis of bacteriorhodopsin as well as some other researches of 1990-s have approximated industrial application of molecular environments in computer equipment.

In 1990-s the understanding of the fact that the molecules, the switchback of which from one state to the other occurs at the expense of electron-conformational transfer, had provided for the development of electronic diagrams prospective elements, and made it necessary to look for specific molecules of such a type, which would satisfy the theoreticians' expectations. Organic chemistry synthetic methods potential, which sharply grew up in the second half of the 20th century, as well as development of chemical build-up theory on the basis of quantum-chemical views – provided for making synthesis of a number of new molecules.

Among them there were molecules that were built-up from squeezed into each other cycles (i.e., bonded cyclic fragments, which are connected as chain elements), which received the name "catenans" (from Lat."catena" – chain). Rotaxanes – chemical compounds, where cyclic group threads through linear chain of molecular fragments – are close to catenans by structural features. Voluminous molecular groups at the end of the chain exclude the molecule disintegration at the expense of cyclic fragment exit from the chain. Similar structures, built up by the principle of purely mechanical bonding of fragments, received the molecules' name "the ones without chemical bonding". In the root of their synthesis there was the idea of molecular structure self-organization and an analogy with biologic principles of big molecules synthesis.

Exactly the molecules of catenans and rotaxanes have become a foundation of break-thorough in creating molecular electronic diagrams, which occurred at the beginning of 2000-s on the initiative of a well-known US company «Hewlett-Packard» and California university in Los Angeles. To form up a memory device on the basis of Rotaxane molecule R (which is a poly-ether cyclic chain, on which, as a necklace on a string, a cyclic molecular fragment is applied) a unique method, based on the technological principles "bottom-up", was used. The grounding for such methodology was laid by:

- The so-called crossbar architecture of the memory device;
- Imprint-lithography, that provides for forming nanometric size elements on the substrate surface;
- Langmuir-Blodgett method to form up monomolecular films out of Rotaxane R oriented molecules.

To assemble a memory device, Rotaxane monomolecular film was applied on a substrate with the pre-formed array of electrodes, and above it there was another substrate with electrodes perpendicular to the first array electrodes. It's natural that the researchers regarded the accomplished work as only the beginning of complex scientific and technologic research that should lead to industrial production of principally new digital computing systems.

In 1996 after publicizing first results the head of the California University group James Hit shared information about specific features of molecular assemblies and in particular ([14], p.117):

- Molecular assemblies perform the same functions as silicon assemblies but many times better. Those assemblies are much more miniature, more productive (faster) and cheaper;
- Molecular assemblies have no technologic defects, which could be a serious problem when producing semi-conducting integrated circuits;
- Molecular assemblies consume energy an order of magnitude less than semi-conducting circuits.

At the same time there still exist a sufficient number of complex problems including also optimal architecture of huge molecular elements arrays. Regardless of that fact, Mr. Hit was sure that at the beginning of the second decade of our century we should have the first hybrid computer with molecular memory logic elements.

In March 1997 California Molecular Electronics Corporation (CALMEC) was set up in the USA. Leading scientists in the field of switchback and conducting molecules development were its founders. The Corporation's main purpose was checking the concepts of information processing devices' molecular built-up, creating the devices' prototypes with their further licensing and commercialization with the help of other companies. The break-through know-how of the corporation was creating “hiropticene” – a switchback molecule. That optically active molecule was not discovered but invented. Its two optical isomers – two stable states – have reverse directed dipole moments. It gives the opportunity to use electric signals for switching. Barrier between the conformations is sufficiently big to disconnect unwarranted switches that could be caused by accidental fluctuations (though, switching with electric signal is constrained). Therefore, light-sensitive grouping was injected into the molecular structure, and molecular system characteristics were selected in such a way that the energy barrier between molecules conformations in their exited state would be much less than in the major state. Therefore, the required molecule switch occurs with the help of simultaneous impact of light radiation and electric field. Absorption band of light-sensitive grouping, the structure of which is a commercial secret, coincides with the wavelength of He-Ne-laser radiation. With such a scheme the switch-time is in femtosecond (10-19 s) range, and hiropticene is a fast switching element.

CALMEC corporation head determined prospects for hiroptecene use as follows:

- Potential to create memory devices of 16 Tbit capacity in one cubic meter volume (it’s approximately two trillion data units). The developed molecular memory could store in the same volume the amount of information which is 34 times more, than modern semi-conductor’s memory;
- Memory devices structure provides for parallel data read/write. It ensures reading of one million bits of information per one reading out of 2000 readings per second, i.e., achieve the speed of read/writing of about 2 Gb per second.
- Miraculous success of hiropticene and memory developers on the basis of Rotaxane is a top notch of modern technologies. But time and costs would be required to have those devices on sale.

Other forecasted breakthroughs are connected with the following trends [15]: decrease of micro-processing devices’ energy consumption and costs; creation of neuro-computers, that would many times exceed by their characteristics the best samples of computing equipment; emergence of powerful emitters with band frequencies that can rebuild, as well as emergence of broad-band photo-detectors with high efficiency ratio in optoelectronics; development of communication means with higher frequencies that would provide for working range band increase approximately by an order of magnitude; mass production of small but more capacious devices for information storing; emergence of integrated nano-sensor systems to gather and transfer big data arrays at small sizes, weight and energy consumption; creating unmanned transportation means and military hardware operated by high-productive computers.

3.2 Prospects for Developing Micro-electronic Technologies and Producing Devices on Their Bases in Ukraine in 2008–2012

As of today Ukraine has the best starting positions on world markets in the following spheres: lighting equipment on the basis of super-bright light diodes, micro-wave electronics, opto- and infra-red electronics.

On 21.11.2007 the Ukrainian Cabinet of Ministers approved State Target Scientific-technical program (STSTP) “Design and development of micro-electronic technologies, arranging series production of devices and systems on their basis” for the period 2008 – 2012 [16,17]. The most prominent results of the Program during 2010–2012 are presented in Table 1 [18-22].

3.3 Created Science-intensive Sensor Products in Ukraine in 2008-2012

Ukraine possesses the necessary science and production potential capable to ensure development of the national sensor technologies, scientific-technical and design-technological engineering directed to create sensor science-intensive products. In the latest years Ukrainian scientists and designers have achieved substantial results in that sphere. At the same time, considerable lag of the national industry from the world development of intellectual and hardware means on the basis of sensor technologies can be explained among other things by departmental apartness of scientific academic and industry-specific establishments from higher educational establishments and industrial enterprises, by low level of innovations implementation within local companies, by insufficient financing of science in general.

Table 1. The most prominent results of accomplishing STSP of NAS of Ukraine "Design and development of micro-electronic technologies, arranging series production of devices and systems on their basis" for the period 2008–2012

Year	Program direction	Most prominent result	Practical value
1	2	3	4
2008	Creating radiation detectors and sensors	Method to manufacture 32-channel X-radiation detectors with increased spatial separation was developed on the basis of scintillation linear arrays of varying thicknesses	Producing X-radiation detectors
		New method to register fast neutrons basing on the mechanism of inelastic scattering in non-organic scintillators' grating was developed; the testing results proved high efficiency of that method	New method to register fast neutrons
		New types schematic electrical diagrams were developed, and dummies of charge-sensitive preamplifier and amplifier pulse-former on the basis of active filter for detecting units on CdZnTe were developed.	Usage of emergency doses and NPP radiation situation evaluation in measuring devices
		Correcting of technology to produce UV sensors on ZnSe(Te) was carried out to enhance sensitivity in spectrum shortwave range (λ ~ 200 nm), and to increase the number of applicable devices	Correcting technology to produce UV sensors
		Production start-up of silicon p- and n-photodiodes that have energy resolution on gamma radiation source at the world level standard was initiated	Production start-up of silicon p- and n-photodiodes
		Technology to produce CdZnTe detectors for broad-band detecting of emergency spectrometric units was created	Technology to produce CdZnTe detectors
	Developing technology to produce nano-ceramics	The method to produce quantum dots CdSe/ZnS was developed using accessible and safe synthetic predecessors of cadmium and zinc.	Method of quantum dots synthesis
	Production of high-quality sapphire substrates	Commissioning and setting in operation two resistive installations to grow sapphire by Kiropulos method	Two resistive installations to grow sapphire
	Production of photodetectors-emitters	Main components of optoelectronic component base were developed to create production-technological foundation an adjusting small-series production of infra-red vision devices on the basis of photodetectors	Parts of optoelectronic component base
	Production of super-high-frequency elements base	The work to create multi-elements photodetectors of IF-range on the basis of CdHgTe was completed. Experimental sample of IF photo detecting matrix was manufactured with the format 128 x 128 for 3 -5 μm spectral range.	Photo detecting matrix for IF-range device
		Technical documentation to ensure production of diodes' dummies, the parameters of which are stable in temperature range -60 до +80ºC and with the thermo-cycle within the same temperature limits, was developed	Potential to manufacture diodes dummies

2009	Creation of radiation detectors and sensors	Preparation for industrial production of UV and X-ray sensors, UV measuring device and X-ray testing device was completed Assembly and pre-commissioning operations for two growth units to get semi-conducting crystals up to 50 mm diameter were completed	Preparation for production of sensors, measurer and tester Growth units to get semi-conducting crystals
		New method for surface passivation of crystal CdZnTe-spectrometers of ionizing radiation that ensures 20-times decrease of loss currents was developed	New method for surface passivation of crystal CdZnTe-spectrometers of ionizing radiation
		P- and n-photodiode linear array was manufactured and their characteristics researched; the array provides for increasing spatial resolution of X-ray scintielectron detectors by an order of magnitude	P- and n-photodiode linear array that enhances X-ray scintielectron detectors
	Developing technology to produce nano-ceramics	The method for getting semi-conducting quantum dots with photo-luminescence within the range 420-450 nm, 530–540 nm, 570–580 nm and 620–630 nm was improved.	Method for getting semi-conducting quantum dots
		Optimum relative concentration of composite system components that ensures maximum intensity of luminescent quantum dots was found	Optimization of composite system components concentration
	Production of photodetector-emitters	Experimental samples of UV photodetectors on silicon carbide with the photosensitivity range 200 – 430 nm was manufactured	UV photodetectors samples
	Production of super-high-frequency element base	Dummy of thermal vision camera was developed with 3-5 μm spectral range, the parameters of which meet the world standards	Dummy of thermal vision camera of 3-5 μm spectral range
		Dummies of samples of silicon pulse avalanche transit-time diodes of 8-mm range with thermostable contacts were manufactured	Dummies of samples of silicon pulse avalanche transit-time diodes
2010	Creating radiation detectors and sensors	Three types of high-sensitive sensors to register UV radiation in 200 – 400 nm range were created.	Sensors to register UV radiation
		Characteristics of X-radiation detectors with increased spatial separation were developed and researched for a new generation devices that form up X-ray image	New generation X-ray detectors
		Sample of spectrometric portal was manufactured to control motor transport during customs clearance; its testing demonstrated that the main parameters go in line with the best world examples	Spectrometric portal to exercise control of motor transport during customs clearance
		Monocrystals were grown, structures were developed and detection units on the basis of cadmium tungstate $CdWO_4$ were manufactured for stationary spectrometric portal compatible with metal-detector	Detecting units for spectrometric portal compatible with metal-detector
		Detecting broad-band units on the basis of CdZnTe-sensors were manufactured to control ionizing radiation at nuclear power plants, independent spent fuel storage installations (ISFSI) and radioactive waste	Detecting units to control ionizing radiation at NPPs, ISFSIs, etc.

2011	Creating radiation detectors and sensors	Experimental samples of self-contained radiometer- dosimeter was designed and manufactured on the basis of micro-assemblies, digital controlling module and semi-conducting detectors CdZnTe	Samples of self-contained radiometer-dosimeter
		Research samples of 64- and 128-channels X-ray detectors of low-energy and high-energy ranges were manufactured; a site for industrial production of portal monitors and X-ray scanners was set up	Preproduction of portal monitors and X-ray scanners
	Production of photodetector-emitters	4-layers light diode with composite emission layer was created to radiate white light at the expense of summarizing auxiliary colors – blue and orange; process regulations to produce light diodes was developed	Light diode with composite emission layer to radiate white light
	Production of super-high-frequency element base	IR imager on the basis of photo-sensitive matrix of spectral ranges 3–5 μm and 8–12 μm was created together with powerful generating SHF module on silicon pulse avalanche transit-time diodes of 8-mm range	IR imager on the basis of photo-sensitive matrix
2012	Production of high-quality sapphire substrates	Technology to grow voluminous sapphire up to 60 kg weight by Kiropulos method, sapphire plates growing by Stepanov method with the 120 mm thickness and the technology to get high quality substrates for “silicon on sapphire” structures, as well as light diodes and other components for microelectronic devices were developed	Technologies to grow voluminous sapphire, sapphire plates and getting high quality substrates
		Structurally complete substrates from sapphire with (50,80±0,05) mm diameter, [(0,30–0,50) ±0,02] mm thickness with crystallographic orientations (0001) $(10\bar{1}2)$ by USA standard MIL-0-13830 were obtained.	Structurally complete substrates from sapphire by USA MIL-0-13830 standard
		On the basis of comparative techno-economic study of technologies to grow sapphire by different methods there were developed technical requirements to industrial equipment to grow sapphire by Kiropulos and Stepanov methods as well as requirements to servicing equipment necessary to manipulate and mechanically treat the crystals weighing more than 60 kg	Technical requirements to industrial equipment to grow sapphire by Kiropulos and Stepanov methods as well as requirements to servicing equipment
		Research-industrial sites to grow crystals and manufacture substrates for big integrated circuits, light diodes etc.	Sites to grow crystals and manufacture substrates

Composed by: [18-22]

In the result there has appeared the need to implement the program of scientific and technical research, directed to design and create such sensor science-intensive products as nano-structured materials, intellectually saturated sensor systems, appliances and technologies, the degree of development of which would provide for technological upgrading of economy branches.

The Ukrainian Cabinet of Ministers Resolution No.1395, dated 05.12.2007, approved the State Target Scientific-technical Program to develop and create sensor science-intensive products for the period 2008–2012 [17]. The program aims at creating Ukrainian sensor science-intensive products to form up scientific-technical basis for information technology and competitive products manufacturing. To solve those issues inter-disciplinary approach was applied which is underlain by a system of scientific design and research in the sphere of physics, chemistry, biology, materials science, informatics, electronics, etc. Problem solving with regard to the necessity to implement sensor science-intensive products was accomplished by ways of:

- Developing research technologies for producing science-intensive materials for sensor enginery to create national technological equipment;
- Ensuring wide implementation of micro- and optoelectronic sensors, devices and multi-functional sensor systems in production sphere;
- Creating bio-multi-sensor multi-functional technologies and information systems capable to recreate functions of smell electronic registration ("electronic nose") and taste registration ("electronic tongue");
- Implementing devices and their systems for high-efficiency energy- and resource-saving technologies;
- Ensuring development of certification system as well as metrological and standardization systems development for sensor enginery providing for decreasing their cost, enhancing the level of their competitive power on electronic products and materials markets.

The most prominent results of the Program implementation in 2010-2012 are presented in Table 2 [18-22].

Table 2. The most prominent results of the State Target Scientific-technical Program to develop and create sensor-based science-intensive products for the period 2008–2012

Year	Program direction	Most prominent result	Praactical value
1	2	3	4
2008	Developing research technologies to produce science-intensive materials for sensor enginery	Technologies to grow thin-film hetero-structures in the system of wide-band compounds A^2B^6, which helps producing new generation UV-radiation sensors, were developed. The advantage of the technology – local technologic base is used for the purpose; its efficiency is higher than the existing foreign analogues demonstrate	Technology providing to manufacture new generation UV-radiation senor
		Semi-conducting material – new type optical Germanium was created and patented; it is characterized by improved characteristics in comparison with the existing industrial material and is prospective for use primarily in new branches of IR-enginery	Semi-conducting material – new type optical Germanium
	Using micro- and optoelectronic sensors, devices and multi-functional sensor systems	Method of contact-free temperature measurement in high-temperature technological processes was developed	Method of contact-free temperature measurement
		New method to measure natural gas humidity directly in gas pipeline with considerable content of heavy hydrocarbons and admixtures was developed.	New method to measure natural gas humidity directly in gas pipeline
	Creating bio-multi-sensor multi-functional technologies and information systems	Industrial technology to produce cryogenic temperature sensors, magnetic field sensors and multi-functional sensors for simultaneous measurement of low temperatures and strong magnetic fields was developed	Production of cryogenic temperature sensors and magnetic field sensors
	Implementing devices and their systems for high-efficiency energy- and resource-saving technologies	Experimental sample of unique small-size microelectronic tester «BEO-01» to measure energy density of solar electromagnetic radiation was manufactured and commissioned first time in Ukraine; it ensures determining energy efficiency of ground-based solar power-engineering facilities' components	Small-size microelectronic tester «BEO-01» to measure energy density of solar electromagnetic radiation

2009	Developing research technologies to produce science-intensive materials for sensor enginery	Science –intensive technologies were developed to produce optochemical sensors on the basis of multi-layer diffraction gratings with anti-correlated relief	Optochemical sensors on the basis of multi-layer diffraction gratings with anti-correlated relief
	Utilizing micro- and optoelectronic sensors, devices and multi-functional sensor systems	Micro-structures of high-efficiency energy-saving sensor systems were manufactured to measure liquids and gases pressure; their characteristics meet world standards	Micro-structures of sensor systems to measure liquids and gases pressure
		Diagnostic system using non-destructive UV methods to find defects and their spatial distribution in big semi-conducting crystals was created; the system also ensures precise measurement of profile of crystal surfaces mechanical irregularities	Diagnostic system using non-destructive UV methods to find defects
	Creating bio-multi-sensor multi-functional technologies and information systems	Bio-multi-sensor multi-functional technologies to produce bio-refractometers was designed and produced; their sensitivity and measurement precision considerably exceed the known analogues	Bio-multi-sensor multi-functional technologies to produce bio-refractometers
		Multi-parametric multi-element colorimetric gas sensor was manufactured by the method of modelling multi-layer interference thin-film system	Multi-parametric multi-element colorimetric gas sensor
	Implementing devices and their systems for high-efficiency energy- and resource-saving technologies	Temperature micro-sensors were produced to perform experiments in studying turbulent flows of liquid Helium in the National laboratory for strong magnetic fields in c.Tallahassee, USA, and in the Center for nuclear research, Grenoble, France.	Temperature micro-sensors to perform experiments in studying turbulent flows of liquid Helium
		Experimental samples of differential pressure integrated converters were passed over to State enterprise “Arsenal factory” (Kyiv, Ukraine) for testing and designing household appliances to account natural gas consumption on their basis	Differential pressure integrated converters for household appliances of gas account
		Experimental samples of pressure converters were passed over to scientific-production company “Rost” (Kyiv, Ukraine) to be tested in technological processes automatic control systems used in sugar production	Samples of pressure converters for auto-matic control systems used in sugar production
2010	Developing research technologies to produce science-intensive materials for sensor enginery	Research-industrial equipment to get Germanium dioxide of semi-conducting frequency from different origin raw materials was produced; the equipment ensure 99% Germanium extraction from raw material concentrates having initial Germanium concentration	Research-industrial equipment to get Germanium dioxide of semi-conducting frequency
		In nano-structured compound on the basis of porous silicon, white light radiation (with radiation spectrum close to solar light) was obtained at the expense of controlling radiation spectral colors intensity	Nano-structured compound on the basis of porous silicon that can emit light close to solar one
	Utilizing micro- and optoelectronic sensors, devices	Experimental testing of resistor thermometers and temperature diode sensors in the temperature range 1.8–4.2 K was carried out. Super sensitivity of those sensors in comparison with the best	Resistor thermometers and temperature diode sensors in the

	and multi-functional sensor systems	foreign analogues helps carrying unique research at low and super-low temperatures.	temperature range 1.8–4.2 K of super sensitivity
	Creating bio-multi-sensor multi-functional technologies and information systems	Multi-sensor system of “electronic nose” type with analyte automated supply (light toxic and environmentally hazardous compounds) was designed and created; it solves the problem of recognizing analyte mixtures by their chemical images	Multi-sensor system of “electronic nose” type with analyte automated supply
	Implementing devices and their systems for high-efficiency energy- and resource-saving technologies	Experimental samples of new silicon photoconverters were designed and created; their utilization in solar power engineering faci-lities of concentrating type will decrease elec-tric power production cost price by 20–30% in comparison with the current photoelectric devices	Samples of new silicon photoconverters that decrease electric power production cost price by 20–30%
2011	Developing research technologies to produce science-intensive materials for sensor enginery	Technology to grow Germanium crystals with using high-frequency flux was developed; it ensures high degree of purity and structural perfection of crystals to produce unique ionizing radiation sensors	Technology to grow Germanium crystals to produce unique ionizing radiation sensors
	Utilizing micro- and optoelectronic sensors, devices and multi-functional sensor systems	Experimental samples of sensor devices to determine the level of light oil products, consumption of air, gas, liquid as well as dynamic change of pressure in car engines cylinders, ship engine cylinders, etc., were produced. By their characteristics the sensors meet the world standards	Sensor devices to determine the level of light oil products, consumption of air, gas, liquid as well as dynamic pressure change in engines cylinders
		Experimental sample of analytical device for express-diagnostics of water-alcohol solutions with alcohol high content was created; methods to identify alcohol beverages brands were also developed on the basis of comparing research samples characteristics with the pre-prepared database of reference drinks	Device for express-diagnostics of water-alcohol solutions with alcohol high content
	Creating bio-multi-sensor multi-functional technologies and information systems	To research multi-molecular protein complexes the procedures were developed that help carry out their quantitative analysis and obtain information on spatial setting of multi-component molecules, proteins and viruses assemblies Laboratory prototype of high-sensitive multi-bio-sensor on the basis of a number of bio-selective elements and ion-selective field-effect transistors matrix was created to determine toxic substances during environmental monitoring	Procedures were developed that help carry out research of multi-molecular protein assemblies Prototype of high-sensitive multi-bio-sensor to determine toxic substances
	Implementing devices and their systems for high-efficiency energy- and resource-saving technologies	Big volume work was carried out to implement the designed samples at industrial enterprises and in medical establishments	Implementation of the designed samples at industrial enterprises and in medical establishments
2012	Developing research	Technology to synthesize adsorption materials on the basis of apatite-like nano-systems was	Technology to synthesize adsorption

technologies to produce science-intensive materials for sensor enginery	developed. The samples were tested as matrixes for radioactive waste dumping and receiving hazardous compounds	materials which could be used for radioactive waste dumping
Utilizing micro- and optoelectronic sensors, devices and multi-functional sensor systems	Dummy samples of two- and three-terminals electronic nano-sensors on the basis of multi-layer nitride hetero-structures of GaN/AlGaN type produced at a single technologic platform were produced; they were tested as basic elements in integrated diagnostic, analytical, control and information-intellectual multi-sensor systems	Electronic nano-sensors for integrated diagnostic, analytical, control and information-intellectual multi-sensor systems
	Adaptive system to control pharmaceutical and food processing products was created; it provides for performing express-diagnostic of corresponding to food product standard (reference), the composition of which is not known (food products, beverages, medical drugs, etc.)	Adaptive system to control pharmaceutical and food processing products
Creating bio-multi-sensor multi-functional technologies and information systems	In polarization optics a new effect of resonance reflection gigantic sensitivity was discovered in biologic environment, on the basis of which a modulating polarimeter was created to correspond to the best world samples. The device provides for conducting super-sensitive registration of changes in biologic material opticophysical properties under the action of different physical, chemical and medical-biologic factors.	Modulating polarimeter that provides for conducting super-sensitive registration of changes in biologic material opticophysical properties
	Super-sensitive polarimetric device was produced to research distribution of thermal stress in solid bodies that enables registering mechanical stress at the level of 0.1 kg/cm^2, which occur at temperature variation by 0.01°C	Super-sensitive polarimetric device to research distribution of thermal stress in solid bodies
Implementing devices and their systems for high-efficiency energy- and resource-saving technologies	Unique system for electro-optic diagnostics was created; with its help the major criteria to certify optic Germanium crystals ere determined. It provides for determining fitness of crystals for IR enginery components production	System for electro-optic diagnostics to determine major criteria for optic Germanium crystals certification
	Joint research with the experts from the Institute of experimental pathology, oncology and radio-biology of NASU and National institute of cancer at Ministry of Health of Ukraine was conducted with using the method of determining the number of free radicals and dynamics of their generation in biological objects with the aim of studying oncological disease course	Implementing the method of determining the number of free radicals and dynamics of their generation in biological objects

Composed by: [18-22]

4. CONCLUSION

Hence, we may conclude that in order to set up information economy material base, during 2008-2012 Ukraine undertook efforts to develop and implement the following modern microelectronic technologies:

Creating radiation detectors and sensors with the aim of controlling luggage, passenger cars and trucks, for X-ray equipment in medicine, radiation safety monitoring at nuclear power plants' sites, arranging production of portals and X-ray scanners;

- Developing technology to produce nano-ceramics on the basis of heavy oxides of rare earth metals to register ionizing radiation;
- Arranging production of high-quality sapphire substrates for silicon-on-sapphire structures, light diodes and other component parts for micro-electronics;
- Developing and mastering production of multi-element IR-range photodetectors and IR emitters with optical resolution close to diffraction boundary and necessary to get maximum-possible volume of information;
- Mastering production of non-cooled multi-element sensitive detectors of THz range on the basis of semiconductors of A2B6 and A4B6 type for active vision systems and for identifying explosion hazardous substances, narcotics, etc.;
- Arranging production of super-high-frequency element base of millimeter range for integrated circuits, micro-devices to support new generation small-size super high-frequency systems, including car radar sensors, small-size transmitting-receiving modules for small-size ship and helicopter radars and super-fast radio-relay communication means.

Moreover, implementation of the Program of creating sensor science-intensive products in Ukraine would provide for:

- Satisfying needs of a number of local economy branches in science-intensive modern semiconducting materials and structures and sensor devices on their basis;
- Increasing national energy potential at the expense of accelerated development of solar power engineering as well as decreasing energy intensity of industrial products at the expense of implementing intellectual sensor control systems for technological processes in power engineering, metallurgy, machine-building, food processing, aviation and space industries;
- Fully equip local certification laboratories with high-quality diagnostic enginery and create conditions to arrange centers of general utilization of equipment for diagnostics, metrology, attestation and certification of sensor science-intensive products, which is a mandatory condition for local science-intensive products to enter international markets;
- Implement bio-sensor systems for environmental monitoring as well as monitoring in the spheres of medicine, pharmaceutics, food processing, etc;
- Improve the available and create new consumer properties, increase quality and competitiveness of local products (services);
- Enhance efficiency of diagnostic and diseases treatment efficiency by implementing new devices and diagnostic methods;
- Accelerate development of new materials and drugs for medical and pharmaceutical industries.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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